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PhD Thesis

Methodological proposal for social impact assessment and environmental conflict analysis

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Abbreviations

AHP : Analytic hierarchy process.

AM : Arithmetic mean.

CI : Consistency index.

CR : Consistency ratio.

CTWF : Triangular whitenization weight functions.

ECA : Environmental conflict analysis.

EIA : Environmental impact assessment.

EW : Entropy-weight.

FAHP : Fuzzy analytic hierarchy process.

GC : Grey clustering.

GDP : Gross domestic product.

GM : Geometric mean.

IGCEW : Integrated grey clustering and entropy-weight.

RI : Random consistency index.

SIA : Social impact assessment.

Summary

Social impact assessment (SIA) is a part of environmental impact assessment (EIA), which is characterized by a high level of uncertainty and the subjective aspects that are presents in the methods used during its conduction. In addition, environmental conflict analysis (ECA) has become a key factor for the viability of projects and welfare of affected populations. In this thesis, an integrated method for SIA and ECA is proposed, by the combination of the grey clustering method and the entropy-weight method.

SIA was performed using the grey clustering method, which enables qualitative information coming from a stakeholder group to be quantified. In turn, ECA was performed using the entropy-weight method, which identifies the criteria in which there is greater divergence between stakeholder groups, thus enabling to establish measures to prevent potential environmental conflicts. Then, in order to apply and test the proposed integrated method, two case studies were conducted.

The first case study was a mining project in northern Peru. In this study, three stakeholder groups and seven criteria were identified. The results revealed that for the urban population group and the rural population group, the project would have a positive and negative social impact, respectively. For the group of specialists the project would have a normal social impact. It was also noted that the criteria most likely to generate environmental conflicts in order of importance were: access to drinking water, poverty, GDP per capita, and employment.

The second case study considered was a hydrocarbon exploration project located in the Gulf of Valencia, Spain. In this study, four stakeholder groups and four criteria were identified. The results revealed that for the group of specialists the project would have a negative social impact, and contrary

perceptions were shown between the group of those directly affected by the project and the group of citizens in favour. It was also noted that the criteria most likely to generate environmental conflict were the percentage of unemployment and GDP per capita.

The proposed integrated method in this thesis showed great potential on the studied cases, and could be applied to other contexts and other projects, such as water resources management, industrial projects, construction projects, and to measure social impact and prevent conflicts during the implementation of government policies and programs.

Resumen

La evaluación del impacto social (SIA) forma parte de la evaluación de impacto ambiental (EIA), y está caracterizada por su alto nivel de incertidumbre, y por los aspectos subjetivos presentes en los métodos usados para su realización. Por otro lado, el análisis del conflicto ambiental (ECA) se ha convertido en un factor clave para la viabilidad de los proyectos y el bienestar de la población afectada. En esta tesis, se propone un método integrado para la SIA y el ECA, mediante la combinación de los métodos *grey clustering* y *entropy-weight.*

La SIA fue desarrollada usando el método *grey clustering*, el cual permite cuantificar la información cualitativa recogida de los grupos de interés o *stakeholders*. Sucesivamente, el ECA fue realizado usando el método *entropy-weight*, el cual identifica los criterios en los cuales existe gran divergencia entre los grupos de interés, permitiendo así establecer medidas para prevenir potenciales conflictos ambientales. Luego, con el fin de aplicar y testear el método integrado propuesto fueron realizados dos casos de estudio.

El primer caso de estudio fue un proyecto minero ubicado en el norte de Perú. En este estudio se identificaron tres grupos de interés y siete criterios. Los resultados revelaron que para el grupo población urbana y el grupo población rural, el proyecto tendría un impacto social positivo y negativo, respectivamente. Para el grupo de los especialistas el proyecto tendría un impacto social normal. También fue notado que los criterios más probables de generar conflicto ambiental en orden de importancia fueron: acceso al agua potable, pobreza, PIB per cápita, y empleo.

El segundo caso de estudio considerado fue un proyecto de exploración de hidrocarburos ubicado en el Golfo de Valencia, España. En este estudio se

identificaron cuatro grupos de interés y cuatro criterios. Los resultados revelaron que para el grupo de los especialistas el proyecto tendría un impacto social negativo, y contrarias percepciones se encontraron entre el grupo de los directamente afectados y el grupo de los ciudadanos a favor. También fue notado que los criterios más probables de generar conflicto ambiental fueron el porcentaje de desempleo y el PIB per cápita.

El método integrado propuesto en esta tesis mostró un gran potencial sobre los casos estudiados, y podría ser aplicado a otros contextos y otros tipos de proyectos, tales como gestión de recursos hídricos, proyectos industriales, proyectos de construcción de obras públicas, y para medir el impacto social y prevenir conflictos durante la aplicación de políticas y programas gubernamentales.

Resum

L’avaluació de l'impacte social (SIA) és una part de l’avaluació de l'impacte ambiental (EIA), la qual està caracteritzada pel seu alt nivell d’incertitud i els aspectes subjectius presents en els mètodes amprats durant la seua conducció. A més, la anàlisis del conflicte ambiental (ECA) s'ha convertit en un factor clau per a la viabilitat dels projectes i el benestar de la població afectada. En esta tesis es proposa un mètode integrat per a l’avaluació de l'impacte social i la anàlisis del conflicte ambiental, mitjançant la combinació del mètode *grey clustering* i el mètode *entropy-weight*.

L’avaluació de l'impacte social ha segut realitzada usant el mètode *grey clustering*, el qual permet que la informació qualitativa arreplegada dels grups d’interès siga quantificada. Successivament, la anàlisis del conflicte ambiental ha segut realitzada usant el mètode *entropy-weight*, el qual identifica els criteris en els quals existeix gran divergència entre els grups d’interès, la qual cosa permet establir mides per a prevenir conflictes ambientals potencials. Després, amb la finalitat d'aplicar i testejar el mètode integrat proposat han segut realitzats dos casos d'estudi.

El primer d’ells ha segut un projecte miner al nord de Perú. En aquest estudi, tres grups d’interès i set criteris foren identificats. Els resultats revelaren que per al grup població-urbana i el grup població-rural, el projecte experimentaria un positiu i un negatiu impacte social respectivament. Per al grup dels especialistes el projecte tindria un impacte social normal. Per altra banda també va ser reconegut que els criteris més probables de generar conflicte ambiental en orde d’importància foren: accés a l'aigua potable, pobresa, PIB per càpita, i ofici.

El segon cas d'estudi considerat va ser un projecte d’exploració d'hidrocarburs ubicat al Golf de València, Espanya. En este estudi, quatre

grups d'interès i quatre criteris foren identificats. Els resultats revelaren que per al grup dels especialistes el projecte tindria un impacte social negatiu, mentre que entre el grup dels directament afectats i el grup dels ciutadans a favor es mostraren percepcions contraries. Va ser també reconegut que els criteris més probables de generar conflicte ambiental foren el percentatge de desocupació i el PIB per càpita.

El mètode integrat proposat en aquesta tesis mostra un gran potencial sobre els casos estudiats, i pot ser aplicat a altres contexts i altres tipus de projectes com gestió de recursos hídrics, projectes industrials i projectes de construcció d'obres públiques. A més pot fer-se servir per mesurar l'impacte social i prevenir conflictes durant l'aplicació de polítiques i programes governamentals.

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CHAPTER I

INTRODUCTION

1. Introduction

An environmental factor within of environmental impact assessment is the social factor, which is characterized by its high level of uncertainly and the methods used for conducing that are mainly qualitative, as evidenced by studies of social impact assessment related to food safety (Dreyer, Renn, Cope, & Frewer, 2010), marine protected area (Voyer, Gladstone, & Goodall, 2012), earthquakes caused by gas extraction (van der Voort & Vanclay, 2015) or fisheries closure (Hattam, Mangi, Gall, & Rodwell, 2014).

In turn, environmental conflicts often accompany the planning and implementation of projects and programs, as evidenced by studies of conflicts related to water management (Bolin, Collins, & Darby, 2008; Saqalli, Thiriot, & Amblard, 2010), energy (Fontaine, 2010; Karjalainen & Järvikoski, 2010), exploitation of natural resources (Correia, 2007; Madani, Rouhani, Mirchi, & Gholizadeh, 2014; Warnaars, 2012) or ecological tourism (Yang, Ryan, & Zhang, 2013). In Addition, environmental conflicts are generated between stakeholder groups within communities, due to the differences in the assessment of an determined project (Arun, 2008; Luyet, Schlaepfer, Parlange, & Buttler, 2012). For this reason, social impact assessment should first be performed for each stakeholder group and then the gap between the groups should be determined in order to predict and prevent possible environmental conflicts.

In this thesis an integrated method for SIA and ECA is proposed, which could contribute to improve the qualitative and quantitative methods existing so far. In addition, in order to apply and test the proposed integrated method, SIA and ECA were conducted on a project in Peru and a project in Spain.

1.1 Conceptual framework

In this section an explanation of the concepts of environmental impact assessment, social impact assessment, and environmental conflict are developed.

1.1.1 Environmental impact assessment

Environmental impact assessment (EIA) should be conducted on the environmental factors, which are classified as shown below (Romero I., 2012):

1. Climate.
2. Geology and geomorphology.
3. Surface and groundwater hydrology.
4. Edaphology.
5. Atmosphere.
6. Biotic environment.
7. Landscape.
8. Social, economic and cultural environment.

In this thesis, the social environmental is studied and integrated with environmental conflict analysis.

EIA has been conducted by different methods, according to environmental factor under study, for example EIA on watersheds (Dubé et al., 2013), solar radiation (Jedrzej et al., 2013) or environmental noise (Giménez A., 2010). In addition, the reflexion on the advances of EIA is permanent (Pope et al., 2013).

1.1.2 Social impact assessment

Social impact assessment has been conducted so far, mainly by qualitative approaches, as shown by studies based on public participation (B. Tang, Wong, & Lau, 2008), game theory (Prenzel & Vanclay, 2014) or stakeholder's views (Hattam et al., 2014). However, there are quantitative approaches for EIA and SIA, as evidenced by studies based on Delphi and fuzzy (Chang, Qisen, Zheng, & Zhang, 2009) or logic fuzzy (Peche & Rodríguez, 2011).

In this thesis, a method to improve the qualitative and quantitative approaches for SIA is proposed. In addition, the proposed method enabled to integrate SIA and ECA. Moreover, considering that SIA and ECA are topics very subjective and inconstant; the proposed method should be flexible and effective, in order to apply to other type of projects and in different contexts.

1.1.3 Environmental conflict

Environmental conflicts are characterized by the interaction between (1) ecological and (2) social complexity (Wittmer, Rauschmayer, & Klauer, 2006).

(1) "*One central feature of environmental conflicts is the complexity of the ecological system which is the natural base of the conflicts. Even if its understanding is accompanied by a high degree of scientific sophistication, there remains substantial uncertainty and ignorance. Therefore, the process leading to the resolution of environmental conflicts must take into account scientific and idiosyncratic knowledge and must cope with unavoidable uncertainty and ignorance. Certain forms of multi-criteria decision aid could satisfy this demand*" (Wittmer et al., 2006).

(2) "*Another central feature of environmental conflicts is social complexity. Some stakeholders are also actors who may impede the implementation of a decision, or, put positively, their agreement is necessary for a successful implementation of the decision. Social complexity calls for stakeholder participation. Decision structuring tools offer the possibility to make participatory decision processes more transparent*" (Wittmer et al., 2006).

The resolution of environmental conflicts should concentrate on both aspects, social and ecological complexity. Moreover, environmental conflicts are increasing worldwide, as shown in Figure 1.1 (Environmental justice, 2015), where is showed that environmental conflicts could be present in different fields, such as water management, biodiversity conservation, mineral ores extractions, industrial companies, tourism and recreation, nuclear energy, etc. In this thesis, a method to analyse environmental conflict, which is integrated with social impact assessment, is proposed. In addition, in order to prevent possible environmental conflicts, it is necessary to perform a social impact assessment during all the stages of development of project under study (Prenzel & Vanclay, 2014).

Source: retrieved from environmental justice

Figure 1.1: Map of environmental conflicts.

1.2 Legal framework

The proposed method was applied to a project in Peru and then a project in Spain. Therefore, Peruvian law and Spanish law, in relationship with SIA and ECA, are presented below.

1.2.1 Peruvian law

In Peru, EIA is regulated by law Nº 27446 *"Ley del Sistema Nacional de Evaluación del Impacto Ambiental"* (MINAM, 2011a). This law establishes in article Nº 34 that the EIA must include SIA. In addition, it mentions that must consider measures to ensure an adequate social management, and prevention of environmental conflicts. As well as, prevention, control, mitigation and eventual compensation for social impacts that could be generated.

1.2.2 Spanish law

A law in European Union on EIA is Directive Nº 2011/92/UE, which establishes, in article 2 (incise 1), that the member states must adopt measures to grant authorization for projects that could have significant effects on environment. In addition, in article 3 (incise a), it indicates that the EIA must identify, describe and asses the direct and indirect effects on humans (Parlamento europeo, 2011).

In Spain, the law Nº 21/2013 *"Ley de evaluación ambiental",* which establishes, in Annexe VI (apart 2, incise e), that the selection of the best alternative must be supported by a multi-criteria global analysis, which considers economic, social and environmental aspects (Jefatura del estado, 2013).

In *"Comunitat Valenciana"* there is a law Nº 6/2014 *"Ley de Prevención, Calidad y Control Ambiental de la Comunidad Valenciana"*, which establishes, in article 2 (incise d), that the purposes of this law are contributing to do effective the sustainable development through a system of environmental administrative intervention, which harmonizes economic and social development with environmental protection (Comunitat Valenciana, 2014).

1.3 Objectives of the thesis

The specific objectives of this thesis are to:

1. Propose an integrated method for SIA and ECA.
2. Apply the integrated method for SIA and ECA to the concrete context of the exploitation plans of the poly-metallic mine in Peru.
3. Apply the integrated method for SIA and ECA to the concrete context of the hydrocarbon exploration project in Valencia, Spain.
4. Explore if the method proposed exhibits potential for other contexts.

1.4 Organization of the thesis

This thesis is organized according to the following chapters:

CHAPTER I	:	The introduction of the thesis is described.
CHAPTER II	:	The state of the art of the main methodologies for SIA and ECA are described.
CHAPTER III	:	The details of the proposed integrated method for SIA and ECA are provided.
CHAPTER IV	:	The case study on a mining project in Peru is described.
CHAPTER V	:	The case study on a hydrocarbon exploration project in Spain is described.
CHAPTER VI	:	The general discussion and conclusions of the thesis are provided.

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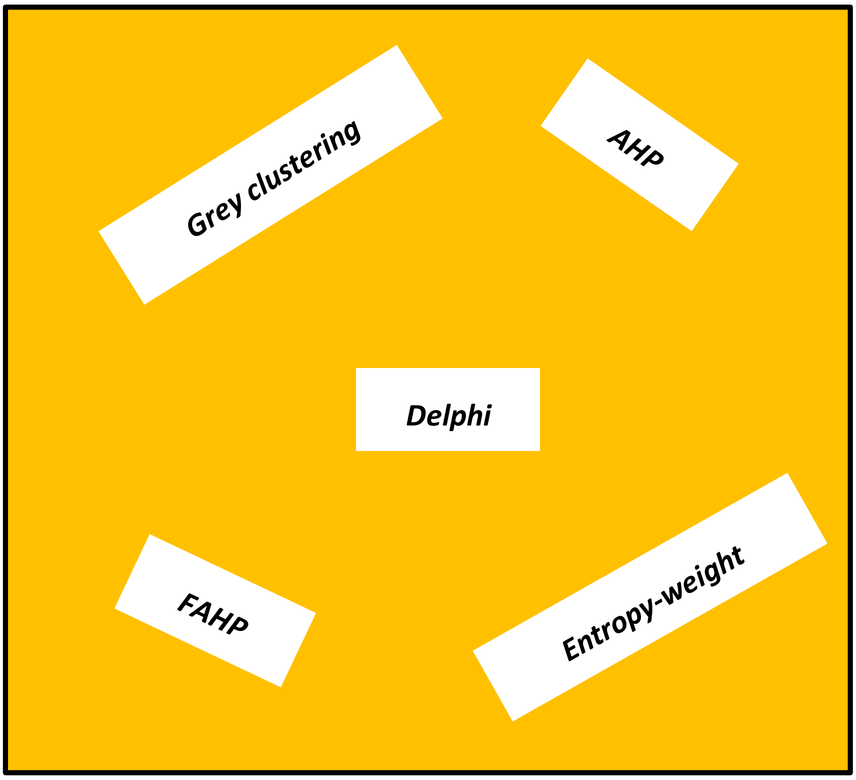
CHAPTER II

STATE OF THE ART



2. State of the art

2.1 Introduction

Social impact assessment is a topic very inconstant and with high level of uncertainty (Corbetta, 2007), therefore it demands to be studied under approaches which consider the qualitative characteristic of social issues, and also include the uncertainty within their analysis. In addition, to assess social impact on future projects is convenient to use approaches with low cost, which consider the uncertainty in prospective studies (Landeta, 2002). The main approaches to analyse the uncertainty are statistical, fuzzy logic, and grey systems (S. Liu & Lin, 2010). As discussed in this thesis, the statistical approaches are not considered, due to their high cost that they could have during its application. Moreover, the FAHP method based on fuzzy logic, and grey clustering method based on grey systems are discussed as alternatives for SIA. In addition, the multi-criteria analysis methods could be considered as an alternative for SIA (Wittmer et al., 2006); therefore, the Delphi method and the AHP method, which are classical multi-criteria methods, are also discussed as other alternatives for SIA.

In turn, environmental conflict analysis has two aspects, the ecological complexity and the social complexity, which could be treated with multi-criteria methods (Wittmer et al., 2006). But, environmental conflict analysis has also a high level of uncertainty and demands a method that analyses the divergence, as discussed in this thesis the entropy-weight method could satisfy this demand.

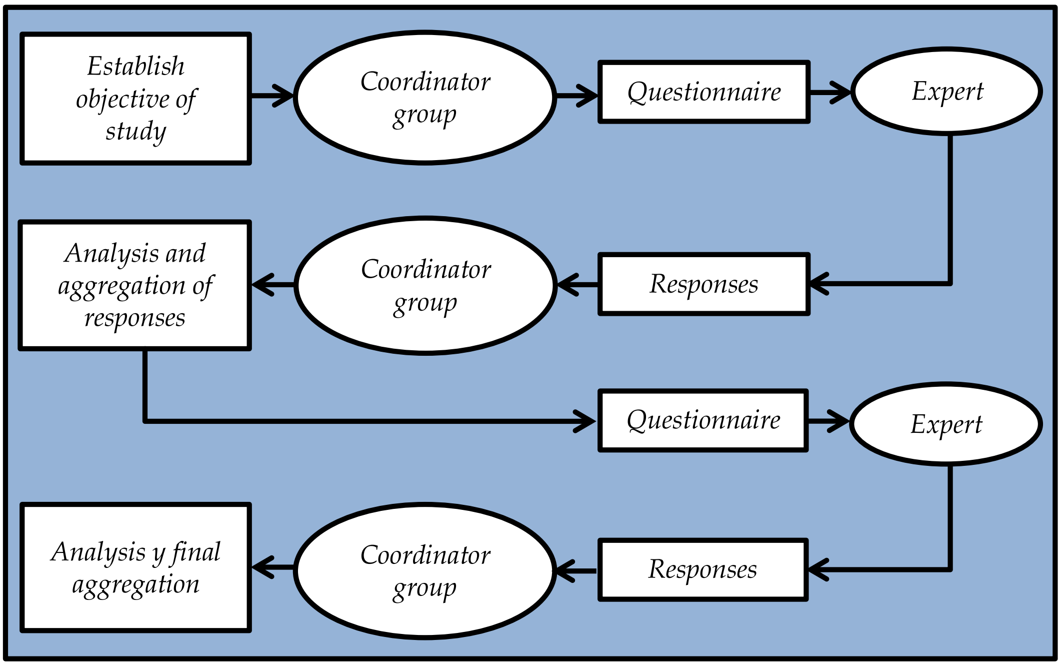
Consequently, in this thesis, the Delphi method, the AHP method, the FAHP method, and grey clustering method, are discussed as alternatives for SIA. In addition, the entropy-weight method is discussed and selected for ECA.

2.2 The Delphi method

The name of Delphi is the translation from English of the word *Delfos*, which was a Greek city that was known for its oracles of Apollo. The Delphi method has a development since the mid-twentieth century. A decisive work, on this method, was conducted by Abraham Kaplan in 1949 (Landeta, 2002). A study with the Delphi method consists in the selection of an expert team, which is asked on future events. The estimates from experts are made in successive anonymous rounds, the objective is to achieve consensus, but with the maximum autonomy for the participants (Astigarraga, 2005).

2.2.1 Procedure for the Delphi method

Landeta proposed a schema for the Delphi method, in which, there is a coordinator group (see Figure 2.1); this group directs all the process of application of the Delphi method, as well as, it conducts the anonymous rounds through the information obtained from expert team. A schema, for the process of Delphi method, proposed by Landeta is shown in Figure 2.1 (Landeta, 2002):



Source: retrieved from Landeta (2012)

Figure 2.1: Global schema of Delphi process.

Another procedure for the Delphi method was provided by Astigarraga, which is summarized by the following steps (Astigarraga, 2005):

Step 1: the problem is formulated according to type and context of case under study.

Step 2: the experts are selected according to experience of every professional.

Step 3: the questionnaire is made and the first round is performed and obtained from experts.

Step 4: the second round is performed, giving to every expert, the results of the first round. The rounds number depends of the results of the mean and the standard deviation. The definitive results are processed when the rounds are finished.

An example of application of the Delphi method is the work of Ortega Mohedano on a study of prospective of audio-visual sector in the *Castilla y León* community, a brief summary is presented below (Ortega Mohedano & Ortega, 2008).

Step 1: the problem, on a study of prospective of audio-visual sector in the *Castilla y León* community, was formulated in 2008, with horizon until 2015.

Step 2: the expert number was 32, of which 13 were from communication media, 14 were from university, and 5 were from other sectors, such as, marketing and content producers.

Step 3: the questionnaire was formed by 38 items, which was sent to experts. The responses from experts were processed with excel software, which were sent to expert for second round.

Step 4: in the second round, after analysing the results of the mean and the standard deviation, the study is finished. According to the consensus between experts on the proposed questions, the results indicated that audio-visual sector will be characterized by a greater concentration of companies, specialization of content, professionalization of resources, and increasing regional market share.

2.2.2 Summary of the Delphi method

The Delphi method was also applied to other contexts, as evidenced by studies on the Delphi method applied to economy from natural recourses in Spain (Soliño Millán, 2004), horticultural cooperatives (Campos-Climent, Apetrei, & Chaves-Ávila, 2012), the best nutrition counselling practices for the treatment of anorexia nervosa (Mittnacht & Bulik, 2014) or the lifelong learning in nursing (Davis, Taylor, & Reyes, 2014).

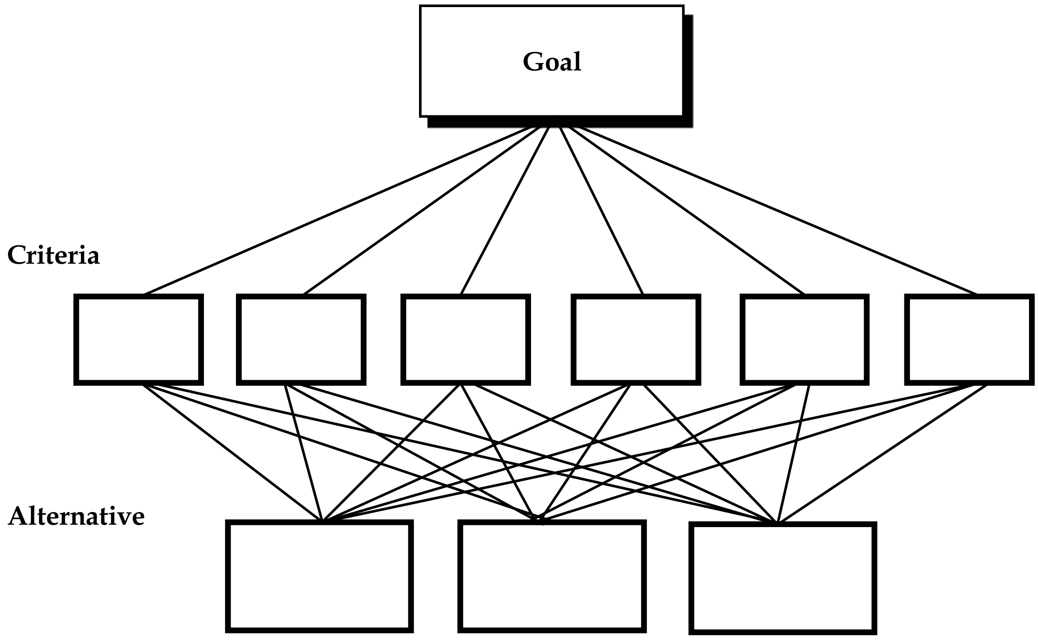
The characteristics of the Delphi method, in relationship with SIA, could summarize as following:

- The Delphi method mainly is applied to make prospective studies, using the opinion from expert team.
- The data processing is performed by basic statistic, such as, mean and standard deviation.
- The Delphi method uses anonymous rounds, which avoids conflict between experts.
- The Delphi method does not consider the uncertainty in the responses from the experts.

The application de anonymous rounds from the Delphi method could be used as a complement within other methodologies for SIA. In addition, the Delphi method should be complemented with other method, which considers the level of uncertainly, due to the fact that SIA is a topic with high level of uncertainly.

2.3 The AHP method

Analytic hierarchy process (AHP) is a method that was proposed by Thomas L. Saaty in 1980 (T. L. Saaty, 1980), which is a basic approach for decision making. The AHP method is designed to select the best alternative in function to a criteria number, this process for decision making is conducted by pairwise comparison judgments, which is used to develop overall priorities to classify the alternatives (T. Saaty & Vargas, 2012). A general schema of priories for the AHP method is shown in figure 2.2.



Source: retrieved from Saaty and Vargas (2012)

Figure 2.2: General schema of the AHP method.

2.3.1 Procedure for the AHP method

The procedure of the AHP method could be summarized as follows (Ahammeda & Azeem, 2013; Aznar & Guijarro, 2012; Delgado & Romero, 2015):

Step 1: the alternatives for the evaluation are defined as: A_1, A_2, A_3,..., Am.

Step 2: the criteria for the evaluation are defined as: C_1, C_2, C_3,..., Cm.

Step 3: the comparison matrix and its consistency are performed.

To determine the weight of each criterion, a paired comparison matrix is used. The comparison is performed according to the scale proposed by Saaty, which is shown in Table 2.1 (Vargas, 2010).

Table 2.1: The Saaty scale for the relative importance.

Scale	*Numerical rating*	*Reciprocal*
Extremely recommended	***9***	***1/9***
Very strong to extremely	*8*	*1/8*
Very strongly preferred	***7***	***1/7***
Strongly to very strongly	*6*	*1/6*
Strongly preferred	***5***	***1/5***
Moderately to strongly	*4*	*1/4*
Moderately preferred	***3***	***1/3***
Equally to moderately	*2*	*1/2*
Equally preferred	***1***	***1***

Source: retrieved from Vargas (2012).

The results of the comparison between criteria C_1, C_2, C_3,…, Cm, are presented by the matrix shown in Equation 2.1.

$$\begin{matrix} C_1 \rightarrow \\ C_2 \rightarrow \\ \vdots \\ C_n \rightarrow \end{matrix} \overbrace{\begin{pmatrix} 1 & p_{12} & \cdots & p_{1n} \\ \frac{1}{p_{12}} & 1 & \cdots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{p_{1n}} & \frac{1}{p_{2n}} & \cdots & 1 \end{pmatrix}}^{\begin{matrix} C_1 & C_2 & \ldots\ldots & C_n \\ \downarrow & \downarrow & & \downarrow \end{matrix}} = P_{n \times n} \tag{2.1}$$

Now, the matrix P is normalized in each column dividing each element by the total sum of the respective column: $S_{1\times n} = (s_1 \quad s_2 \quad s_3 \quad \cdots \quad s_n)$. Then, the weight of each criterion is calculated by the arithmetic mean (AM) of the elements in each row of the normalized matrix. The matrix of weight of the criteria is presented in Equation 2.2.

$$W_{n\times 1} = (w_1 \quad w_2 \quad w_2 \quad \cdots \quad w_n)^t \tag{2.2}$$

To determine the consistency of the comparison matrix, first the consistency index (CI) is computed using Equation 2.3.

$$CI = \frac{\lambda_{Max} - n}{n-1} \tag{2.3}$$

Where "n" is the size or order of the matrix, and λ_{Max} is the maximum eigenvector, which is calculated by Equation 2.4.

$$\lambda_{Max} = \sum_{i=1}^{n} s_i . w_i \qquad (2.4)$$

There are other procedures to compute λ_{Max} and weight of the criteria, but the difference of the results is insignificant (Vargas, 2010), therefore the procedure for AHP method used here is accepted. Then, the random consistency index (RI) is assigned, according to values of Table 2.2, in which "n" is the size or order of the matrix (T. Saaty & Vargas, 2012).

Table 2.2: Values of IR.

n	1	2	3	4	5	6	7	8	9	10
IR	0	0	0,52	0,89	1,11	1,25	1,35	1,40	1,45	1,49

Source: retrieved from Saaty and Vargas (2012).

Then, the consistency ratio (CR) is computed by Equation 2.5.

$$CR = \frac{CI}{RI} \qquad (2.5)$$

The consistency of the matrix is finally determined by comparison of the consistency ratio (CR) with the values of Table 2.3, which were established by Saaty (Aznar & Guijarro, 2012).

Table 2.3: Maximum values of CR.

Size of the matrix (n)	*Consistency ratio*
3	0.05
4	0.09
5 o mayor	0.10

Source: retrieved from Aznar and Guijarro (2012).

The matrix of comparison will be consistent, if the value of CR is minor than the value indicated in Table 2.3, according the size of the matrix (n).

Step 4: The ranking of the alternatives, for the final decision, is established.

The alternatives: A_1, A_2, A_3,..., Am are evaluated according to each criterion: C_1, C_2, C_3,..., Cm. The results for each criterion are presented according to matrix shown in Equation 2.6.

$$\begin{matrix} A_1 \rightarrow \\ A_2 \rightarrow \\ \vdots \\ A_m \rightarrow \end{matrix} \overbrace{\begin{pmatrix} 1 & q_{12} & \cdots & q_{1m} \\ \frac{1}{q_{12}} & 1 & \cdots & q_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{q_{1m}} & \frac{1}{q_{2m}} & \cdots & 1 \end{pmatrix}}^{\begin{matrix} A_1 & A_2 & \ldots\ldots & A_m \\ \downarrow & \downarrow & & \downarrow \end{matrix}} = Q^n_{m\times m} \qquad (2.6)$$

After of checking the consistency of every comparison matrix, the weight of the alternatives is determined for every criterion. The results are presented according to Equation 2.7.

$$\begin{matrix} C_1 \rightarrow \\ C_2 \rightarrow \\ \vdots \\ C_n \rightarrow \end{matrix} \overbrace{\begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{pmatrix}}^{\begin{matrix} A_1 & A_2 & \ldots\ldots & A_m \\ \downarrow & \downarrow & & \downarrow \end{matrix}} = T_{n\times m} \qquad (2.7)$$

The ranking of the alternatives is established according to the results of the multiplication of the matrixes W^t and T. Finally, the results are presented in Equation 2.8.

$$R_{1\times m} = (W_{n\times 1})^t . T_{n\times m} \qquad (2.8)$$

An example of application of the AHP method is the study conducted by Vargas in 2010, on an organization called ACME, which aims to select a project to ACME (Vargas, 2010). In this study six alternatives and twelve criteria were defined, which are grouped in four categories. A summary on this study is presented below:

Step 1: the alternatives, in this study, were defined as following:

A_1: Moving to new office.

A_2: New ERP computer system.

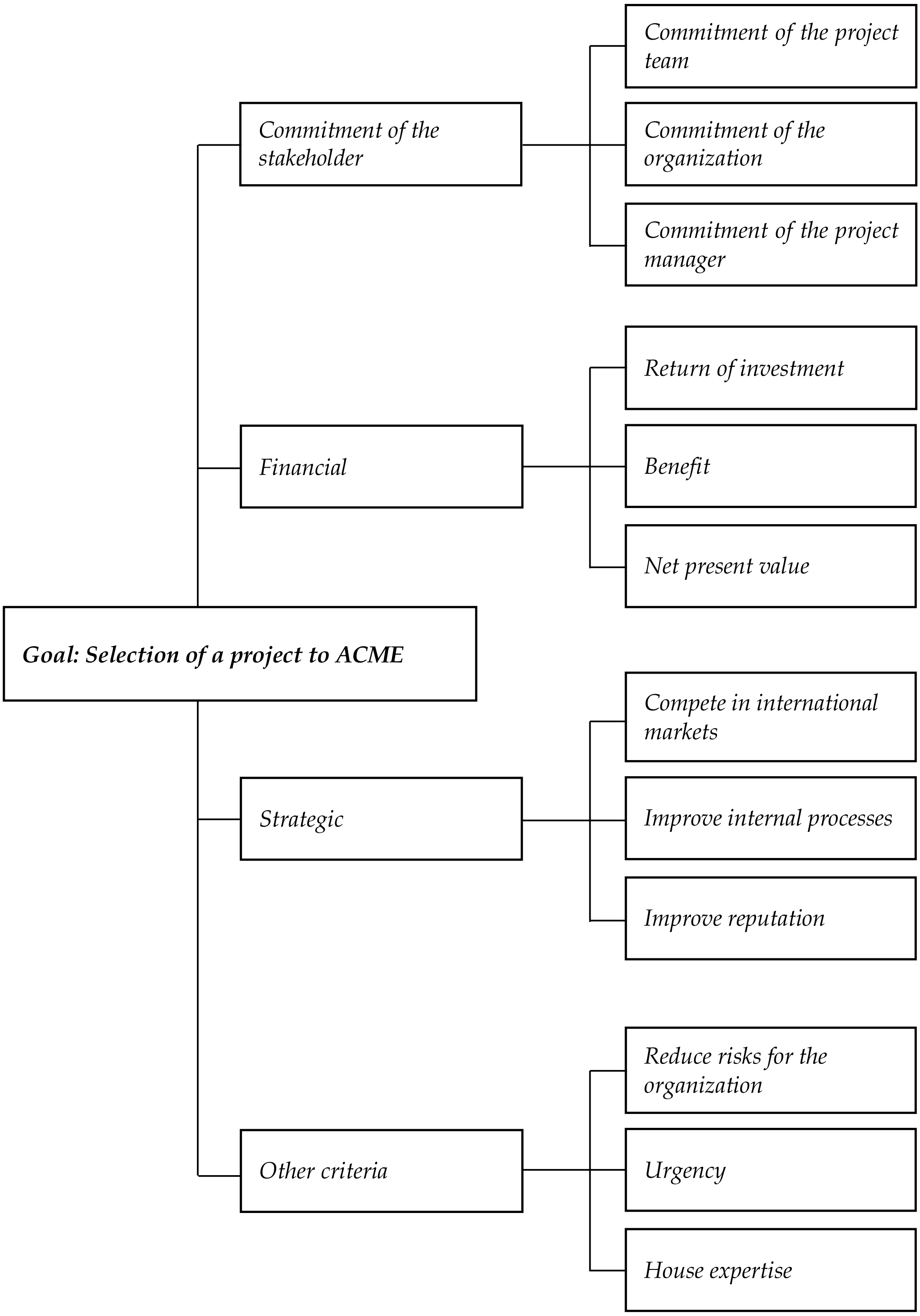
A_3: New office in China.

A_4: New product to international commerce.

A_5: IT Infrastructure to outsourcing.

A_6: New local campaign of marketing.

Step 2: twelve criteria, in this study, were defined. The tree diagram is presented in Figure 2.3:



Source: retrieved from Vargas (2010)

Figure 2.3: Hierarchy of criteria to select a project in ACME.

Step 3: The weights of the criteria of first level are computed.

First, the paired matrix obtained from experts is normalized. The results are presented in Table 2.4.

Table 2.4: Criteria of first level normalized.

	Commitment of the stakeholder	*Financial*	*Strategic*	*Other criteria*
Commitment of the stakeholder	*1*	*1/5*	*1/9*	*1*
Financial	*5*	*1*	*1*	*5*
Strategic	*9*	*1*	*1*	*5*
Other criteria	*1*	*1/5*	*1/5*	*1*
Total (Sum)	***16,00***	***2,40***	***2,31***	***12,00***
Results:				
Commitment of the stakeholder	*1/16=0,063*	*0,083*	*0,048*	*0,083*
Financial	*5/16=0,313*	*0,417*	*0,433*	*0,417*
Strategic	*9/16=0,563*	*0,417*	*0,433*	*0,417*
Other criteria	*1/16=0,063*	*0,083*	*0,087*	*0,083*

Source: retrieved from Vargas (2010).

Second, the weights of the criteria of first level are determined by the eigenvector. The results are shown in Table 2.5.

Table 2.5: Calculation of eigenvector.

	Eigenvector (calculation)	*Eigenvector*
Commitment of the stakeholder	*[0.063+0,083+0,048+0,083]/4=0,0693*	*0.0693 (6.93%)*
Financial	*[0,313+0,417+0,433+0,417]/4=0,3946*	*0.3946 (39.46%)*
Strategic	*[0,563+0,417+0,433+0,417]/4=0,4571*	*0.4571 (45.71%)*
Other criteria	*[0,063+0,083+0,087+0,083]/4=0,0789*	*0.0789 (7.89%)*

Source: retrieved from Vargas (2010).

Now, the consistency test is performed. First, λ_{Max} is calculated, the details of the calculations are presented in Table 2.6.

Table 2.6: Calculation of maximum eigenvector.

	Commitment of the stakeholder	*Financial*	*Strategic*	*Other criteria*
Eigenvector	*0.0693*	*0.3946*	*0.4571*	*0.0789*
Total (Sum)	*16.00*	*2.40*	*2.31*	*12.00*
Maximum eigenvalue (λ_{Max})	*[(0,0693x16,00)+(0,3946x2,40)+(0,4571x2,31)+(0,0789x12,00)]=4,06*			

Source: retrieved from Vargas (2010).

Then, the consistency index (CI) is calculated by Equation 2.3:

$$CI = \frac{\lambda_{Max} - n}{n - 1} = \frac{4.06 - 4}{4 - 1} = 0.02$$

The random consistency index (RI) is obtained from Table 2.2, for n=4, we have IR=0.89. Then, the consistency ratio (CR) is calculated by Equation 2.5:

$$CR = \frac{0.02}{0.89} = 0.0225 = 2.25\%$$

The value of CR obtained is compared with the maximum value of consistency ratio of table 2.3, which, for n=4, has a value of 0.09. It is observed that the value obtained 0.0225 is minor than 0.09. Therefore, it is concluded that the matrix of comparison is consistent, and the weights of the criteria of first level are valid.

In turn, the weights of the criteria of second level are calculated. The values obtained from experts are presented in Table 2.7.

Table 2.7: Values of the criteria the second level.

	Criteria of commitment of the stakeholder		
	Commitment of the project team	*Commitment of the organization*	*Commitment of the project manager*
Commitment of the project team	*1*	*3*	*1/5*
Commitment of the organization	*1/3*	*1*	*1/9*
Commitment of the project manager	*5*	*9*	*1*
	Financial criteria		
	Return of investment	*Benefit*	*Net present value*
Return of investment	*1*	*1/5*	*1/5*
Benefit	*5*	*1*	*1*
Net present value	*5*	*1*	*1*
	Strategic criteria		
	Compete in international markets	*Improve internal processes*	*Improve reputation*
Compete in international markets	*1*	*7*	*3*
Improve internal processes	*1/7*	*1*	*1/5*
Improve reputation	*1/3*	*5*	*1*
	Other criteria		
	Reduce risks for the organization	*Urgency*	*House expertise*
Reduce risks for the organization	*1*	*5*	*1/3*
Urgency	*1/5*	*1*	*1/7*
House expertise	*3*	*7*	*1*

Source: retrieved from Vargas (2010).

Using the same procedure, developed for the criteria of first level, the weight the criteria of second level are obtained, for every category, which are multiplied with the weights of the criteria of first level to obtain the global weights. The results are presented in Table 2.8.

Table 2.8: Global weight of the criteria.

	Weight of criteria of first level	Weight of criteria of second level	Global weight of criteria
Commitment of the project team	0,0693	0,1782	0,012
Commitment of the organization	0,0693	0,0704	0,005
Commitment of the project manager	0,0693	0,7514	0,052
Return of investment	0,3946	0,0909	0,036
Benefit	0,3946	0,4545	0,179
Net present value	0,3946	0,4545	0,179
Compete in international markets	0,4571	0,6491	0,297
Improve internal processes	0,4571	0,0719	0,033
Improve reputation	0,4571	0,2790	0,128
Reduce risks for the organization	0,0789	0,2790	0,022
Urgency	0,0789	0,0719	0,006
House expertise	0,0789	0,6491	0,051

Source: retrieved from Vargas (2010).

Step 4: The ranking of the alternatives, for the final decision, is established. The six alternatives were evaluated according to each criterion. The results obtained from experts were processed. For example, the results for first criteria are presented in Table 2.9.

Table 2.9: Evaluation of the alternatives for the first criterion.

Criterion: commitment of the project team						
	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	5	3	1/3	9	7
A_2	1/5	1	1/5	1/7	1	1/3
A_3	1/3	5	1	1/3	7	3
A_4	3	7	3	1	5	5
A_5	1/9	1	1/7	1/5	1	1/3
A_6	1/7	3	1/3	1/5	3	1

Source: retrieved from Vargas (2010).

Now, the weights of the alternatives for the first criterion were determined. With same procedure the weights of the alternatives were obtained for other criteria. All the results are presented in Table 2.10.

Table 2.10: Weight of the alternatives for every criterion.

	A_1	A_2	A_3	A_4	A_5	A_6
Commitment of the project team	*0.2968*	*0.0378*	*0.0721*	*0.3961*	*0.1613*	*0.0358*
Commitment of the organization	*0.0993*	*0.0326*	*0.0608*	*0.2884*	*0.4875*	*0.0315*
Commitment of the project manager	*0.1586*	*0.0402*	*0.0733*	*0.3546*	*0.3444*	*0.0288*
Return of investment	*0.0296*	*0.0415*	*0.1014*	*0.4564*	*0.3066*	*0.0645*
Benefit	*0.0315*	*0.0307*	*0.1092*	*0.4685*	*0.2917*	*0.0685*
Net present value	*0.0366*	*0.0611*	*0.1178*	*0.4743*	*0.2449*	*0.0653*
Compete in international markets	*0.1033*	*0.0371*	*0.0241*	*0.3767*	*0.4076*	*0.0512*
Improve internal processes	*0.1903*	*0.3975*	*0.0512*	*0.0363*	*0.0455*	*0.2792*
Improve reputation	*0.0421*	*0.0680*	*0.3389*	*0.1736*	*0.3520*	*0.0254*
Reduce risks for the organization	*0.2994*	*0.1168*	*0.4230*	*0.0890*	*0.0279*	*0.0439*
Urgency	*0.0553*	*0.0924*	*0.0528*	*0.4774*	*0.2879*	*0.0342*
House expertise	*0.4796*	*0.0242*	*0.3313*	*0.0366*	*0.0605*	*0.0678*

Source: retrieved from Vargas (2010).

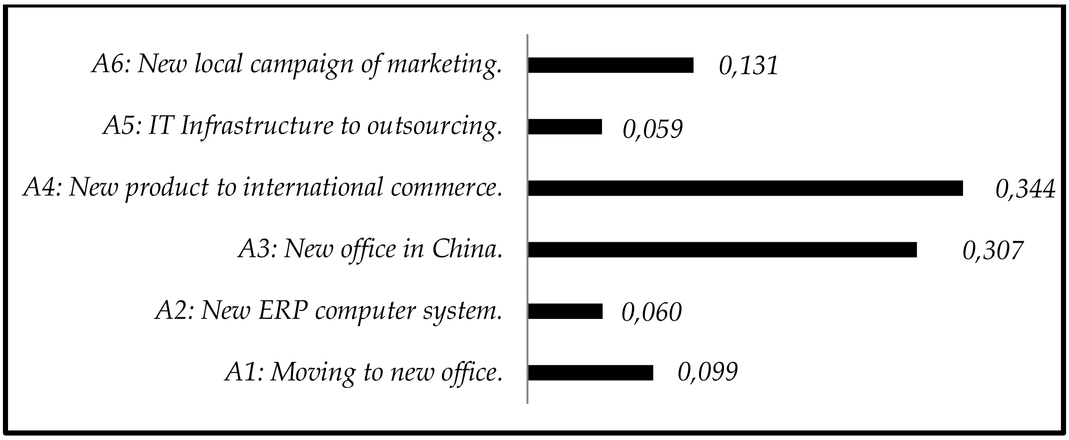
Then, the weight of each alternative is multiplied with the global weight of each criterion. For example, for the first alternative (A_1), the calculation is presented in Table 2.11.

Table 2.11: Final weight of the alternative A1.

	Weight of the alternative A_1	*Global weight of the criteria*	*Results of the multiplication*
Commitment of the project team	*0.2968*	*0.012*	*0.004*
Commitment of the organization	*0.0993*	*0.005*	*0.000*
Commitment of the project manager	*0.1586*	*0.052*	*0.008*
Return of investment	*0.0296*	*0.036*	*0.001*
Benefit	*0.0315*	*0.179*	*0.006*
Net present value	*0.0366*	*0.179*	*0.007*
Compete in international markets	*0.1033*	*0.297*	*0.031*
Improve internal processes	*0.1903*	*0.033*	*0.006*
Improve reputation	*0.0421*	*0.128*	*0.005*
Reduce risks for the organization	*0.2994*	*0.022*	*0.007*
Urgency	*0.0553*	*0.006*	*0.000*
House expertise	*0.4796*	*0.051*	*0.024*
	Final weight of the alternative A_1		***0.099***

Source: retrieved from Vargas (2010).

The same procedure was performed with all the alternatives. All the results are presented in Figure 2.4.



Source: retrieved from Vargas (2010)

Figure 2.4: Results of the hierarchy of the alternatives.

In conclusion, from figure 2.4, the alternative A_4, New product to international commerce, will be the project selected by the AIME organization, due to the fact that this alternative presents the major score.

2.3.2 Summary of the AHP method

The AHP method has also been applied to other fields and other contexts. Such as, the studies on optimal allocation of energy subsidy (Sadeghi & Ameli, 2012), selection of priorities for recycling (Kim, Jang, & Lee, 2013), or emergency treatment and disposal in accidents (Shenggang, Jingcan, Li, Wenyan, & Liqiu, 2014).

A summary of the AHP method, in relationship with SIA, is presented below:

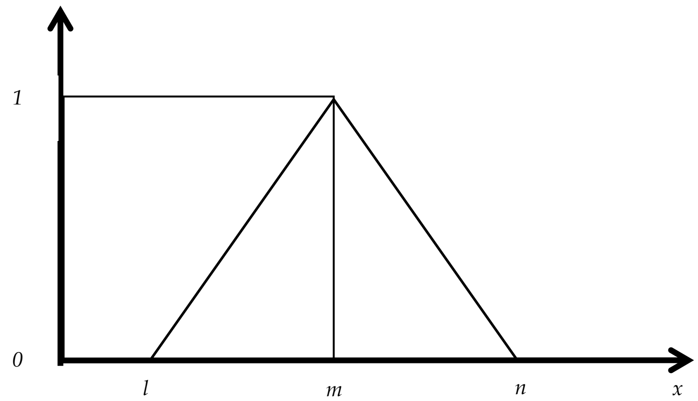
- An advantage of the AHP method is that it is able to attribute weights to the evaluation criteria.
- The procedure of the AHP method is relatively easy. This fact makes that this method can be applied on different field.
- A disadvantage of the AHP method is that it does not consider the uncertainly within its analysis.

Considering that the SIA is a social topic, which has a high level of uncertainly, the AHP method should be supplemented with other approach, which considers the uncertainly.

2.4 The FAHP method

Fuzzy analytic hierarchy process (FAHP) is a method, which adds the theory of fuzzy logic to the classical AHP. The FAHP method is an approach, which considers the uncertainty within its analysis.

Fuzzy logic was proposed by Professor Lotfi A. Zadeh, who published his work on "Fuzzy sets" in 1965, which proposes a type of logic based on an infinite number of responses for a proposition (Zadeh, 1965). This fact, is a great difference with respect to the classical Aristotelian logic, which proposes only two possibilities for the responses of a proposition, true or false (Hernández Rojas, 1997). The fuzzy logic involves a new type of number, which is called fuzzy triangular number defined as (l, m, n), and represented in Figure 2.5 (Guarino, Gabriel, & Ribas, 2012):



Source: retrieved from Guarino, Gabriel, and Ribas (2012)

Figure 2.5: Fuzzy triangular number.

The membership function $\mu_A(x)$ is defined as:

$$\mu_A(x) = \begin{cases} \dfrac{(x-1)}{(m-1)}, & se\ x \in [1\ , m] \\ \dfrac{(x-u)}{(m-u)}\ , & se\ x \in [m\ , u] \\ 0\ , & in\ another\ case \end{cases} \tag{2.9}$$

$Where:$

$l = Lower\ limit$

$m = Modal\ value\ (membership\ value = 1)$

$n = Upper\ limit$

The operation rules of the fuzzy triangular numbers are defined as follows:

1. $(l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2)$
2. $(l_1, m_1, u_1) \odot (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2)$
3. $(\lambda, \lambda, \lambda) \odot (l_1, m_1, u_1) = (\lambda l_1, \lambda m_1, \lambda u_1)$, $\lambda > 0, \lambda \in R$
4. $(l_1, m_1, u_1)^{-1} = (1/u_1, 1/m_1, 1/l_1)$

2.4.1 Procedure for the FAHP method

The main steps of the FAHP method are descripted as follows (Guarino et al., 2012; Rodríguez, 2009):

Step 1: The alternatives and the criteria for evaluation are defined.

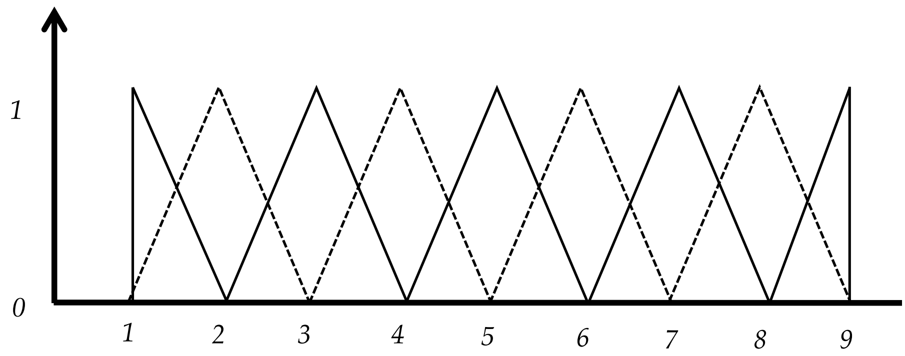
Step 2: The weights of the criteria are determined by a paired comparison. This comparison is performed using the fuzzy values, which are shown in Table 2.12.

Table 2.12: Numerical rating for FAHP.

Numerical rating		*Reciprocal*	
AHP	*FAHP*	*AHP*	*FAHP*
1	*(1, 1, 1)*	*1/1*	*(1, 1, 1)*
2	*(1, 2, 3)*	*1/2*	*(1/3, 1/2, 1)*
3	*(2, 3, 4)*	*1/3*	*(1/4, 1/3,1/2)*
4	*(3, 4, 5)*	*1/4*	*(1/5, 1/4, 1/3)*
5	*(4, 5, 6)*	*1/5*	*(1/6, 1/5, 1/4)*
6	*(5, 6, 7)*	*1/6*	*(1/7, 1/6, 1/5)*
7	*(6, 7, 8)*	*1/7*	*(1/8, 1/7, 1/6)*
8	*(7, 8, 9)*	*1/8*	*(1/9, 1/8, 1/7)*
9	*(8, 9, 9)*	*1/9*	*(1/9, 1/9, 1/8)*

Source: retrieved from Rodriguez (2009)

The membership functions of the numerical rating for FAHP are represented by Figure 2.6.



Source: retrieved from Rodriguez (2009)

Figure 2.6: Membership functions for numerical rating of FAHP.

Now, the values of the criteria obtained from the experts are aggregated using geometric mean (GM) or arithmetic mean (AM), and then the value of fuzzy synthetic extent (S_i) is calculated using Equation 2.10.

$$S_i = (l_{row\ i}, m_{row\ i}, u_{row\ i}) \odot \left(1/u_{\sum column}, 1/m_{\sum column}, 1/l_{\sum column}\right) \quad (2.10)$$

Then, the grade of possibility of $S_2 \geq S_1$ is represented as $V(S_2 \geq S_1)$ and defined as:

If $S_1 = (l_1, m_1, u_1)$ and $S_2 = (l_2, m_2, u_2)$ are convex fuzzy numbers:

$$V(S_2 \geq S_1) = hgt(S_1 \cap S_2) = \mu_{S_2}(d) = f(x)$$

$$= \begin{cases} 1, & Si\ m_2 \geq m_1 \\ 0, & Si\ l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & in\ other\ case \end{cases} \quad (2.11)$$

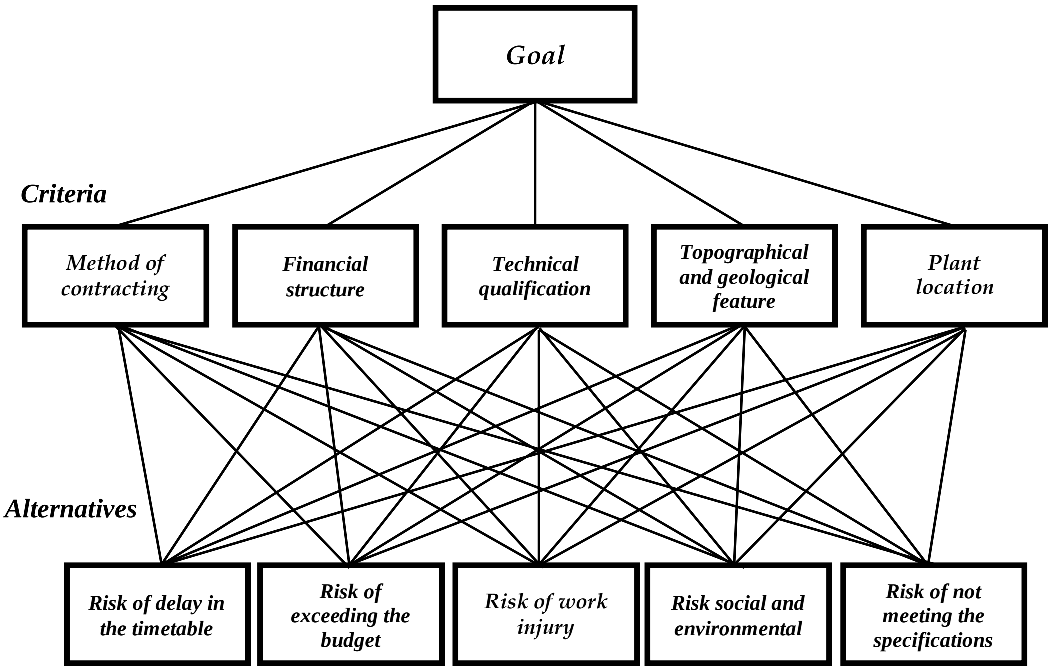
Then, choosing the minor value of $V(S_i \geq S_k)$ for each S_i , the vector of priorities is obtained, which is normalized, in order to determine the weight of the criteria.

Step 3: The alternatives are evaluated with respect to each criteria. This procedure is performed in same way that step 2.

Step 4: Finally, the ranking of the alternatives is established, which is obtained by the scalar multiplication of the weight of the criteria with the weight of the alternatives.

An example of application of the FAHP method is the study conducted by Guarino, Grabiel and Ribas, on a risk analysis of a hydroelectric power station in stage of construction (Guarino et al., 2012). A summarize of this study is presented below.

Step 1: The alternatives (*A_1, A_2, A_3, A_4, and A5*) and the criteria (*C_1, C_2, C_3, C_4, and C5*) for evaluation, in this study, are represented in Figure 2.7.



Source: retrieved from Guarino, Gabriel, and Ribas (2012)

Figure 2.7: Alternatives and criteria of the example of FAHP.

Step 2: The weights of the criteria (*C_1, C_2, C_3, C_4, and C5*), are determined by a paired comparison. This comparison is performed using the fuzzy values shown in Table 2.12. The values obtained from the experts are aggregated using the geometric mean. The results are shown in Table 2.13.

Table 2.13: Aggregated values from the experts.

	C1	C2	C3	C4	C5
C1	(1,1,1)	(4.18,4.72,5.25)	(0.22, 0.25, 0.29)	(0.16, 0.18, 0.2)	(3.04, 3.56, 4.07)
C2	(0.19,0.21,0.24)	(1,1,1)	(0.21, 0.24, 0.27)	(0.16, 0.18, 0.2)	(1.04, 1.71, 2.31)
C3	(3.44, 3.98, 4.51)	(3.7, 4.22, 4.73)	(1,1,1)	(0.34, 048, 0.62)	(5.17, 5.74, 6.18)
C4	(5.09, 5.59, 6.1)	(5.09, 5.59, 6.1)	(1.46, 2.08, 2.64)	(1,1,1)	(2.16, 2.33, 2.47)
C5	(0.25, 0.28, 0.33)	(0.36, 0.58, 0.79)	(0.16, 0.17, 0.19)	(0.41, 0.43, 0.46)	(1,1,1)

Source: retrieved from Guarino, Gabriel, and Ribas (2012)

Now, the total sum of the rows and columns are presented in Table 2.14.

Table 2.14: Total sum of rows and columns of the example.

	Sum of rows	Sum of columns
C1	(8.60835, 9.704684, 10.80256)	(9.9608, 11.0656, 12.17928)
C2	(2.605937, 3.337851, 4.018992)	(14.3247, 16.1131, 17.8695)
C3	(13.65049, 15.41576, 17.04645)	(3.05670, 3.74277, 4.3933)
C4	(14.79327, 16.59394, 18.30305)	(2.07761, 2.26805, 2.4779)
C5	(2.169801, 2.469944, 2.779249)	(12.4079, 14.3326, 16.030)
	Sum of sum of the columns (41.82785, 47.52218, 52.9503)	

Source: retrieved from Guarino, Gabriel, and Ribas (2012)

The values of fuzzy synthetic extent (S_i) are calculated using Equation 2.10. The results are shown below:

S_1= (0.16257, 0.20421, 0.258262)

S_2= (0.049214, 0.07023, 0.0960841)

S_3= (0.257798, 0.32439, 0.407538)

S_4= (0.27938021, 0.34918, 0.437580)

S_5= (0.0409780, 0.05197455, 0.066444)

Then, the comparison between the values of fuzzy synthetic extent (S_i) is performed by Equation 2.11. The results are presented below:

$V\ (S_1 \geq S_2) = 1$	$V\ (S_1 \geq S_3) = 0.003847$	$V\ (S_1 \geq S_4) = 0$	$V\ (S_1 \geq S_5) = 1$
$V\ (S_2 \geq S_1) = 0$	$V\ (S_2 \geq S_3) = 0$	$V\ (S_2 \geq S_4) = 0$	$V\ (S_2 \geq S_5) = 1$
$V\ (S_3 \geq S_1) = 1$	$V\ (S_3 \geq S_2) = 1$	$V\ (S_3 \geq S_4) = 0.837907$	$V\ (S_3 \geq S_5) = 1$
$V\ (S_4 \geq S_1) = 1$	$V\ (S_4 \geq S_2) = 1$	$V\ (S_4 \geq S_3) = 1$	$V\ (S_4 \geq S_5) = 1$
$V\ (S_5 \geq S_1) = 0$	$V\ (S_5 \geq S_2) = 0.485448$	$V\ (S_5 \geq S_3) = 0$	$V\ (S_5 \geq S_4) = 0$

Finally, choosing the minor value of $V(S_i \geq S_k)$ for each S_i, the vector of priorities is obtained:

$$W'_c = (0,\ 0,\ 0.837907,\ 1,\ 0)$$

The vector of priorities is normalized, in order to determine the weight of each criterion:

$$W_c = (0,\ 0,\ 0.455903,\ 0.544097,\ 0)$$

Step 3: The alternatives are evaluated with respect to each criteria. The results of the aggregated evaluations, from the experts, are presented in Table 2.15.

Table 2.15: Aggregated results from experts in the example of FAHP.

C1	***A1***	***A2***	***A3***	***A4***	***A5***
A1	*(1,1,1)*	*(0.34, 0.48, 0.62)*	*(7.11, 7.61, 7.97)*	*(5.17, 5.74, 6.18)*	*(2.2, 3, 3.62)*
A2	*(1.46, 2.08, 2.64)*	*(1,1,1)*	*(5.17, 5.74, 6.18)*	*(3.76, 4.33, 4.8)*	*(1.07, 1.44, 1.75)*
A3	*(0.13, 0.13, 0.14)*	*(0.16, 0.17, 0.19)*	*(1,1,1)*	*(0.62, 0.69, 0.79)*	*(0.22, 0.25, 0.29)*
A4	*(0.16, 0.17, 0.19)*	*(0.21, 0.23, 0.27)*	*(1.27, 1.44, 1.62)*	*(1,1,1)*	*(0.46, 0.52, 0.6)*
A5	*(0.25, 0.33, 0.41)*	*(0.52, 0.69, 0.85)*	*(3.44, 3.98, 4.51)*	*(1.67, 1.91, 2.19)*	*(1,1,1)*

C2	***A1***	***A2***	***A3***	***A4***	***A5***
A1	*(1,1,1)*	*(0.85, 1.44, 1.99)*	*(6.29, 6.8, 7.19)*	*(6.29, 6.8, 7.19)*	*(6.29, 6.8, 7.19)*
A2	*(0.41, 0.69, 0.97)*	*(1,1,1)*	*(3.02, 3.98, 4.66)*	*(3.02, 3.98, 4.66)*	*(2.67, 3.56, 4.2)*
A3	*(0.14, 0.15, 0.16)*	*(0.19, 0.25, 0.3)*	*(1,1,1)*	*(0.5, 1, 1.5)*	*(0.41, 0.69, 0.97)*
A4	*(0.14, 0.15, 0.16)*	*(0.19, 0.25, 0.3)*	*(0.5, 1, 1.5)*	*(1,1,1)*	*(0.36, 0.58, 0.79)*
A5	*(0.14, 0.15, 0.16)*	*(0.22, 0.28, 0.34)*	*(0.85, 1.44, 1.99)*	*(1.04, 1.71, 2.31)*	*(1,1,1)*

C3	***A1***	***A2***	***A3***	***A4***	***A5***
A1	*(1,1,1)*	*(2.01, 2.76, 3.4)*	*(1.78, 2.47, 3.07)*	*(2.2, 3, 3.62)*	*(0.43, 0.48, 0.54)*
A2	*(0.27, 0.36, 0.45)*	*(1,1,1)*	*(0.71, 1, 1.28)*	*(0.85, 1.44, 1.99)*	*(0.21, 0.23, 0.27)*
A3	*(0.3, 0.41, 0.51)*	*(0.71, 1, 1.28)*	*(1,1,1)*	*(1.18, 1.91, 2.56)*	*(0.18, 0.19, 0.22)*
A4	*(0.25, 0.33, 0.41)*	*(0.54, 0.69, 0.97)*	*(0.32, 0.52, 0.7)*	*(1,1,1)*	*(0.15, 0.16, 0.18)*
A5	*(1.46, 2.08, 2.64)*	*(3.76, 4.33, 4.8)*	*(4.57, 5.13, 5.57)*	*(5.56, 6.08, 6.48)*	*(1,1,1)*

C4	***A1***	***A2***	***A3***	***A4***	***A5***
A1	*(1,1,1)*	*(0.41, 0.69, 0.97)*	*(4.18, 4.72, 5.25)*	*(4.18, 4.72, 5.25)*	*(2.67, 3.56, 4.2)*
A2	*(0.85, 1.44, 1.99)*	*(1,1,1)*	*(2.76, 3.66, 4.39)*	*(4.73, 5.28, 5.82)*	*(4.57, 5.13, 5.57)*
A3	*(0.19, 0.21, 0.24)*	*(0.21, 0.27, 0.33)*	*(1,1,1)*	*(1.48, 1.71, 1.97)*	*(1.43, 1.61, 1.8)*
A4	*(0.19, 0.21, 0.24)*	*(0.17, 0.19, 0.21)*	*(0.51, 0.58, 0.68)*	*(1,1,1)*	*(0.84, 1.12, 1.36)*
A5	*(0.22, 0.28, 0.34)*	*(0.18, 0.19, 0.22)*	*(0.56, 0.62, 0.7)*	*(0.67, 0.89, 1.08)*	*(1,1,1)*

C5	***A1***	***A2***	***A3***	***A4***	***A5***
A1	*(1,1,1)*	*(0.41,0.69,0.97)*	*(1.46, 2.08, 2.64)*	*(0.62, 0.69, 0.79)*	*(1.04, 1.22, 1.4)*
A2	*(0.85, 1.44, 1.99)*	*(1,1,1)*	*(3.7, 4.22, 4.73)*	*(0.81, 0.92, 1.06)*	*(1.27, 1.44, 1.62)*
A3	*(0.34, 0.48, 0.62)*	*(0.21, 0.24, 0.27)*	*(1,1,1)*	*(0.36, 0.58, 0.79)*	*(0.61, 0.84, 1.05)*
A4	*(1.27, 1.44, 1.62)*	*(0.94, 1.09, 1.24)*	*(1.04, 1.71, 2.31)*	*(1,1,1)*	*(1.21, 1.44, 1.7)*
A5	*(0.72, 0.82, 0.96)*	*(0.62, 0.69, 0.79)*	*(0.86, 1.19, 1.49)*	*(0.59, 0.69, 0.82)*	*(1,1,1)*

Source: retrieved from Guarino, Gabriel, and Ribas (2012)

Then, the weights of the alternatives are determined. This procedure is performed in same way that step 2. The results are shown in Table 2.16.

Table 2.16: Weight of the alternatives in the example of FAHP.

	A1	*A2*	*A3*	*A4*	*A5*
C1	*63.6*	*36.4*	*0*	*0*	*0*
C2	*67.7*	*32.3*	*0*	*0*	*0*
C3	*1.1*	*0*	*0*	*0*	*98.9*
C4	*44.4*	*55.6*	*0*	*0*	*0*
C5	*17.7*	*52.7*	*0*	*29.6*	*0*

Source: retrieved from Guarino, Gabriel, and Ribas (2012)

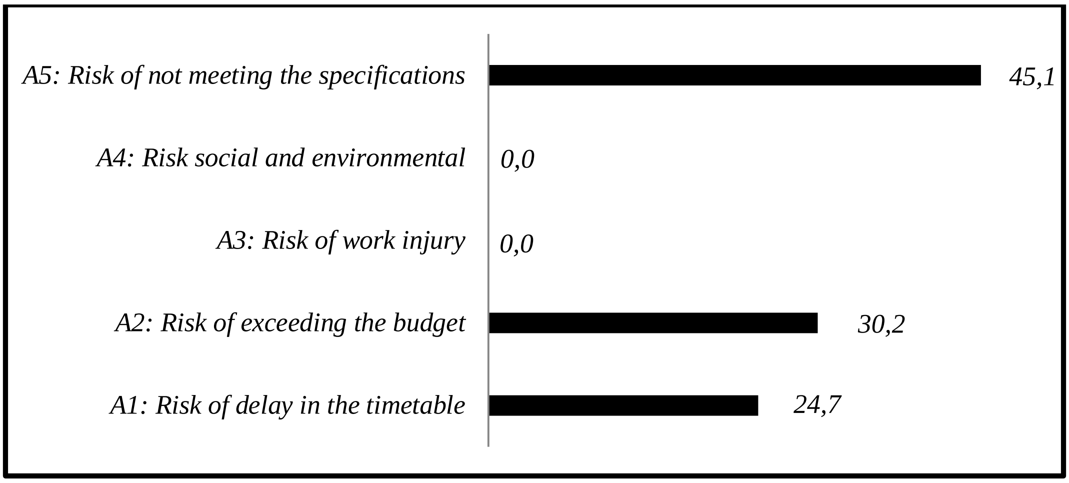
Step 4: The ranking of the alternatives is established by the scalar multiplication of the weight of the criteria with the weight of the alternatives, as is shown in Table 2.17:

Table 2.17: Hierarchy of the alternatives of the example of FAHP.

C1	*C2*	*C3*	*C4*	*C5*		*A1*	*A2*	*A3*	*A4*	*A5*	
0	*0*	*0.46*	*0.54*	*0*		*63.6*	*36.4*	*0*	*0*	*0*	***C1***
						67.7	*32.3*	*0*	*0*	*0*	***C2***
						1.1	*0*	*0*	*0*	*98.9*	***C3***
						44.4	*55.6*	*0*	*0*	*0*	***C4***
						17.7	*52.7*	*0*	*29.6*	*0*	***C5***
					Hierarchy of the alternatives	***24.7***	***30.2***	***0***	***0***	***45.1***	

Source: retrieved from Guarino, Gabriel, and Ribas (2012)

The final results are presented in Figure 2.8.



Source: retrieved from Guarino, Gabriel, and Ribas (2012)

Figure 2.8: Final result of the example of FAHP.

In this example, the final conclusion is that the alternative A_5 (Risk of not meeting the specifications) has the major score. Therefore the major risk that could have the project is the risk of not meeting the specifications.

2.4.2 Summary of the FAHP method

The FAHP method has also been applied to other contexts, as evidenced by studies on the selection of academic staff (Rouyendegh & Erkan, 2012), the decision for selection of lead-free equipment (Y. C. Tang & Lin, 2011), the selection of the multimedia applications for learning (Volaric, Tomislav;Brajkovic, 2013) or the evaluation of the software quality (X. Liu & Pang, 2010).

The main characteristics of the FAHP method could be summarized as following:

- Similarly as AHP, The FAHP method is able to attribute weights to the evaluation criteria.
- An advantage of the FAHP method is that it considers the uncertainty within its analysis. This is due to the fact that the FAHP method uses the fuzzy logic within of its procedure.

- The FAHP method is an approach based on fuzzy logic, which is characterized for the application to problems with clear intention and unclear extension. *"For example, the instance, "young man" is a fuzzy concept, because everybody understands the idea of "young man". However, if you are going to determine the exact range within which everybody is young and outside which everybody is not young, then you will find yourself in difficulty. This is because the concept of young man does not have a clear extension"* (S. Liu & Lin, 2010).

A methodology for SIA, which considers the uncertainty within its analysis, should include the analysis of problems with clear extension, due to the fact that the affected population, who are interviewed in order to conduct a SIA, know or perceive the minimum and maximum value of a social variable under analysis.

2.5 The grey clustering method

The grey clustering method is an approach, which is based on grey systems theory. The grey systems theory was established by Julong Deng (Deng, 1985), which is applied to research problems with limited information and small samples (S. Liu & Lin, 2010). This fact makes that the grey systems theory can be applied to different fields, such as water management (L. N. Zhang, Wu, & Jia, 2013), safety management (Li, Chen, & Xiang, 2015), transport management (Leng et al., 2012), or evaluation of web sites (Bindu, Padmaja, & Chandulal, 2010).

The grey clustering method can be applied using grey incidence matrices or grey whitenization weight functions. The grey clustering method is used to classify observation objects into definable classes, called grey classes. In this thesis, the grey clustering method, based on center-point triangular whitenization weight functions (CTWF), is used; as stakeholder groups can be treated as observation objects for SIA. In addition, since respondents tend to be more certain about the center-point of a grey class compared with other points within the grey class, conclusions based on such cognitive certainty are more scientific and reliable (S. Liu & Lin, 2010).

2.5.1 Procedure for the grey clustering method

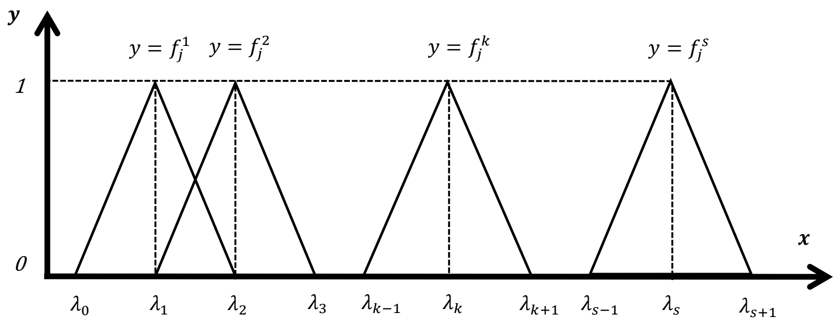
The procedure for the grey clustering method, based on center-point triangular whitenization weight functions (CTWF) is developed below (S. Liu & Lin, 2010; Y. Zhang, Ni, Liu, & Jian, 2014):

First, assume a set of *m* objects, a set of *n* criteria and a set of *s* different grey classes, according to the sample value x_{ij} $(i=1, 2, \ldots, m; j=1, 2, \ldots, n)$ of the *i*th $(i=1, 2, \ldots, m)$ object, for the criterion *j* $(j=1, 2, \ldots, n)$. Then, the steps for the grey clustering method based on CTWF can be developed as follows:

Step 1: The range of each criterion is divided into *s* grey classes, and then center-points $\lambda_1, \lambda_2, \ldots, \lambda_s$ of grey classes $1, 2, \ldots, s$ are determined.

Step 2: The grey obtained classes are expanded in two directions, adding the grey classes *0* and $(s+1)$ with their center-points λ_0 and λ_{s+1} respectively. Therefore, the new sequence of center-points is established as $\lambda_0, \lambda_1, \lambda_2, \ldots, \lambda_s, \lambda_{s+1}$ (see Figure 2.9). The CTWF for the *k*th grey class, $k=1, 2, \ldots, s$, of the *j*th criterion, $j=1, 2, \ldots, n$, for an observed value x_{ij} is defined by Equation 2.12.

$$f_j^k(x_{ij}) = \begin{cases} 0 \quad , & x \notin [\lambda_{k-1}, \lambda_{k+1}] \\ \dfrac{x - \lambda_{k-1}}{\lambda_k - \lambda_{k-1}}, & x \in [\lambda_{k-1}, \lambda_k] \\ \dfrac{\lambda_{k+1} - x}{\lambda_{k+1} - \lambda_k}, & x \in [\lambda_k, \lambda_{k+1}] \end{cases} \tag{2.12}$$



Source: retrieved from Liu and Lin (2010).

Figure 2.9: Center-point triangular whitenization weight functions (CTWF).

Step 3: The comprehensive clustering coefficient σ_i^k, for object *i*, *i=1, 2,…, m*, with respect to the grey class *k*, *k*=1,…, *s* is calculated by Equation 2.13.

$$\sigma_i^k = \sum_{j=1}^{n} f_j^k(x_{ij}).\eta_j \tag{2.13}$$

where $f_j^k(x_{ij})$ is the CTWF of the *k*th grey class of the *j*th criterion, and η_j is the weight of criterion *j*.

Step 4: If $\max_{1\le k\le s}\{\sigma_i^k\} = \sigma_i^{k^*}$, it is decided that object *i* belongs to grey class *k**. When there are several objects in grey class k*, these objects can be ordered according to the magnitudes of their comprehensive clustering coefficients.

In order to describe the procedure of the grey clustering method based on CTWF, a study on the evaluation of the quality from educational programs of a university is summarized below (S. Liu & Lin, 2010).

In this study six evaluation criteria and three educational programs were established. In addition, the weights of the criteria were defined as follows η_1*=0.21,* η_2*=.0.24,* η_3*=0.23,* η_4*=0.14,* η_5*=0.10,* and η_6*=0.08.* The aggregated results obtained from expert team are shown in Table 2.18.

Table 2.18: Values of three educational programs.

Program #	*Faculty*	*Scholarly works*	*Talent Production*	*Disciplinary platform*	*Working environment*	*Scholarly exchange*
1	*83*	*89*	*93*	*78*	*74*	*63*
2	*79*	*80*	*82*	*66*	*72*	*47*
3	*83*	*40*	*51*	*56*	*70*	*45*

Source: retrieved from Liu and Lin (2010)

Step 1: The values range is divided into four grey classes: excellent, good, fine, and poor. All of values of the programs are within range of 40 to 95. Then, the interval [40 , 95] is divided in four intervals according to the grey classes. These intervals are: [40,60>, [60,75>, [75,85>, and [85,95>. The center-points are determined as follows: λ_1=90, λ_2=80, λ_3=70, λ_4=50.

Step 2: The grey classes are expanded in two directions, adding the grey classes *0* and *5* with their center-points *100* and *30* respectively. Therefore, the new sequence of center-points is: λ_0 =100, λ_1 =90, λ_2 =80, λ_3 =70, λ_4 =50, λ_5 =30. From Equation 2.12, the CTWF for the *k*th grey class, *k=1, 2, 3, 4,* of the *j*th criterion, *j=1, 2, 3, 4, 5, 6,* for an observed value x_{ij} are defined by Equations 2.14, 2.15, 2.16, and 2.17.

$$f_j^1(x) = \begin{cases} 0, & x \notin [80\,,100] \\ \dfrac{x-80}{10}, & x \in [80\,,90] \\ \dfrac{100-x}{10}, & x \in [90\,,100] \end{cases} \tag{2.14}$$

$$f_j^2(x) = \begin{cases} 0, & x \notin [70\,,90] \\ \dfrac{x-70}{10}, & x \in [70\,,80] \\ \dfrac{90-x}{10}, & x \in [80\,,90] \end{cases} \tag{2.15}$$

$$f_j^3(x) = \begin{cases} 0, & x \notin [50, 80] \\ \frac{x-50}{20}, & x \in [50, 70] \\ \frac{80-x}{10}, & x \in [70, 80] \end{cases} \tag{2.16}$$

$$f_j^4(x) = \begin{cases} 0, & x \notin [30, 70] \\ \frac{x-30}{20}, & x \in [30, 50] \\ \frac{70-x}{20}, & x \in [50, 70] \end{cases} \tag{2.17}$$

Step 3: The comprehensive clustering coefficient σ_i^k, for object *i*, *i=1, 2, 3,* with respect to the grey class *k*, *k=1, 2, 3, 4,* is calculated by Equation 2.13. The results are shown in Table 2.19.

Table 2.19: The comprehensive clustering coefficient for each program.

Grey class	X_1	X_2	X_3	X_4	X_5	X_6	σ_1^k
1	0.3	0.9	0.7	0	0	0	0.44
2	0.7	0.1	0	0.8	0.4	0	0.323
3	0	0	0	0.2	0.6	0.65	0.14
4	0	0	0	0	0	0.35	0.028
Grey class	X_1	X_2	X_3	X_4	X_5	X_6	σ_2^k
1	0	0	0.2	0	0	0	0.046
2	0.9	1	0.8	0	0.2	0	0.817
3	0.1	0	0	0.8	0.8	0	0.213
4	0	0	0	0.2	0	0.85	0.096
Grey class	X_1	X_2	X_3	X_4	X_5	X_6	σ_3^k
1	0.3	0	0	0	0	0	0.063
2	0.7	0	0	0	0	0	0.147
3	0	0	0.05	0.3	1	0	0.1535
4	0	0.5	0.95	0.7	0	0.75	0.4965

Source: retrieved from Liu and Lin (2010)

Step 4: From:

$$\max_{1\le k\le 4}\{\sigma_1^k\} = \sigma_1^1 = 0.44 \quad \max_{1\le k\le 4}\{\sigma_2^k\} = \sigma_2^2 = 0.817 \quad \max_{1\le k\le 4}\{\sigma_3^k\} = \sigma_3^4 = 0.4965$$

it is concluded that: the quality of the program 1 is into the grey class of "excellent" , of the program 2 is "good", and of the program 3 is "poor". Therefore, the program 1 has more quality than other two programs.

2.5.2 Summary of the grey clustering method

The grey clustering method based on CTWF has also been applied to other fields, as shown by the studies on the analysis of a water rights allocation system (L. N. Zhang et al., 2013), the classification of innovation strategic alliances (Y. Zhang et al., 2014), or the evaluation of low-carbon urban transport development (Guo, Zhao, & Yimin, 2015).

The main characteristics of the grey clustering method based on CTWF could be summarized as follows:

- As AHP and FAHP, the grey clustering method based on CTWF is able to accept weights to the evaluation criteria.
- Similarly as FAHP, the grey clustering method based on CTWF also considers the uncertainty within its analysis.
- The grey clustering method based on CTWF is an approach, which is characterized for the application to problems with unclear intention and clear extension. This fact is the main difference of the grey clustering method based on CTWF, with respect to other approaches based on fuzzy logic (S. Liu & Lin, 2010).

The grey clustering method based on CTWF could benefit to SIA, as this method considers the uncertainty within its analysis, and it is adequate to apply to problems with clear extension. This fact helps to the affected population, as they know or perceive the minimum and maximum value of a social variable under analysis. This fact eases the gathering of information during the field work.

2.6 The entropy-weight method

The entropy-weight method is based on Shannon entropy theory. Shannon entropy or information theory of Shannon, was originally proposed by Shannon (Shannon & Weaver, 1947). Shannon entropy is a concept which is applied to measure the contrast between criteria, this information is important for decision-making (Zeleny, 1996). This fact makes that Shannon entropy can be applied to different fields, such as, clinical neurophysiology

(Cao & Slobounov, 2011), transport systems (Chen, Leng, Mao, & Liu, 2014), or environmental time series data (Srivastav & Simonovic, 2014).

Shannon developed measure H which satisfies the following properties for all p_i within an estimated joint probability distribution P (Shemshadi, Shirazi, Toreihi, & Tarokh, 2011; Zitnick & Kanade, 2004):

1. H is a continuous positive function;
2. If all p_i are equal, $p_i = 1/n$, then H should be a monotonic increasing function of n; and,
3. For all,

$$n \geq 2, H(p_1, p_2, \ldots, p_n) = h(p_1 + p_2, p_3, \ldots, p_n) + (p_1 + p_2)H(\frac{p_1}{p_{1+}p_2}, \frac{p_2}{p_{1+}p_2})$$

Shannon showed that the only function which satisfies these properties is:

$$H_{Shanon} = -\sum_{i}^{n} p_i log(p_i) \quad (2.18)$$

where: $0 \leq p_i \leq 1;\ \sum_{j=1}^{n} p_i = 1$

2.6.1 Procedure for the entropy-weight method

The procedure of the entropy-weight can be summarized as follows (Fagbote, Olanipekun, & Uyi, 2014; Ji, Huang, & Sun, 2015; Wang & Lee, 2009; Xie & Yang, 2011):

First, assume that there are m objects for evaluation and each one has n evaluation criteria, which form decision matrix $Z = \{z_{ij};\ i = 1, 2, \ldots, m; j = 1, 2, \ldots, n\}$. Then, the steps of the entropy-weight method can be expressed as follows:

Step 1: The decision matrix $Z = \{z_{ij};\ i = 1, 2, \dots, m; j = 1, 2, \dots, n\}$ is normalized for each criterion Cj (j=1, 2,..., n). The normalized values Pij are calculated by Equation 2.19.

$$P_{ij} = \frac{z_{ij}}{\sum_{i=1}^{m} z_{ij}} \quad (2.19)$$

Step 2: The entropy H_j of each criterion Cj is calculated by Equation 2.20.

$$H_j = -k \sum_{i=1}^{m} P_{ij}\, ln(P_{ij}) \quad (2.20)$$

k is a constant, let $k = (ln(m))^{-1}$.

Step 3: The degree of divergence div_j of the intrinsic information in each criterion Cj is calculated by Equation 2.21.

$$div_j = 1 - H_j \quad (2.21)$$

Step 4: The entropy weight w_j of each criterion Cj is calculated by Equation 2.22.

$$w_j = \frac{div_j}{\sum_{j=1}^{n} div_j} \quad (2.22)$$

In order to illustrate the procedure of the entropy-weight method, a study on valuation of companies (Aznar & Guijarro, 2012; Diakoulaki, Mavrotas, & Papayannakis, 1995), is summarized below. In this study, eight companies are valuated, according to three criteria: cost effectiveness, market share, and productivity. The information on the eight companies is presented in Table 2.20.

Table 2.20: Information from the companies.

Company	Cost effectiveness (%)	Market share (%)	Productivity (Millions of dollars)
A	61	1.08	4.33
B	20.7	0.26	4.34
C	16.3	1.98	2.53
D	9	3.29	1.65
E	5.4	2.77	2.33
F	4	4.12	1.21
G	0.01	3.52	2.1
H	0.01	3.31	0.98

Source: retrieved from Aznar and Guijarro (2012); Diakoulaki, Mavrotas, and Papayannakis (1995)

Step 1: The values of Table 2.20 are normalized in each criterion. The normalized values are calculated by Equation 2.19. The results are shown in Table 2.21.

Table 2.21: Normalized values in each criterion.

Company	Cost effectiveness	Market share	Productivity
A	0.5240	0.0531	0.2224
B	0.1778	0.0128	0.2229
C	0.1400	0.0974	0.1299
D	0.0773	0.1618	0.0847
E	0.0464	0.1363	0.1197
F	0.0344	0.2027	0.0621
G	0.0001	0.1731	0.1079
H	0.0001	0.1628	0.0503

Source: retrieved from Aznar and Guijarro (2012); Diakoulaki, Mavrotas, and Papayannakis (1995)

Step 2: The entropy H_j of each criterion Cj is calculated by Equation 2.20. The results are presented in Table 2.22.

Table 2.22: Entropy values of each criterion.

	Cost effectiveness	*Market share*	*Productivity*
H_j	*0.66305*	*0.92691*	*0.94285*

Source: retrieved from Aznar and Guijarro (2012); Diakoulaki, Mavrotas, and Papayannakis (1995)

Step 3: The degree of divergence div_j of in each criterion *Cj* is calculated by Equation 2.21. The results are shown in Table 2.23.

Table 2.23: Degree of divergence in each criterion.

	Cost effectiveness	*Market share*	*Productivity*
div_j	*0.33695*	*0.07309*	*0.05715*

Source: retrieved from Aznar and Guijarro (2012); Diakoulaki, Mavrotas, and Papayannakis (1995)

Step 4: The entropy weight w_j of each criterion *Cj* is calculated by Equation 2.22. The results are presented in Table 2.24.

Table 2.24: Entropy weight of each criterion.

	Cost effectiveness	*Market share*	*Productivity*
w_j	*0.7212*	*0.1564*	*0.1223*

Source: retrieved from Aznar and Guijarro (2012); Diakoulaki, Mavrotas, and Papayannakis (1995)

In conclusion, the weights of the criteria are established as follows:

Cost effectiveness : 72.12%
Market share : 15.64%
Productivity : 12.23%

As additional information, in this study, the authors suggested a ranking of the companies by a weighted sum, considering the weights of the criteria and the values of Table 2.20. The results are shown in Table 2.25.

Table 2.25: Ranking of the companies.

Company	*Cost effectiveness (%)*	*Market share (%)*	*Productivity (Millions of dollars)*	*Ranking*
A	*61*	*1.08*	*4.33*	*44.69*
B	*20.7*	*0.26*	*4.34*	*15.50*
C	*16.3*	*1.98*	*2.53*	*12.37*
D	*9*	*3.29*	*1.65*	*7.21*
E	*5.4*	*2.77*	*2.33*	*4.61*
F	*4*	*4.12*	*1.21*	*3.68*
G	*0.01*	*3.52*	*2.1*	*0.81*
H	*0.01*	*3.31*	*0.98*	*0.64*
w_j	*0.7212*	*0.1564*	*0.1223*	

Source: retrieved from Aznar and Guijarro (2012); Diakoulaki, Mavrotas, and Papayannakis (1995)

2.6.2 Summary of the entropy-weight method

The entropy-weight method is an approach that considers the uncertainty within its analysis. In addition, this method also allows us identifying the conflictive criteria into of an environmental conflict under study. Due to the fact that the entropy-weight method for a certain criterion, if there is a large difference between the alternatives, the criterion will give decision makers a large amount of information and the criterion can be regarded as an important factor (Kou et al., 2011). It can thus be argued that the entropy-weight method could be applied for ECA to determine those criteria for which there is divergence between the stakeholder groups.

The entropy-weight method should be combined with other method, which assesses the social impact, in order to integrate social impact assessment and environmental conflict analysis. In this thesis, a combined method based on the grey clustering method and the entropy-weight method is proposed, to integrate social impact assessment and environmental impact analysis.

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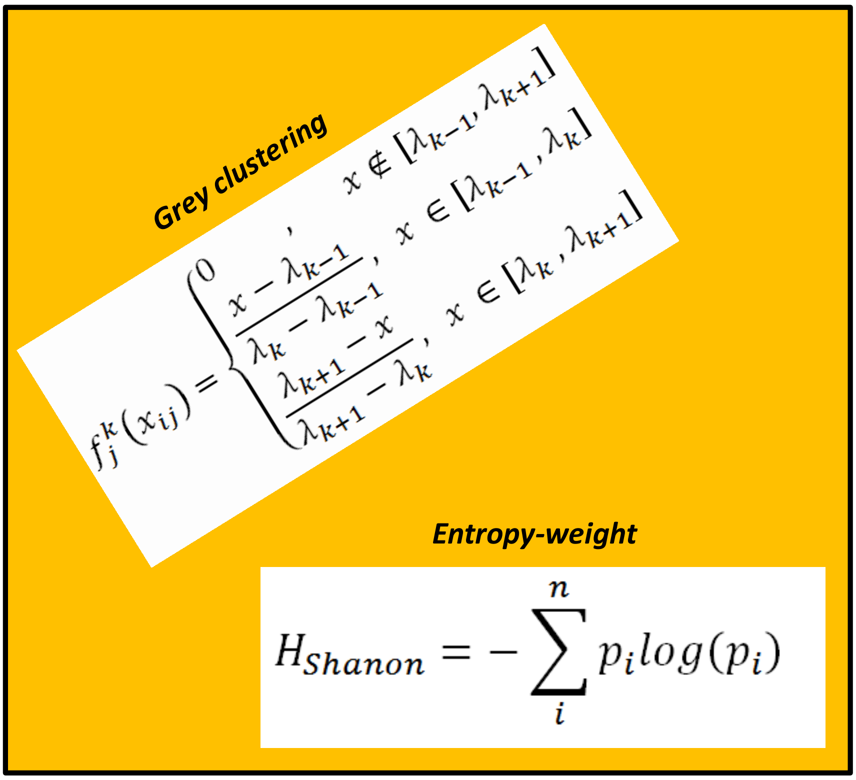
CHAPTER III

FORMULATION OF THE PROPOSED METHOD



3. Formulation of the proposed method

3.1 Introduction

In this chapter, the formulation and details of the proposed integrated method for SIA and ECA are developed.

First, in section 3.2, an initial study published in a journal on the selection of a method for SIA is translated and adapted in this thesis. In this study, the opinion form expert team, on the best method for SIA, is collected and processed.

Second, in section 3.3, the proposed integrated method is developed and discussed. The integration of SIA and ECA is performed by combining the grey clustering method based on CTWF and the entropy-weight method.

3.2 Initial study to explore a method for SIA

In this section, in order to explore the best method for SIA, an initial study, by processing of the opinion from expert team using AHP, is presented. This study was published in the journal *"Revista ECIPerú"*, which is a journal of open access (public domain), with ISSN: 1813-0194. This article was translated and adapted for this thesis.

Link of the English version from data base, *Hyper Article en Ligne (HAL):*
https://hal.archives-ouvertes.fr/hal-01242027v1
Link of the Spanish version from data base, *Hyper Article en Ligne (HAL):*
https://hal.archives-ouvertes.fr/hal-01188398v2
Link from the journal:
http://www.reddeperuanos.com/revista/eci2015irevista/index.htm

Paper 1: Selection of a method for SIA using AHP

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Abstract

Increasing of environmental conflicts during the planning or execution of projects makes social impact assessment necessary and objective, in order to prevent potential environmental conflicts. In this paper, we present a study to select the best alternative methodology available and applicable for social impact assessment (SIA) on projects and programs. The selection was conducted using the methodology of analytic hierarchy process (AHP). In this study, four alternative methods for social impact assessment were proposed: Delphi, AHP, FAHP and grey clustering, which were ranked according to criteria: quantification, robustness and standardization. To make the selection using AHP, a panel of four experts was convoked for this study. The results showed that the best method for social impact assessment is the grey clustering complemented with Delphi method and other qualitative procedures during field work and data collection.

Keywords: Social Impact Assessment (SIA), Analytic Hierarchy Process (AHP)

3.2.1 Introduction

Environmental conflicts are increasing due to developing of investment projects that demand to exploit natural resources, which affect to population into influence area from determined project, as evidenced by studies on environmental conflicts of water management (Saqalli et al., 2010), or of exploitation of energy resources (Karjalainen & Järvikoski, 2010). To prevent possible environmental conflicts is necessary to conduct social impact assessment (SIA), before, during, and after of execution of a project.

Social impact assessment has been mainly conducted under qualitative approaches, as descripted by study on social impact assessment on a infrastructure developing project (Prenzel & Vanclay, 2014). Qualitative methods contribute with much information during analysis of a problem, but it has limitations for decision making, as there is lack of numeric information, which allows doing a good discrimination. Therefore, qualitative methods must be complemented with other quantitative approaches, in order to improve assessment and decision making.

Between the main available methodological alternatives for social impact assessment, which allow quantifying the qualitative information, we have: first, the Delphi method, which is used to do studies on prospective and indicators construction, as evidenced by study on construction of indicators to evaluate university institutions (Garcia Aracli, 2012). Second, the AHP method, used to make decisions, as shown by the study on decision making for allocation of subsidised energy (Sadeghi & Ameli, 2012). Third, the FAHP method that is an extension of AHP, which includes fuzzy logic within its analysis. FAHP is a method that is used, among other things, for decision making as shown in the study on the evaluation of alternatives in the production cycle (Weck, Klocke, Schell, & Riienauver, 1997). Fourth, the grey clustering method, which is used to classify objects using evaluation criteria, as shown by the study on the risk assessment of investment in an energy project (Ke, Xiaoliu, Zhongfu, & Wenyan, 2012).

The AHP method is a practical and useful option to choose the best alternative between a set of them, as shown by studies on the selection of recycle alternatives (Kim et al., 2013), or the emergency control of accidents of environmental pollution (Shenggang et al., 2014). Therefore, the AHP method is a tool , which helps us to choose the best alternative for SIA by evaluating of the four alternatives propose in this study.

The criteria established to select the best method for SIA were: quantification, robustness and standardization. This criteria were sectioned according to main approaches on quality that must have the methods (Vinagre, 1995), and by the opinion of the expert team.

To conduct the process of selection of a method for SIA, we convoked to four specialist experts from fields of multi-criteria methods, decision making, social sciences, and environmental sciences. The characterises of these experts are that they know their speciality and also have a holistic view on socio-environmental problem, which is a requirement in opinion of Landeta (Landeta, 2002).

The objectives in this study are to: select the best method for SIA using AHP, and characterize the method chosen.

This article is organized as follows: In Section 3.2.2, the methodology is developed. The application of AHP to select a method for SIA is performed in Section 3.2.3. In Section 3.2.4, the results and discussion are provided. The conclusions of this study are presented in Section 3.2.5.

3.2.2 Methodology

The methodology used in this study to select a method for SIA was AHP. AHP method was proposed by Thomas L. Saaty (T. L. Saaty, 1980). AHP was designed to select the best alternative from a set of proposed alternatives, which are evaluated according to previously established criteria (T. Saaty & Vargas, 2012). The procedure of AHP method can be summarized by the following steps (Ahammeda & Azeem, 2013; Aznar & Guijarro, 2012):

Step 1: The alternatives for evaluation are defined as: A_1, A_2, A_3,..., A_m.

Step 2: The criteria for evaluation are defined as: C_1, C_2, C_3,…, C_n.

Step 3: The matrix of comparison and its consistency are established.

To determine the weight for each criterion, a matrix of paired comparison is used. This matrix is constructed used a scale that was proposed by Saaty (Vargas, 2010). The values are shown in Table 3.1.

Table 3.1: Relative importance of the Saaty scale.

Scale	*Numerical rating*	*Reciprocal*
Extremely recommended	*9*	*1/9*
Very strong to extremely	*8*	*1/8*
Very strongly preferred	*7*	*1/7*
Strongly to very strongly	*6*	*1/6*
Strongly preferred	*5*	*1/5*
Moderately to strongly	*4*	*1/4*
Moderately preferred	*3*	*1/3*
Equally to moderately	*2*	*1/2*
Equally preferred	*1*	*1*

Source: retrieved from Vargas (2010)

The results of the comparison between the criteria: $C_1, C_2, C_3, \ldots, C_n$, are established according to the matrix shown in Equation 3.1.

$$\begin{matrix} \\ C_1 \rightarrow \\ C_2 \rightarrow \\ \vdots \\ C_n \rightarrow \end{matrix} \overbrace{\begin{pmatrix} 1 & p_{12} & \cdots & p_{1n} \\ \frac{1}{p_{12}} & 1 & \cdots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{p_{1n}} & \frac{1}{p_{2n}} & \cdots & 1 \end{pmatrix}}^{\substack{C_1 \; C_2 \; \ldots\ldots \; C_n \\ \downarrow \;\; \downarrow \;\;\;\;\;\;\; \downarrow}} = P_{n\times n} \tag{3.1}$$

Now, the matrix P is normalized in each column by the division of each element by total sum of the column: $S_{1\times n} = (s_1 \quad s_2 \quad s_3 \quad \cdots \quad s_n)$. Then, the weight of each criterion is calculated by the arithmetic mean of the elements of each row. The weight matrix is represented by Equation 3.2.

$$W_{n\times 1} = (w_1 \quad w_2 \quad w_2 \quad \cdots \quad w_n)^t \tag{3.2}$$

To determine the consistency of the comparison matrix, first, the consistency index (CI) is calculated by Equation 3.3.

$$CI = \frac{\lambda_{Max} - n}{n-1} \tag{3.3}$$

Where ***n*** is the order of the matrix, and λ_{Max} is the maximum eigenvector, which is calculated by Equation 3.4.

$$\lambda_{Max} = \sum_{i=1}^{n} s_i . w_i \tag{3.4}$$

As additional information, there are other procedures to calculate the weight of the criteria, but the difference between results is insignificant (Vargas, 2010). Therefore, the procedure used in this article is valid. Next, the random consistency index (RI) is determined according to values of Table 3.2, which were calculated by Saaty (T. Saaty & Vargas, 2012), where ***n*** is the order of the matrix.

Table 3.2: Values of IR established by Saaty.

n	1	2	3	4	5	6	7	8	9	10
IR	*0*	*0*	*0,52*	*0,89*	*1,11*	*1,25*	*1,35*	*1,40*	*1,45*	*1,49*

Source: retrieved from Saaty and Vargas (2012).

Then, the consistency ratio (CR) is calculated by Equation 3.5.

$$CR = \frac{CI}{RI} \tag{3.5}$$

The consistency of the matrix is finally determined by comparison between the consistency ratio (CR) and the values established by Saaty (Aznar & Guijarro, 2012), which are shown in Table 3.3.

Table 3.3: Values of CR established by Saaty.

Order of the matrix (n)	*Consistency ratio(CR)*
3	*0.05*
4	*0.09*
5 o mayor	*0.10*

Source: retrieved from Aznar and Guijarro (2012).

The matrix of comparison will be consistent, if the value of CR is minor than the value from Table 3.3, according to order of the matrix (n).

Step 4: The ranking of the alternatives for the final decision is established.

The alternatives A_1, A_2, A_3,..., A_m, are evaluated according to criteria C_1, C_2, C_3,…, C_n. The results for each criterion are presented in Equation 3.6.

$$\begin{matrix} A_1 \rightarrow \\ A_2 \rightarrow \\ \vdots \\ A_m \rightarrow \end{matrix} \overbrace{\begin{pmatrix} 1 & q_{12} & \cdots & q_{1m} \\ \frac{1}{q_{12}} & 1 & \cdots & q_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{q_{1m}} & \frac{1}{q_{2m}} & \cdots & 1 \end{pmatrix}}^{\begin{matrix} A_1 & A_2 & \dots\dots & A_m \\ \downarrow & \downarrow & & \downarrow \end{matrix}} = Q^n_{m \times m} \qquad (3.6)$$

After of checking the consistency of each comparison matrix, the weight of the alternatives is determined, with respect to each criterion. The results are shown in Equation 3.7.

$$\begin{matrix} C_1 \rightarrow \\ C_2 \rightarrow \\ \vdots \\ C_n \rightarrow \end{matrix} \overbrace{\begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{pmatrix}}^{\begin{matrix} A_1 & A_2 & \dots\dots & A_m \\ \downarrow & \downarrow & & \downarrow \end{matrix}} = T_{n \times m} \qquad (3.7)$$

The ranking of the alternatives is established according to results of the multiplication of matrix W^t and the matrix T, by Equation 3.8.

$$R_{1\times m} = (W_{n\times 1})^t . T_{n\times m} \quad (3.8)$$

3.2.3 AHP on the selection of a method for SIA

The application of the AHP method for selection of a method for SIA is described below.

3.2.3.1 Alternatives

The alternatives were established according to literature review on SIA, method for environmental impact assessment, method of muti-criteria analysis, and by consultation to expert team. In this study the following alternatives were established:

A1: The Delphi method

The Delphi method was developed since mid-twentieth century. *"The name "Delphi" is the English translation of Delfos, a city of ancient Greece [...] known by the oracles that Apollo performed by a priestess (Pythia) [...] the Delphi method was conceived in the core of the research centre of the American Rand Corporation from late forties [...] a decisive study for the scientific support of the technical was carried out by Abraham Kaplan in 1949"*(Landeta, 2002). A Delphi is the selection of a group of experts who are asked on their opinions of issues related to future events. The estimates from experts are made in successive anonymous rounds, the objective is to try to achieve consensus, but with maximum autonomy in the participants (Astigarraga, 2005). The Delphi method has been applied to many researches in the social sciences, for example in the analysis of audio-visual sector prospective (Ortega Mohedano & Ortega, 2008). The Delphi method is an alternative for SIA because it would allow making the evaluation of a project by consulting of experts.

A2: The AHP method

The AHP method developed in this article is an alternative for SIA, as it would allow evaluating a project according to social criteria, which would be defined in concordance with the characteristics of project or program under study.

A3: The FAHP method

The FAHP is a method, which include the fuzzy logic within the AHP method. The formal starting of fuzzy logic is considered in 1965, in which Lotfi A. Zadeh published his work on "Fuzzy Sets" (Zadeh, 1965). The FAHP method has been applied to a diversity of problems, as for example to determine the perception of hotel services quality (Yen-Cheng, Tung-Han, Pei-Ling, & Ching-Sung, 2014), to determine the indicators of entrepreneurial in an university (Reza, 2014), or to evaluate the risks in a mining company (Verma & Chaudhri, 2014). The FAHP method is an alternative for SIA, because it could assess social impact using criteria, in same way that AHP, but incorporating fuzzy logic within its analysis.

A4: The grey clustering method

The grey clustering method is based on grey systems theory, which was developed by Deng (Deng, 1985). Grey systems study the problems with small samples or with limited information, in real world there are many problems of this type, this fact makes grey systems can be applied to different fields. As for example to evaluate web sites (Bindu et al., 2010), the water management (L. N. Zhang et al., 2013), or occupational safety management (Li et al., 2015). The grey clustering method is an alternative for SIA, because it assesses social impact using criteria, and also establishes intervals or grey classes, which help to determine a ranking of the social impact.

3.2.3.2 Criteria of selection

The criteria to select a method for SIA were established using attributes, which determine the quality of a method (Vinagre, 1995). In addition, the opinion from the experts was also used, in order to determine the criteria of evaluation. Three criteria ware finally established:

C1: Quantification

One of the limitations of some methods for SIA is its lack of capacity to quantify the results. Therefore, this criterion evaluates the level of quantification of alternative methods for SIA, presented in this study.

C2: Robustness

This criterion evaluates the scientific solidity of alternatives methods for SIA, analysing theories on which are supported and the procedure that is used to assess social impact.

C3: Standardization

This criterion evaluates the level of applicability of the alternatives methods for SIA. In other words, this criterion evaluates the capacity of the alternatives methods to be applied to other contexts and other type of projects.

The hierarchy to select a method for SIA, including the alternatives and the criteria, is shown in Figure 3.1.

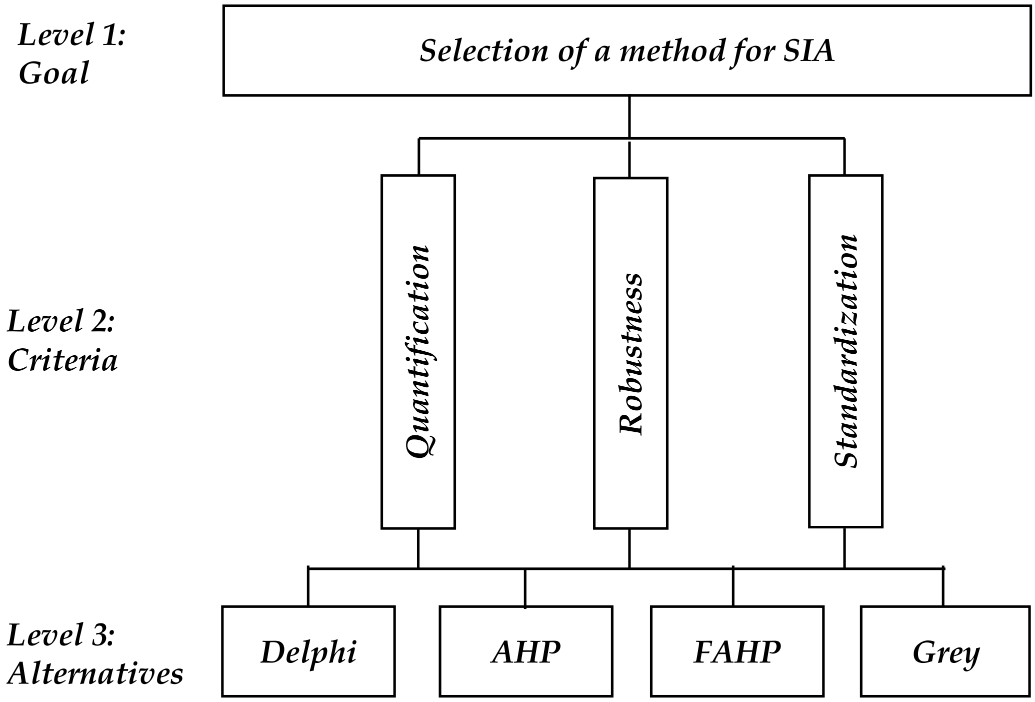

Figure 3.1: Hierarchy to select a method for SIA.

3.2.3.3 Matrix and index of consistency

The expert team are represented by E_1, E_2, E_3, and E_4, who performed the evaluation of the criteria, in order to determine the weights of each criterion. This evaluation was performed according the values from Table 3.1. The results of the paired comparison obtained from the experts are presented in Table 3.4.

Table 3.4: Paired comparison between criteria.

	E1	*E2*	*E3*	*E4*	*GM*
C1-C2	*1.00*	*2.00*	*1.00*	*2.00*	*1.41*
C1-C3	*2.00*	*3.00*	*0.50*	*3.00*	*1.73*
C2-C3	*3.00*	*1.00*	*0.33*	*1.00*	*1.00*

The results obtained from the expert team were aggregated using the geometric mean (GM) (Aznar & Guijarro, 2012). The aggregated comparison matrix is shown in Table 3.5.

Table 3.5: Accumulated comparison matrix from the experts.

	C1	*C2*	*C3*
C1	*1*	*1.41*	*1.73*
C2	*0.71*	*1*	*1.00*
C3	*0.58*	*1.00*	*1*
S	*2.28*	*3.41*	*3.73*

Now, the weight of each criterion and the consistency of the comparison matrix are calculated. First, the matrix is normalized by division of each element by the total sum of its respective column. Second, the weights of each criterion are calculated by the arithmetic mean of the elements of each row. The normalized matrix and the weights of the criteria are shown in Table 3.6.

Table 3.6: Comparison matrix normalized.

	C1	*C2*	*C3*	*W*
C1	*0.44*	*0.41*	*0.46*	*0.44*
C2	*0.31*	*0.29*	*0.27*	*0.29*
C3	*0.25*	*0.29*	*0.27*	*0.27*

To determine the consistency of the matrix, first, λ_{Max} is calculated using Equation 3.4.

$$\lambda_{Max} = 2.28 \times 0.44 + 3.41 \times 0.29 + 3.73 \times 0.27$$

$$\lambda_{Max} = 3.0048$$

Then, the consistency index (CI) for matrix of order 3x3 (n=3) is calculated using Equation 3.3.

$$CI = \frac{3.0048 - 3}{3 - 1} = 0.0024$$

According the values from Table 3.2 for n=3, the IR is 0.52, with which the consistency ratio (CR) is calculated using Equation 3.5.

$$CR = \frac{0.0024}{0.52} = 0.0046$$

In Table 3.3 for n=3 the maximum consistency ratio is 0.05, and as the value obtained is 0.0046<0.05, therefore the comparison matrix is consistent, and the weights obtained for each criterion are acceptable.

3.2.3.4 Ranking of the alternatives

To establish the ranking of the alternatives, the expert team performed a separate evaluation in each criterion. The results of the aggregated comparison matrixes are shown in Table 3.7.

Table 3.7: Comparison matrixes of the alternatives.

C1	A1	A2	A3	A4
A1	1	0.34	0.26	0.16
A2	2.91	1	0.45	0.31
A3	3.87	2.21	1	0.41
A4	7.79	3.56	1.71	1
S	15.57	7.11	3.42	1.88
C2	**A1**	**A2**	**A3**	**A4**
A1	1	0.45	0.27	0.13
A2	2.21	1	0.45	0.32
A3	3.66	2.21	1	0.50
A4	6.88	3.67	1.72	1
S	13.75	7.33	3.45	1.96
C3	**A1**	**A2**	**A3**	**A4**
A1	1	0.64	0.30	0.21
A2	1.57	1	0.45	0.29
A3	3.31	2.21	1	0.59
A4	5.87	3.85	1.75	1
S	11.75	7.70	3.51	2.10

The normalized comparison matrixes and its respective weights are presented in Table 3.8.

Table 3.8: Normalized matrix of alternatives.

C1	*A1*	*A2*	*A3*	*A4*	*T1*
A1	*0.06*	*0.05*	*0.08*	*0.09*	*0.07*
A2	*0.19*	*0.14*	*0.13*	*0.17*	*0.16*
A3	*0.25*	*0.31*	*0.29*	*0.22*	*0.27*
A4	*0.50*	*0.50*	*0.50*	*0.53*	*0.51*
C2	***A1***	***A2***	***A3***	***A4***	***T2***
A1	*0.07*	*0.06*	*0.08*	*0.07*	*0.07*
A2	*0.16*	*0.14*	*0.13*	*0.17*	*0.15*
A3	*0.27*	*0.30*	*0.29*	*0.26*	*0.28*
A4	*0.50*	*0.50*	*0.50*	*0.51*	*0.50*
C3	***A1***	***A2***	***A3***	***A4***	***T3***
A1	*0.09*	*0.08*	*0.09*	*0.10*	*0.09*
A2	*0.13*	*0.13*	*0.13*	*0.14*	*0.13*
A3	*0.28*	*0.29*	*0.29*	*0.28*	*0.28*
A4	*0.50*	*0.50*	*0.50*	*0.48*	*0.49*

From Table 3.3, the maximum consistency ratio (CR) for a matrix of order 4x4 (n=4) is 0.09, and the values calculated for each matrix in each criterion are: 0.0166, 0.0001, and 0.0373, respectively. As the three values are minors than 0.09, therefore the three matrixes are consistent, and the weights of the alternatives in each criterion are valid.

Finally, using Equation 3.8, the ranking of the alternatives are calculated. The matrix of weights of the criteria is presented below:

$$W_{3\times 1} = (0.44 \quad 0.29 \quad 0.27)^t$$

The matrix of weights of the alternatives with respect to each criterion is:

$$T_{3\times 4} = \begin{pmatrix} 0.07 & 0.16 & 0.27 & 0.51 \\ 0.07 & 0.15 & 0.28 & 0.50 \\ 0.09 & 0.13 & 0.28 & 0.49 \end{pmatrix}$$

The ranking of the alternatives is calculated below:

$$R_{1\times4} = (W_{3\times1})^t . T_{3\times4}$$

$$R_{1\times4} = (0.44 \quad 0.29 \quad 0.27)\begin{pmatrix} 0.07 & 0.16 & 0.27 & 0.51 \\ 0.07 & 0.15 & 0.28 & 0.50 \\ 0.09 & 0.13 & 0.28 & 0.49 \end{pmatrix}$$

$$R_{1\times4} = \begin{matrix} (0.07 & 0.15 & 0.28 & 0.50) \\ A_1 & A_2 & A_3 & A_4 \end{matrix}$$

3.2.4 Results and discussion

In Figure 3.2, the results of the application of AHP are shown. In which the best method for SIA is the grey clustering method, second place is occupied by the FAHP method, third place is occupied by the AHP method, and last place is occupied by the Delphi method.

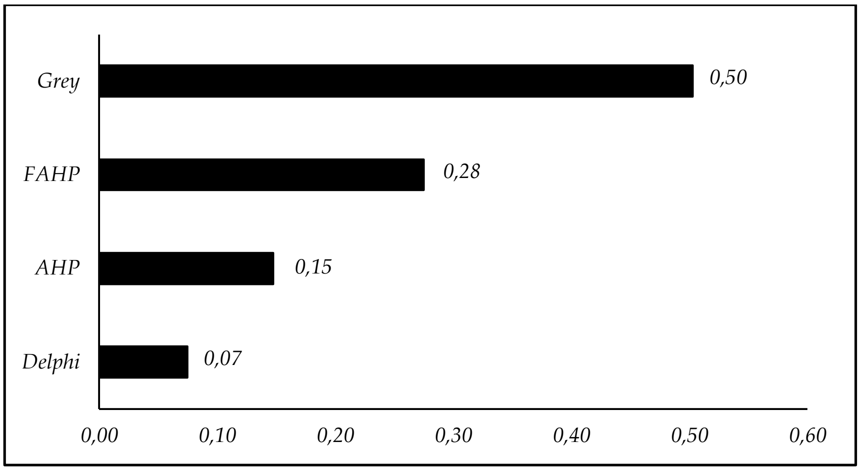

Figure 3.2: Ranking of alternatives methods for SIA.

The potential of each alternative method for SIA, according to literature review and opinion from the experts, is analysed below:

The advantage of the Delphi method is that experts can argument their responses anonymously, in addition, the opinion from an expert team could be considered as subjective, but it is not arbitrary, therefore Delphi could be completed with other methodology for SIA. The disadvantage of the Delphi method is that a basic statistic is used during the data processing. This fact makes that the Delphi method presents minor capacity of quantification; in addition, experts tend to change their opinions when too many rounds are conducted.

The AHP method has the following advantage, the use of evaluation criteria and the determination of weights for each criterion improves the level of objectiveness of the evaluations with respect to the Delphi method; in addition, the calculations relatively easy in this method makes that it used in different fields. The disadvantage of the AHP method is that due to its elementary mathematic base used during its analysis, it should be complemented with other theories to achieve a SIA more objective.

The advantage of the FAHP method with respect to the AHP method is that it incorporates fuzzy logic within its analysis, with which the level of quantification is improved. On the other hand, during the data collection it is important to take care, to obtain good results applying the FAHP method. For example, in some cases, there are not quantitative data for facilitating the evaluation from the experts; this fact makes the evaluation being subjective. Therefore, it is necessary previously to make a quantification of the variables using the grey systems theory as an alternative.

The grey clustering method has advantage with respect to the FAHP method, due to the fact that it has good level of quantification, and also it allows having a range of evaluation for the experts, as the grey clustering method uses grey classes in each criterion to conduce SIA. Consequently, this fact improves the data collection.

Finally, according to literature review and the opinion from the experts, the best method for SIA of projects and programs is the grey clustering method. The grey clustering method could be complemented with the Delphi method during the data collection. In addition, to assess social impact is necessary to analyse stakeholder groups within affected population, as these stakeholder groups could have a different evaluation on the determined project; therefore, it is necessary to make social impact assessment in each stakeholder group, in order to prevent possible environmental conflicts.

3.2.5 Conclusions

The AHP method allowed us selecting the best method for SIA by the evaluation from expert team, who finally established that the best method for SIA is the grey clustering method, due to the fact that it facilitate data collection from stakeholder groups within affected population; in addition, the grey clustering method has a good level of quantification, as it uses a solid mathematic theory.

The grey clustering method could be complemented with a Delphi during the data collection from the effected population, and from the expert team, who evaluate a determined project. In addition, it is convenient to make social impact assessment in each stakeholder group, in order to determine the differences between them, and then to propose measures to prevent possible environmental conflicts.

In future researches, the grey clustering method could be tested and applied to assess social impact of projects such as, water management projects, mining exploitation projects, hydrocarbon exploration projects, public works construction projects, etc. This method could also be applied to assess social impact of public or private programs.

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3.3 Formulation of the method for SIA and ECA

This section provides a discussion of the grey clustering method based on CTWF and of the entropy-weight method, followed by details of the proposed integrated method for SIA and ECA.

3.3.1 SIA using the grey clustering method based on CTWF

One characteristic of SIA is its high level of uncertainly (Wittmer et al., 2006). Therefore, SIA should be conducted by a method, which considers the uncertainly.

In classical approaches of multi-criteria analysis, such as Delphi or AHP, the uncertainty is not considered, due to the fact that the importance degrees of criteria and the performance scores of alternatives are assumed to be known precisely (Baykasoğlu & Gölcük, 2015). Moreover, there are many methods used to model the uncertainly: fuzzy logic approaches, probabilistic approaches or grey systems approaches are some options.

Approaches based on fuzzy logic, such as FAHP emphasizes the investigation of problems with cognitive uncertainty, where the research objects possess the characteristic of clear intention and unclear extension. The focus of approaches based on grey systems theory is on the uncertainty problems, where the research objects possess the characteristic of unclear intention and clear extension (S. Liu & Lin, 2010). SIA has clear extension of the criteria in a determined study, for example, in a historic range of five years, we know the minimum and maximum value of a social variable under analysis. In addition, affected population within a determined project is clear about when things were good or bad: before or after project implementation.

As additional information, in statistical approaches the concept of large samples represents the degree of tolerance to incompleteness. However, for some situations, even when the sample contains thousands or several tens of thousands of objects, true statistical laws still cannot be successfully revealed (S. Liu & Lin, 2010). Moreover, considering that one of the criteria for evaluating methods is the cost (Wittmer et al., 2006), in this aspect an approach based in grey systems could have lower cost with respect to a statistical approach, due to the fact that sample size influences on the cost during the field work. On the other hand, in 1994, (1) Jiangping Qiu and (2) Xisheng Hua respectively established a theoretically delicate statistical regression model and relatively coarse grey model based on the deformation and leakage data of a certain large scale hydraulic dam. Their work shows that their grey model provided a better fit than the statistical regression model. When comparing the errors between the predictions of the two models with the actual observations, it is found that the prediction accuracy of the grey model is generally better than that of the regression model, for more details see Table 3.9 (S. Liu & Lin, 2010).

Table 3.9: Prediction errors of a statistical model and a grey model.

Nº	*Type*	*Average error*	
		Statistical model	*Grey model*
	Horizontal displacement	*0.862*	*0.809*
1	*Vertical displacement*	*1.024*	*1.029*
	Water level of pressure measurement hole	*6.297*	*3.842*
	Horizontal displacement	*0.446*	*0.232*
2	*Vertical displacement*	*0.465*	*0.449*
	Water level of pressure measurement hole	*0.204*	*0.023*

Source: retrieved from Liu and Lin (2010)

As conclusion, it can be argued that the grey clustering method would benefit SIA, as it considers the uncertainty within its analysis. In addition, the grey clustering method could be more adequate than approaches based on fussy logic, because it considers clear extension of the analysis criteria. Finally, the grey clustering method could be more effective and would have a lower cost than other statistical approaches during its application.

3.3.2 ECA using the entropy-weight method

Environmental conflicts are frequently presents during the planning and implementation of projects and programs as evidenced by studies on conflicts related to energy (Fontaine, 2010; Karjalainen & Järvikoski, 2010), exploitation of natural resources (Correia, 2007), ecological tourism (Yang et al., 2013), or water management (Bolin et al., 2008; Saqalli et al., 2010). Environmental conflicts are generated between stakeholder groups within communities, due to the differences in the assessment of a projects (Arun, 2008; Luyet et al., 2012). For this reason, social impact assessment should first be performed for each stakeholder group and then the gap between the groups should be determined in order to predict and prevent possible environmental conflicts. In addition, SIA and ECA should be integrated, as both aspects are directly related (Prenzel & Vanclay, 2014).

In addition, environmental conflict analysis could be conducted by classical multi-criteria methods (Wittmer et al., 2006), or by statistical approaches (S. Liu & Lin, 2010). However, classical multi-criteria methods do not consider the uncertainty within their analysis (Baykasoğlu & Gölcük, 2015). Furthermore, statistical approaches could have high cost during the field work (Wittmer et al., 2006), and could have a minor precision (S. Liu & Lin, 2010).

The entropy-weight method, which is based on Shannon entropy theory, is a good option for integrating SIA and ECA. First, on the same way and under the same philosophy as the grey clustering method, Shannon entropy is a concept which is proposed as a measure of uncertainty (Zeleny, 1996). Second, in our view, the entropy-weight method would benefit the ECA, as it allows researchers to determine the criteria for which there is divergence between stakeholder groups involved in a conflict (Kou, Sun, & Peng, 2011).

The combination of the grey clustering method and the entropy-weight method could integrate SIA and ECA. The grey clustering method could assess social impact by quantifying of information from stakeholders groups. And then, the entropy-weight method could identify criteria, for which, there are the most divergence between stakeholders groups, within of a project under scrutiny. In addition, the integrated method could be complemented with other qualitative approaches, such as Delphi, in order to improve the information gathering during the field work.

3.3.3 Integrating SIA and ECA using the grey clustering and entropy-weight methods

The integrated method proposed in this thesis can be described using the following sets:

1. A set of m objects or stakeholder groups called $G = \{G_1, G_2,..., G_m\}$
2. A set of n criteria called $C = \{C_1, C_2,..., C_n\}$
3. A set of s grey classes called $V = \{V_1, V_2,..., V_s\}$
4. A set of evaluation values called $X = \{x_{ij}, i = 1, 2,..., m; j = 1, 2,..., n\}$ of G_i $(i = 1, 2,..., m)$ with respect to criterion C_j $(j = 1, 2,..., n)$.

The steps are described below:

Step 1: Criteria and grey classes

A set of n criteria ($C_1, C_2,..., C_n$), and a set of s grey classes ($V_1, V_2,..., V_s$) for SIA and ECA are established based on the characteristics of the project under scrutiny.

Step 2: CTWF and the comprehensive clustering coefficient

The values of CTWF for each stakeholder group are calculated using Equation 3.9.

$$f_j^k(x_{ij}) = \begin{cases} 0\,, & x \notin [\lambda_{k-1}, \lambda_{k+1}] \\ \dfrac{x-\lambda_{k-1}}{\lambda_k - \lambda_{k-1}}, & x \in [\lambda_{k-1}\,, \lambda_k] \\ \dfrac{\lambda_{k+1}-x}{\lambda_{k+1} - \lambda_k}, & x \in [\lambda_k\,, \lambda_{k+1}] \end{cases} \tag{3.9}$$

Then, the comprehensive clustering coefficient $\boldsymbol{\sigma_i^k}$ for object i, $i=1, 2,\ldots, m$, with respect to the grey class k, $k=1,\ldots, s$, is calculated using Equation 3.10.

$$\sigma_i^k = \sum_{j=1}^{n} f_j^k(x_{ij}).\eta_j \tag{3.10}$$

Step 3: Percentage system

Social impact assessment of each stakeholder group is presented as a percentage system (Chang and Qisen, 2009), defined by values $a_1, a_2, a_3,\ldots,$ and a_s, where $a_s=100$, $a_1=100/s$, $a_2=a_1+a_1$, $a_3=a_1+a_2,\ldots,$ and $a_{s-1}=a_1+a_{s-2}$; s is the number of grey classes established. The results are given by Equation 3.11.

$$z_j^i = \sum_{k=1}^{s} f_j^k(x_{ij}).\,\alpha_k \tag{3.11}$$

where $f_j^k(x_{ij})$ is the CTWF of the kth grey class of the jth criterion and α_k is the percentage value of each grey class. The results are represented by a matrix determined by Equation 3.12.

$$Z = \{z_{ij}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n\} \quad (3.12)$$

Step 4: Entropy-weight method

First, matrix $Z = \{z_{ij}, \mathrm{i} = 1, 2, \ldots, \mathrm{m}; \mathrm{j} = 1, 2, \ldots, \mathrm{n}\}$ is normalized for each criterion *Cj (j=1, 2,..., n)*. The normalized values P_{ij} are calculated using Equation 3.13.

$$P_{ij} = \frac{z_{ij}}{\sum_{i=1}^{m} z_{ij}} \quad (3.13)$$

Then, H_j, div_j and w_j are calculated using Equations 3.14, 3.15, and 3.16.

$$H_j = -k \sum_{i=1}^{m} P_{ij}\, ln(P_{ij}) \quad (3.14)$$

$$div_j = 1 - H_j \quad (3.15)$$

$$w_j = \frac{div_j}{\sum_{j=1}^{n} div_j} \quad (3.16)$$

Step 5: Objective assessment

The final stage of the proposed method is the calculation of objective assessment (Shemshadi et al., 2011) for each stakeholder group *i, i=1, 2,…, m,* in each criterion *Cj (j=1, 2,..., n)*. The objective assessment values are defined by Equation 3.17.

$$Q_{ij} = w_j z_{ij} \quad (3.17)$$

where w_j is the entropy weight of each criterion *Cj* and z_{ij} is the result of the social impact assessment for each stakeholder group *i, i=1, 2,…, m*. The results are represented by a matrix determined by Equation 3.18.

$$Q_{ij} = \begin{bmatrix} w_1 z_{11} & w_2 z_{12} & \cdots & w_n z_{1n} \\ w_1 z_{21} & w_2 z_{22} & \cdots & w_n z_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_1 z_{m1} & w_2 z_{m2} & \cdots & w_n z_{mn} \end{bmatrix} \tag{3.18}$$

The first three steps of the integrated method correspond to social impact assessment, developed in accordance with the grey clustering method based on CTWF and represented by a percentage system. The last two steps correspond to environmental conflict analysis, developed by means the entropy-weight method and objective assessment, which identify the criteria for which there is the greatest divergence between the stakeholder groups.

3.3.4 Schema of the proposed method

The integrated method proposed in this thesis for SIA and ECA combines the grey clustering method based on CTWF and the entropy-weight method. This method is called the integrated grey clustering and Shannon-entropy method (The IGCEW method). A schema according to the methods used for integration of SIA and ECA is illustrated in Figure 3.3. This schema was applied to the case study in Peru.

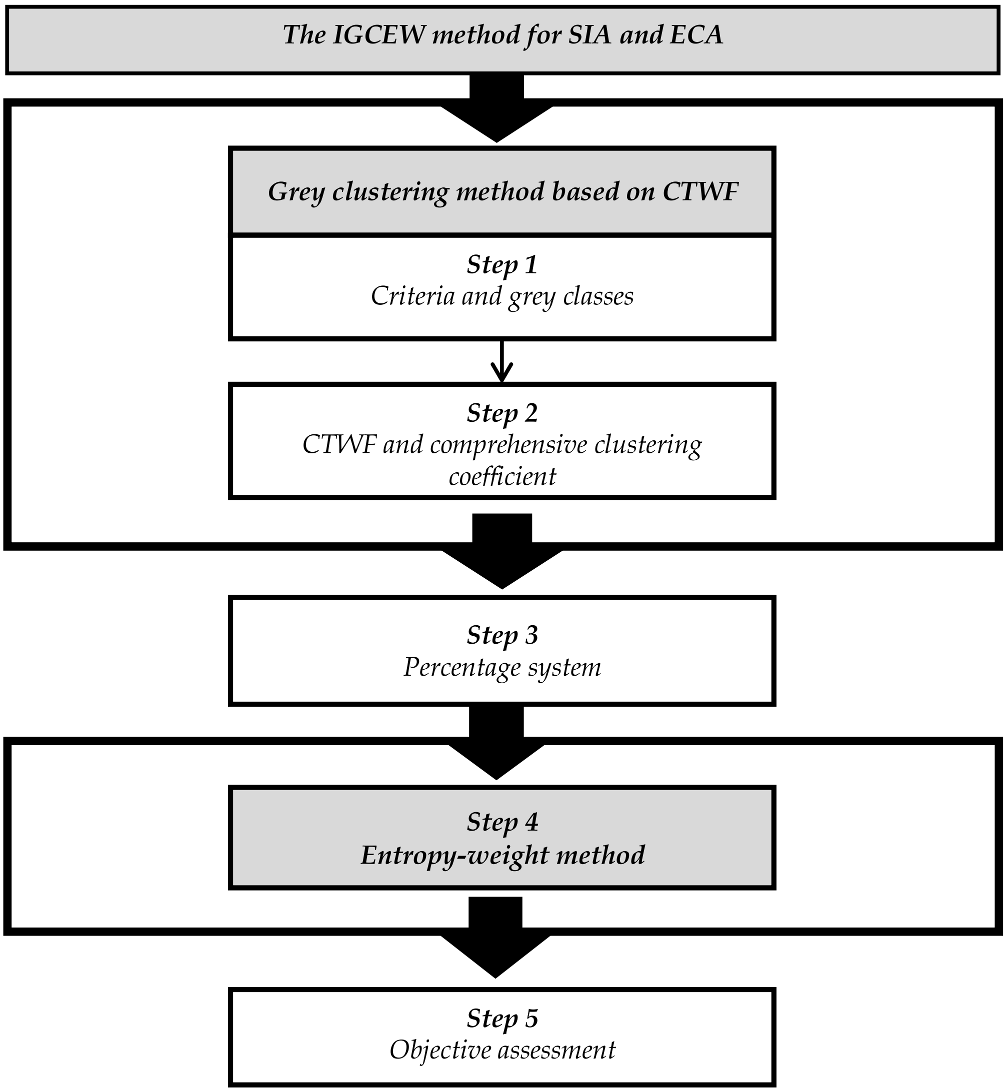

Figure 3.3: Schema according to methods for SIA and ECA.

As other form, the integrated method (The IGCEW Method) can also be represented according to the stages of SIA and ECA, as illustrated in Figure 3.4. This schema was applied to the case study in Spain.

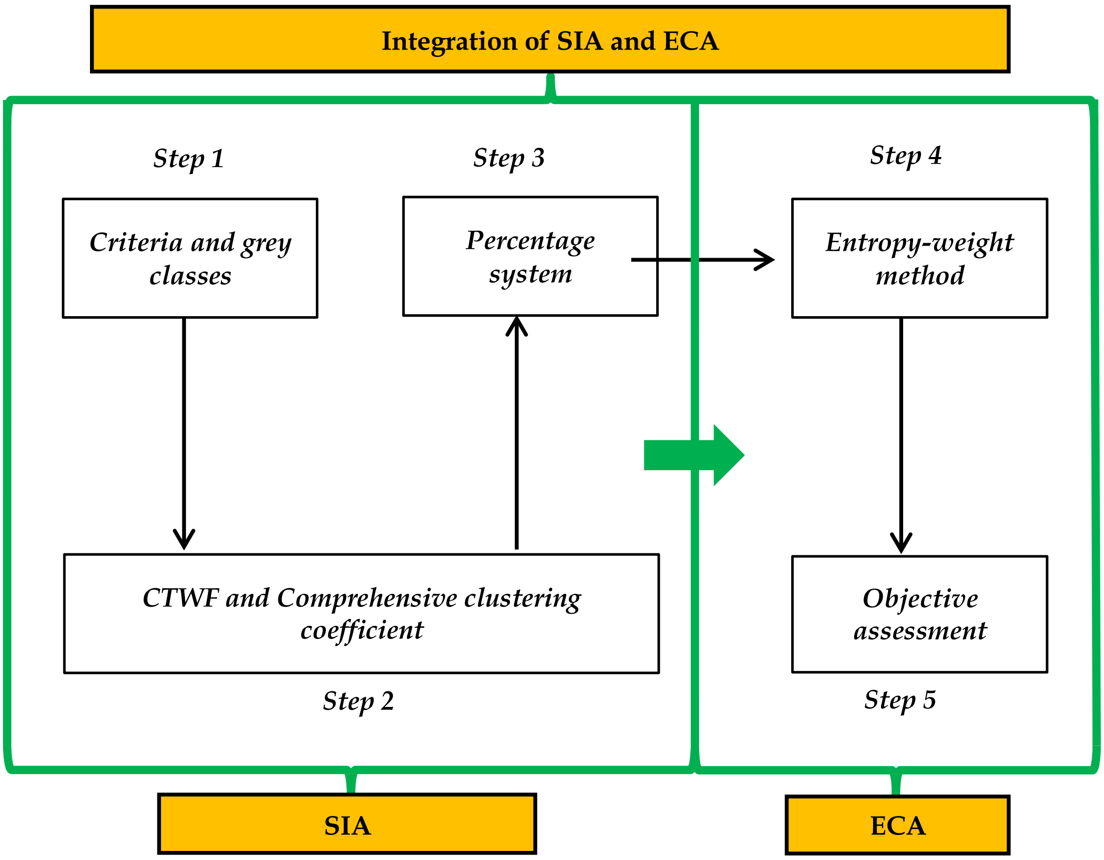

Figure 3.4: Schema according to integration of SIA and ECA.

3.3.5 Advantages and limitations of the proposed method

Based on what has been discussed above, and considering the main previous approaches to study the uncertainty (S. Liu & Lin, 2010). The differences between the IGCEW method for SIA and ECA and other principal approaches, is summarized in Table 3.10.

Table 3.10: Comparison with other main approaches.

Aspect	The IGCEW method	Approaches based on fuzzy logic	Approaches based on statistics
Epistemological paradigm	Integrate qualitative and quantitative paradigms.	Integrate qualitative and quantitative paradigms.	Prioritize quantitative paradigm.
Uncertainty	Focus on the uncertainty problems of small samples and limited information.	Investigation of problems with cognitive uncertainty.	Stochastic uncertainty.
Data requirement	Any distribution.	Known membership.	Typical distribution.
Emphasis of research object	Clear extension and unclear intention.	Clear intention and unclear extension.	Revealing the historical statistical laws.
Objective of research problem	Laws of reality.	Cognitive expression.	Historical statistical laws.
Costs during application	Low, due to the fact that a small sample is used.	Medium, due to the fact that experience is used.	High, due to the fact that a large sample is used.

Source: adapted and modified from Liu and Lin (2010)

Consequently, the main advantages of the IGCEW method may be summarized as follows:

(1) The grey clustering method and the entropy-weight method are combined for first time on the integration of SIA and ECA in the literature.

(2) The proposed integrated method would be more appropriate than other approaches based on multi-criteria analysis, as it analyses problems with high level of uncertainty.

(3) The combined approach integrates social impact assessment and environmental conflict prevention, performing an analysis of stakeholder groups.

(4) The proposed combined approach could be more effective and would have lower cost than other statistical approaches during its application.

(5) The combined approach would be more convenient than other approaches based on fuzzy logic, as it analyses SIA and ECA considering clear extension of criteria.

The limitations of the IGCEW method may be summarized as follows:

(1) It presents some subjective aspects during information gathering and the establishment of limits of grey classes.
(2) The grey systems and Shannon entropy approaches are not widely diffused compared to approaches based on fuzzy logic or on statistics models.
(3) The calculations are a little tedious when processing data. This could be improved by implementing a computer system.
(4) As it is a new approach it needs to be validated in other contexts to improve its effectiveness.

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CHAPTER IV

CASE STUDY: MINING PROJECT IN PERU

4. Case study in Peru

Paper 2: Environmental conflict analysis using an integrated grey clustering and entropy-weight method: A case study of a mining project in Peru

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Abstract

Environmental conflict analysis (henceforth ECA) has become a key factor for the viability of projects and welfare of affected populations. In this study, we propose an approach for ECA using an integrated grey clustering and entropy-weight method (The IGCEW method). The case study considered a mining project in northern Peru. Three stakeholder groups and seven criteria were identified. The data were gathered by conducting field interviews. The results revealed that for the groups urban population, rural population and specialists, the project would have a positive, negative and normal social impact, respectively. We also noted that the criteria most likely to generate environmental conflicts in order of importance were: access to drinking water, poverty, GDP per capita and employment. These results could help regional and central governments to seek appropriate measures to prevent environmental conflicts. The proposed method showed practical results and a potential for application to other types of projects.

Keywords:

Grey clustering method.

Entropy-weight method.

Environmental conflict.

Social impact.

Mining project.

4.1 Introduction

Environmental conflicts often accompany the planning and implementation of projects and programs, as evidenced by studies of conflicts related to water management (Bolin et al., 2008; Saqalli et al., 2010), energy (Fontaine, 2010; Karjalainen & Järvikoski, 2010), exploitation of natural resources (Correia, 2007; Madani et al., 2014; Warnaars, 2012) or ecological tourism (Yang et al., 2013). Therefore, organizations and governments require techniques enabling them to assess social impact and then, given this information, to propose measures for preventing environmental conflicts (Barrow, 2010; Prenzel & Vanclay, 2014). Organizations have obligation as part of their corporate social responsibility to evaluate their social impact to prevent possible conflicts within the affected communities (Kemper, Schilke, Reimann, Wang, & Brettel, 2013). Furthermore, governments are obligated to improve population welfare to achieve sustainable development of countries; therefore, they must measure social impact of their programs and state policies to prevent possible conflicts (Franks & Vanclay, 2013). In addition, stakeholders are a dimension of integrated assessment (Hamilton, ElSawah, Guillaume, Jakeman, & Pierce, 2015), and environmental conflicts are generated between stakeholder groups within communities, due to the differences in the assessment of industrial projects (Arun, 2008; Luyet et al., 2012). For this reason, social impact assessment must first be performed for each stakeholder group and then the gap between the groups must be determined in order to predict and prevent possible environmental conflicts.

Thus far, ECA has been mostly carried out using qualitative methods such as those described by Prenzel and Vanclay based on game theory (Prenzel & Vanclay, 2014), who address environmental conflict from an infrastructure development project, or by Griewald and Rauschmayer based on a capability perspective (Griewald & Rauschmayer, 2014), who consider environmental conflict in a protected nature area. In addition, there are also quantitative methods for ECA, found, for example, in the study by Al-Mutairi et al. based on fuzzy logic (Al-Mutairi, Hipel, & Kamel, 2008) of environmental conflict over aquifer contamination caused by a chemical company. In this article, we apply a method for ECA combining the grey clustering method and the entropy-weight method (The IGCEW method), as an extension to the qualitative and quantitative methods.

The grey clustering method enables quantification of qualitative information and classification of observed objects into definable classes, as well as verification of whether the observed objects belong to predetermined classes – as shown by the studies of (L. N. Zhang et al., 2013), who analysed a water rights allocation system, or by (Y. Zhang et al., 2014), who classified innovation strategic alliances. It can be argued that the grey clustering method is likely to benefit the first stage of ECA in that it helps assess social impact by quantifying the qualitative information obtained from stakeholder groups involved in a given environmental conflict.

In turn, the entropy-weight method is used to calculate objective weights of criteria. If there is a large difference between the objects for a criterion determined, this criterion can be regarded as an important factor for the analysis of alternatives, as shown by the study of (Wang & Lee, 2009), who resolved a software selection problem, or by (Kou et al., 2011), who assessed a case of environmental pollution. In our view, the entropy-weight method would benefit the final stage of ECA, as it allows researchers to determine the criteria for which there is divergence between the stakeholder groups involved in a conflict. The combination of both methods would be beneficial for ECA because it integrates social impact assessment and divergent criteria identification. To illustrate the method we propose, a case study was conducted assessing the exploitation plans of a poly-metallic mine in northern Peru. Three stakeholder groups were identified and a set of seven criteria for ECA were established in the mining project.

The specific objectives of this article are to:

1. Apply the IGCEW method for ECA to the concrete context of the exploitation plans of the poly-metallic mine in Peru.

2. Explore if the IGCEW method exhibits potential for other ECA contexts.

In section 4.2 the literature review is described. Section 4.3 provides the details of the IGCEW method for ECA. In Section 4.4 the case study is described, followed by the results and discussion in Section 4.5. Conclusions are provided in Section 4.6.

4.2 Literature review

Environmental conflicts are characterized by the interaction between (1) ecological and (2) social complexity (Wittmer et al., 2006).

(3) One central feature of environmental conflicts is the complexity of the ecological system which is the natural base of the conflicts. Even if its understanding is accompanied by a high degree of scientific sophistication, there remains substantial uncertainty and ignorance. Therefore, the process leading to the resolution of environmental conflicts should take into account scientific and idiosyncratic knowledge and should cope with unavoidable uncertainty and ignorance. Certain forms of multi-criteria decision aid could satisfy this demand (Wittmer et al., 2006).

(4) Another central feature of environmental conflicts is social complexity. Some stakeholders are also actors who may impede the implementation of a decision, or, put positively, their agreement is necessary for a successful implementation of the decision. Social complexity calls for stakeholder participation. Decision structuring tools offer the possibility to make participatory decision processes more transparent (Wittmer et al., 2006).

The resolution of environmental conflicts should concentrate on both aspects, social and ecological complexity. (Wittmer et al., 2006) suggest approaching both aspects by an intensive integration of stakeholders and multi-criteria analysis. However, environmental conflict is a social issue and has high level of uncertainty. In addition, in classical multi-criteria analysis methods, the importance degrees of criteria and the performance scores of alternatives are assumed to be known precisely. Moreover, the practical constraints of the real world hinder the use of crisp values. The problems faced in practice occur in such an environment that the goals, constraints and consequences of alternatives are not precise. Furthermore, the ambiguities, uncertainties and vagueness inherent in decision makers' evaluations necessitate the use of methods to model uncertainty in decision problems (Baykasoğlu & Gölcük, 2015). There are many methods used to model uncertainty in decision problems. Probabilistic approaches (Augustsson, Filipsson, Öberg, & Bergbäck, 2011), fuzzy logic (Zadeh, 1965), and grey systems (S. Liu & Lin, 2010) are some examples of the options used to model uncertainty.

The grey systems theory is a methodology for studying uncertainty problems (Deng, 1985), in which there are limited information and small samples (S. Liu & Lin, 2010). In order to explore the differences, we compare grey systems with other main approaches, below.

Comparison between grey systems and probabilistic approaches

A comparison study between grey systems and probabilistic approaches was performed in 1994 by (1) Jiangping Qiu and (2) Xisheng Hua respectively, who established a theoretically delicate statistical regression model and relatively coarse grey model based on the deformation and leakage data of a certain large scale hydraulic dam. Their work shows that their grey model provided a better fit than the statistical regression model. When comparing the errors between the predictions of the two models with the actual observations, it is found that the prediction accuracy of the grey model is generally better than that of the regression model, for more details see Table 4.1 (S. Liu & Lin, 2010).

Table 4.1: Comparison of average error of a statistical model and a grey model.

Nº	Type	Average error	
		Statistical model	Grey model
1	Horizontal displacement	0.862	0.809
	Vertical displacement	1.024	1.029
	Water level of pressure measurement hole	6.297	3.842
2	Horizontal displacement	0.446	0.232
	Vertical displacement	0.465	0.449
	Water level of pressure measurement hole	0.204	0.023

As shown in Table 4.1, we believe that a model based on grey system could be more accurate than a statistical model. In addition, considering that environmental conflict is a social issue and a very inconstant and subjective topic, which requires a permanent analysis, and that one of the criteria for evaluating methods for ECA is the cost (Wittmer et al., 2006), in this aspect an approach based in grey systems would have a lower cost with respect to a statistical approach, due to the fact that sample size influences the cost of field research.

Comparison between grey systems and fuzzy logic approaches

Fuzzy mathematics emphasizes the investigation of problems with cognitive uncertainty, where the research objects possess the characteristic of clear intention and unclear extension. For example, the instance, "young man" is a fuzzy concept, because everybody understands the idea of "young man". However, if you are going to determine the exact range within which everybody is young and outside which everybody is not young, then you will find yourself in difficulty. This is because the concept of young man does not have a clear extension. For this kind of problem of cognitive uncertainty with clear intention and unclear extension, the situation is dealt with in fuzzy mathematics by making use of experience and the so-called membership function (S. Liu & Lin, 2010).

The focus of grey systems theory is on the uncertainty problems of small samples and limited information which are difficult to handle for probability and fuzzy mathematics. One of its characteristics is construct models with small amounts of data. What is clearly different of fuzzy mathematics is that grey systems theory emphasizes the investigation of such objects which process clear extension and unclear intention. A summary of the differences between these approaches is shown in Table 4.2 (S. Liu & Lin, 2010).

Table 4.2: Comparison between grey systems and fuzzy math methods.

Object	**Grey systems**	**Fuzzy math**
Research objects	Poor information	Cognitive uncertainty
Basic sets	Grey hazy sets	Fuzzy sets
Methods	Information coverage	Mapping
Procedures	Sequence operator	Cut set
Data requirement	Any distribution	Known membership
Emphasis	Clear extension	Clear intention.
Objective	Laws of reality	Cognitive expression
Characteristics	Small sample	Experience

Based on what is described above, we strongly believe that the grey clustering method based on grey systems could be more convenient than an approach based on fuzzy logic, to analyse an environmental conflict, due to the fact that we have clear extension and unclear intention of ECA criteria. For example, in a historic range of five years, we know the minimum and maximum value of a social variable under analysis. In addition, an affected population within a determined project is clear about when things were good or bad: before or after project implementation.

In turn, ECA should be performed considering stakeholder participation (Wittmer et al., 2006), that is, identifying and analysing divergences between stakeholder groups into the influence areas of a determined project. In addition, social impact assessment and environmental conflict prevention should be integrated (Franks & Vanclay, 2013), in order to properly manage possible environmental conflicts during project development. Stakeholders' analysis is a social topic and has a lot of uncertainty which could be dealt with by applying Shannon entropy theory. Shannon entropy is a quantitative measurement of uncertainty (Kou et al., 2011), which could help us to discern the divergence between stakeholder groups. We strongly believe the entropy-weight method, based on Shannon entropy theory, integrated with the grey clustering method could contribute to ECA, as it integrates social impact assessment and environmental conflict prevention, in a similar way and under the same philosophy as grey systems. However, so far there has been more research on fuzzy logic or on statistics models than on grey systems or Shannon entropy, which could change to the extent that research based on grey systems or Shannon entropy proposes a further development of the theory and establishment of innovative methods in the different fields of knowledge. Based on what has been discussed above, we summarize the differences between the IGCEW method, proposed in this article, and other principal approaches in Table 4.3.

Table 4.3: Comparison between the IGCEW method and other main approaches.

Aspect	The IGCEW method	Approaches based on fuzzy logic	Approaches based on statistics
Epistemological paradigm	Integrate qualitative and quantitative paradigms.	Integrate qualitative and quantitative paradigms.	Prioritize quantitative paradigm.
Uncertainty	Focus on the uncertainty problems of small samples and limited information.	Investigation of problems with cognitive uncertainty.	Stochastic uncertainty.
Data requirement	Any distribution.	Known membership.	Typical distribution.
Emphasis of research object	Clear extension and unclear intention.	Clear intention and unclear extension.	Revealing the historical statistical laws.
Objective of research problem	Laws of reality.	Cognitive expression.	Historical statistical laws.
Costs during application	Low, due to the fact that a small sample is used.	Medium, due to the fact that experience is used.	High, due to the fact that a large sample is used.

The main advantages of the IGCEW method may be summarized as follows:

(1) The grey clustering method and the entropy-weight method are combined for the first time in ECA literature.
(2) The IGCEW method is more appropriate than other classical approaches based on multi-criteria analysis, as it considers uncertainty within its analysis.
(3) The IGCEW method integrates social impact assessment and environmental conflict prevention, performing an analysis of stakeholder groups.
(4) The IGCEW method is more effective and has a lower cost than other statistical approaches during its application.

(5) The IGCEW method is more convenient than other approaches based on fuzzy logic, as it analyses environmental conflict considering clear extension of criteria for ECA.

4.3 Method

This section provides a summary of the grey clustering method and of the entropy-weight method, followed by details of the IGCEW method for ECA.

4.3.1 Grey clustering method based on CTWF

The grey clustering method is based on grey system theory, originally developed by (Deng, 1985). The grey system is a theory which focuses on the study of problems involving small samples and limited information (S. Liu & Lin, 2010). In the real world there are many problems of this type, determining a broad range of applicability of the theory of grey systems, for example:

- Evaluation of web sites (Bindu et al., 2010),
- Transport management (Leng et al., 2012),
- Water management (L. N. Zhang et al., 2013),
- Safety management (Li et al., 2015; Wei, Zhou, Wang, & Wu, 2015).

The grey clustering method was developed for classifying observation indices or observation objects into definable classes using grey incidence matrices or grey whitenization weight functions. The grey clustering method using whitenization weight functions is mainly applied to test whether the objects of observation belong to predetermined classes, so that they can be treated accordingly (S. Liu & Lin, 2010). In this article, we use the grey clustering method based on center-point triangular whitenization weight functions (CTWF) because stakeholder groups can be treated as observation objects for ECA. In addition, since respondents tend to be more certain about the center-point of a grey class as compared with other points within the class, conclusions based on such cognitive certainty are more scientific and reliable (S. Liu & Lin, 2010). This fact is important for collecting information from stakeholder groups and for assessing objectively the social impact they may be affected by.

The grey clustering method based on CTWF is developed according to the following definition.

Definition 1. Assume that there are a set of *m* objects, a set of *n* criteria and a set of *s* different grey classes, according to the sample value x_{ij} *(i=1, 2 ,…, m; j=1, 2, …, n)* of the *i*th *(i=1, 2, …, m)* object, for the criterion *j (j=1, 2, …, n).* The steps for grey clustering based on CTWF can be expressed as follows (S. Liu & Lin, 2010; Y. Zhang et al., 2014):

Step 1: The individual ranges of the criteria are divided into *s* grey classes, and then center-points $\lambda_1, \lambda_2, \ldots, \lambda_s$ of grey classes *1, 2, …, s* are determined.

Step 2: The grey classes are expanded in two directions, adding the grey classes *0* and *(s+1)* with their center-points λ_0 and λ_{s+1} respectively. Therefore, the new sequence of center-points is established $\lambda_0, \lambda_1, \lambda_2, \ldots, \lambda_s, \lambda_{s+1}$ (see Figure 4.1). The CTWF for the *k*th grey class, *k=1, 2,…, s,* of the *j*th criterion, *j=1, 2,…, n,* for an observed value x_{ij} is defined by Equation (4.1).

$$f_j^k(x_{ij}) = \begin{cases} 0 \quad , & x \notin [\lambda_{k-1}, \lambda_{k+1}] \\ \dfrac{x - \lambda_{k-1}}{\lambda_k - \lambda_{k-1}}, & x \in [\lambda_{k-1}, \lambda_k] \\ \dfrac{\lambda_{k+1} - x}{\lambda_{k+1} - \lambda_k}, & x \in [\lambda_k, \lambda_{k+1}] \end{cases} \tag{4.1}$$

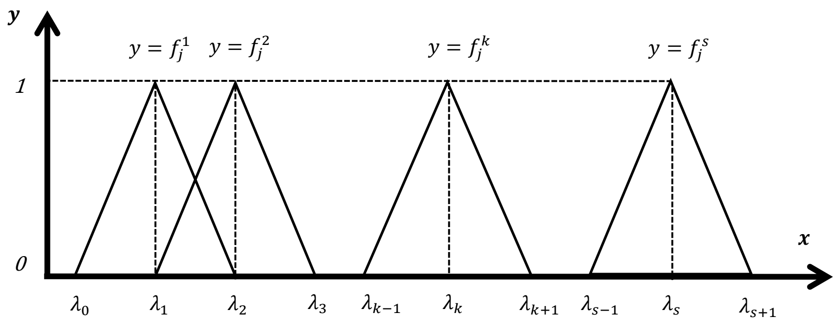

Figure 4.1: Center-point triangular whitenization weight functions (CTWF).

Step 3: The comprehensive clustering coefficient σ_i^k, for object i, i=*1, 2,…, m*, with respect to the grey class k, k=*1,…, s* is calculated by Equation (4.2).

$$\sigma_i^k = \sum_{j=1}^{n} f_j^k(x_{ij}).\eta_j \tag{4.2}$$

where $f_j^k(x_{ij})$ is the CTWF of the kth grey class of the jth criterion, and η_j is the weight of criterion j.

Step 4: If $\max_{1\le k\le s}\{\sigma_i^k\} = \sigma_i^{k^*}$, we decide that object i belongs to grey class k^*. When there are several objects in grey class k^*, these objects can be ordered according to the magnitudes of their comprehensive clustering coefficients.

4.3.2 Entropy-weight method

The entropy-weight method is based on Shannon entropy, originally developed by Shannon (Shannon & Weaver, 1947). Shannon entropy is a concept which is proposed as a measure of uncertainty in information, formulated in terms of probability theory. Since the concept of entropy is well suited to measuring the relative intensities of contrast criteria in order to represent the average intrinsic information transmitted for decision-making (Zeleny, 1996), it is an appropriate and convenient choice for our purpose. Subsequent research on Shannon entropy has contributed to the resolution of a range of problems in areas such as:

- Clinical neurophysiology (Cao & Slobounov, 2011),
- Transport systems (Chen et al., 2014),
- Environmental time series data (Srivastav & Simonovic, 2014),
- Fault detection (Bafroui, Ohadi, Heidari Bafroui, & Ohadi, 2014).

Shannon developed measure *H* which satisfies the following properties for all p_i within an estimated joint probability distribution *P* (Shemshadi et al., 2011; Zitnick & Kanade, 2004):

1. *H* is a continuous positive function;
2. If all p_i are equal, $p_i=1/n$, then *H* should be a monotonic increasing function of *n*; and,

3. For all,

$$n \geq 2, H(p_1, p_2, \ldots, p_n) = h(p_1 + p_2, p_3, \ldots, p_n) + (p_1 + p_2)H(\frac{p_1}{p_{1+}p_2}, \frac{p_2}{p_{1+}p_2})$$

Shannon showed that the only function which satisfies these properties is:

$$H_{Shannon} = -\sum_{i}^{n} p_i log(p_i) \tag{4.3}$$

where: $0 \leq p_i \leq 1; \ \sum_{j=1}^{n} p_i = 1$

For a certain criterion, if there is a large difference between the alternatives, the criterion will give decision makers a large amount of information and the criterion can be regarded as an important factor (Kou et al., 2011). It can thus be argued that the entropy-weight method can be applied in ECA to determine those criteria for which there is divergence between the compared stakeholder groups.

The entropy-weight method is developed according to the following definition.

Definition 2. Assume that there are m objects for evaluation and each has n evaluation criteria, which form decision matrix $Z = \{z_{ij};\ i = 1, 2, \dots, m; j = 1, 2, \dots, n\}$. Then, the steps of the entropy-weight method can be expressed as follows (Fagbote et al., 2014; Ji et al., 2015; Wang & Lee, 2009; Xie & Yang, 2011):

Step 1: The decision matrix $Z = \{z_{ij};\ i = 1, 2, \dots, m; j = 1, 2, \dots, n\}$ is normalized for each criterion Cj (j=1, 2,..., n). The normalized values Pij are calculated by Equation (4.4).

$$P_{ij} = \frac{z_{ij}}{\sum_{i=1}^{m} z_{ij}} \tag{4.4}$$

Step 2: The entropy H_j of each criterion *Cj* is calculated by Equation (4.5).

$$H_j = -k \sum_{i=1}^{m} P_{ij}\, ln(P_{ij}) \tag{4.5}$$

k is a constant, let $k = (ln(m))^{-1}$.

Step 3: The degree of divergence div_j of the intrinsic information in each criterion *Cj* is calculated by Equation (4.6).

$$div_j = 1 - H_j \tag{4.6}$$

Step 4: The entropy weight w_j of each criterion *Cj* is calculated by Equation (4.7).

$$w_j = \frac{div_j}{\sum_{j=1}^{n} div_j} \tag{4.7}$$

4.3.3 Integration of the grey clustering and entropy-weight methods

The IGCEW method for ECA combines the grey clustering method based on CTWF and the entropy-weight method, as illustrated in Figure 4.2.

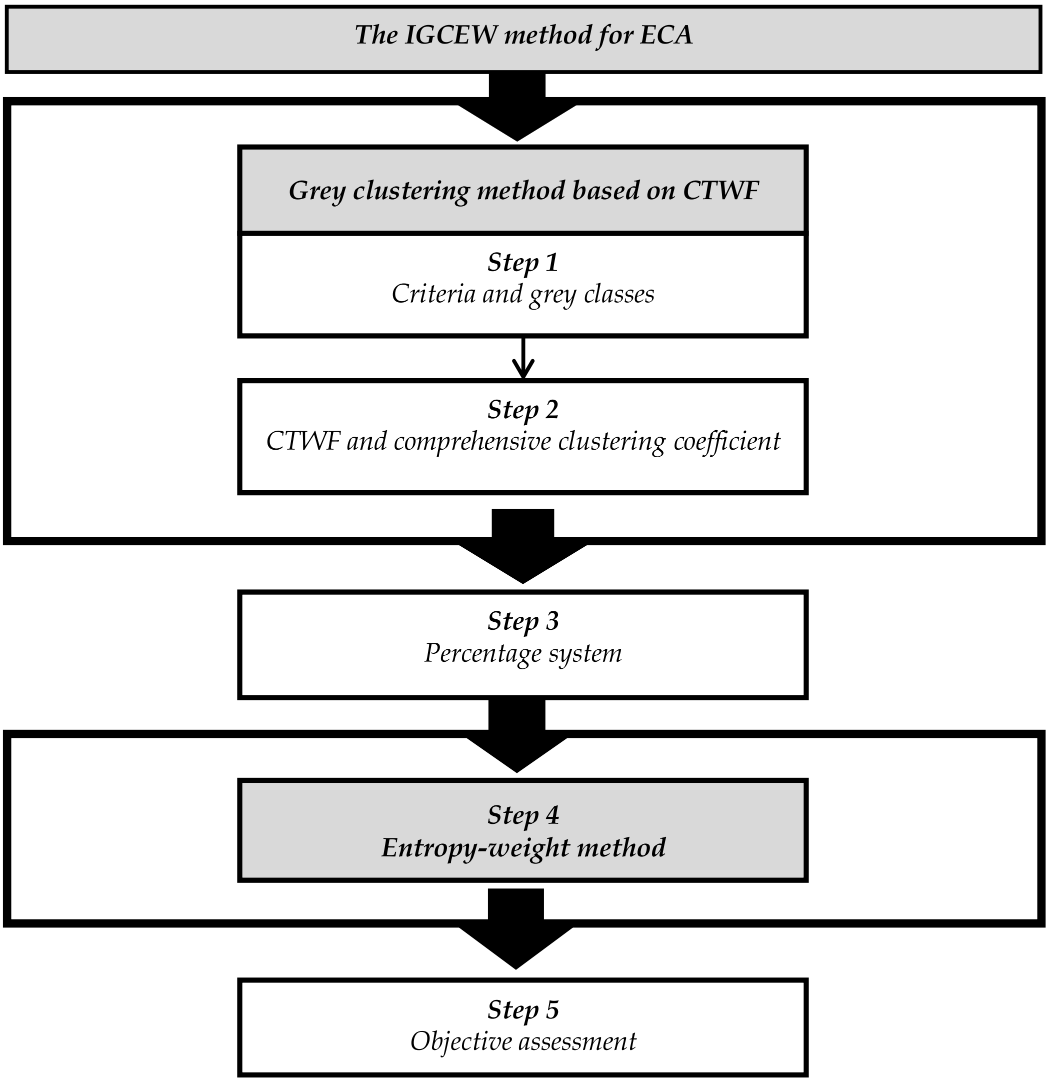

Figure 4.2: Schema of the IGCEW method for ECA

The IGCEW method for ECA can be described using the following sets:

1. A set of m objects or stakeholder groups called $G = \{G_1, G_2,..., G_m\}$

2. A set of n criteria called $C = \{C_1, C_2,..., C_n\}$

3. A set of s grey classes called $V = \{V_1, V_2,..., V_s\}$

4. A set of evaluation values called $X = \{x_{ij}, i = 1, 2,..., m; j = 1, 2,..., n\}$ of G_i $(i = 1, 2,..., m)$ with respect to criterion C_j $(j = 1, 2,..., n)$.

The steps are described below:

Step 1: Criteria and grey classes. A set of n criteria and a set of s grey classes for ECA are established based on the characteristics of the project under scrutiny.

Step 2: CTWF and comprehensive clustering coefficient. The values of CTWF for each stakeholder group are calculated using Equation (4.1). Then, the comprehensive clustering coefficient $\boldsymbol{\sigma_i^k}$ for object i, i=1, 2,…, m, with respect to the grey class k, k=1,…, s, is calculated using Equation (4.2).

Step 3: Percentage system. The social impact assessment of each stakeholder group is presented as a percentage system (Chang et al., 2009), defined by values $a_1, a_2, a_3,\ldots,$ and a_s, where $a_s=100$, $a_1=100/s$, $a_2=a_1+a_1$, $a_3=a_1+a_2,\ldots,$ and $a_{s-1}=a_1+a_{s-2}$; s is the number of grey classes established. The results are given by Equation (4.8).

$$z_j^i = \sum_{k=1}^{s} f_j^k(x_{ij}).\alpha_k \tag{4.8}$$

where $f_j^k(x_{ij})$ is the CTWF of the kth grey class of the jth criterion and α_k is the percentage value of each grey class. The results are represented by a matrix determined by Equation (4.9).

$$Z = \{z_{ij}, i = 1, 2, \dots, m; j = 1, 2, \dots, n\} \tag{4.9}$$

Step 4: Entropy-weight method. First, matrix $Z = \{z_{ij}, \mathrm{i} = 1, 2, \dots, \mathrm{m}; \mathrm{j} = 1, 2, \dots, \mathrm{n}\}$ is normalized for each criterion *Cj (j=1, 2,..., n)*. The normalized values P_{ij} are calculated using Equation (4.4). Then, H_j, div_j and w_j are calculated using Equations (4.5), (4.6) and (4.7).

Step 5: Objective assessment. The final stage of the ECA is the calculation of objective assessment (Shemshadi et al., 2011) regarding each stakeholder group *i, i=1, 2,…, m,* for each criterion *Cj (j=1, 2,..., n).* The objective assessment value is defined by Equation (4.10).

$$Q_{ij} = w_j z_{ij} \tag{4.10}$$

where w_j is the entropy weight of each criterion *Cj* and z_{ij} is the result of the social impact assessment for each stakeholder group *i, i=1, 2,…, m*. The results are represented by a matrix determined by Equation (4.11).

$$Q_{ij} = \begin{bmatrix} w_1 z_{11} & w_2 z_{12} & \dots & w_n z_{1n} \\ w_1 z_{21} & w_2 z_{22} & \dots & w_n z_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_1 z_{m1} & w_2 z_{m2} & \dots & w_n z_{mn} \end{bmatrix} \tag{4.11}$$

The first three steps of the IGCEW method for ECA correspond to social impact assessment, developed in accordance with the grey clustering method based on CTWF and represented by a percentage system. Then, entropy-weight and objective assessment are applied, which identify the criteria for which there is the greatest divergence between the stakeholder groups.

In order to illustrate and validate the IGCEW method for ECA we conducted a case study described below.

4.4 Case study

In order to test the IGCEW method, we performed an ECA of the expansion plans of a poly-metallic mine in northern Peru, in the department of Cajamarca (Figure 4.3). Our study measured the social impact of this project on the zone of influence and, based on the results, determined the criteria likely to generate environmental conflicts between the identified stakeholder groups.

Source: Retrieved from ***(Wikimedia Commons, 2014)***

Figure 4.3: Cajamarca, Peru.

4.4.1 Stakeholder Groups

Our field work identified three different stakeholder groups *(k=3)*, and the composition of these groups was determined on the basis of the similarities found during the overall assessment of the expansion plans of the mine. The sample size in each group was established by the principle of saturation of discourse, which stipulates that information gathering should end when respondents no longer contribute new observations (Corbetta, 2007). The stakeholder groups were defined as follows:

G_1: Urban population

This group was composed of citizens from the urban areas near the exploitation site. They expressed a generally favourable opinion towards the mining project, and tended to stress the importance of private investment for the resolution of social problems. This group was made up of one hundred and fifteen interviewees.

G_2: Rural population

This group was composed of citizens from the rural areas near the exploitation site, consisting of people undertaking productive activities related to agriculture and livestock. The group of rural population had a generally adverse opinion of the mining project and was made up of one hundred and five interviewees.

G_3: Specialists

This group was composed of professionals from different fields who were familiar with the area of influence and the characteristics of the environmental and social impacts of the mining project, and who manifested a generally neutral assessment of the mining project. This group was made up of thirty-five interviewees.

4.4.2 Calculations

The calculations for the case study, based on the steps detailed above, proceeded as follows.

Step 1: Criteria and grey classes

The ECA criteria in the studied case were established by taking into account the economic and social situation of the area of influence and the characteristics of the evaluated mining project, as well as consultations with experts. Initially, during the exploratory study, certain criteria were submitted by stakeholders, such as unexpected death of livestock, lack of health facilities, subsidies for traditional celebrations in the area, and road construction. But these criteria were discarded in the analysis as they were not directly related to the project or were already covered by other previously defined criteria. Seven criteria *(n=7)* were identified as shown in Table 4.4.

Table 4.4: ECA criteria identified in the case study.

Criterion	Code	Description
GDP per capita	C_1	The GDP per capita as soles per month (annual average) in the department of Cajamarca.
Employment rate	C_2	The employment rate per year in the department of Cajamarca.
Poverty rate	C_3	The poverty rate per year in the region.
Number of inhabitants per doctor (GP)	C_4	The number of inhabitants per doctor (GP) per year in the department of Cajamarca.
Enrolment rate in primary education	C_5	The enrolment rate per year in primary education in the region.
Number of reported crimes	C_6	The number of reported crimes per year in the department of Cajamarca.
Access to drinking water rate	C_7	The access to drinking water rate per year in the department of Cajamarca.

Five grey classes (Very Negative, Negative, Normal, Positive and Very Positive) were established for the mining project on the basis of historical information about the 2009-2013 social indicators provided by the Peru government (INEI, 2014) and a qualitative analysis of the consultations with experts – in order to satisfy the need to reflect the social impact of the specific region as accurately as possible (S. Liu & Lin, 2010). It was decided that the criteria had the same weight (η_j = 0.143), inasmuch as they were all social criteria (Corbetta, 2007). The grey classes established for each of the seven criteria are shown in Table 4.5.

Table 4.5: Grey classes for each criterion determined in the case study.

Code	Grey classes				
	Very Negative (V_1)	Negative (V_2)	Normal (V_3)	Positive (V_4)	Very Positive (V_5)
C_1	$611 \le x_1^1 \le 690$	$690 \le x_1^2 \le 768$	$768 \le x_1^3 \le 847$	$847 \le x_1^4 \le 926$	$926 \le x_1^5 \le 1004$
C_2	$61.8 \le x_2^1 \le 66.2$	$66.2 \le x_2^2 \le 70.7$	$70.7 \le x_2^3 \le 75.1$	$75.1 \le x_2^4 \le 79.6$	$79.6 \le x_2^5 \le 84.0$
C_3	$45.4 \le x_3^1 \le 52.5$	$38.3 \le x_3^2 \le 45.4$	$31.2 \le x_3^3 \le 38.3$	$24.1 \le x_3^4 \le 31.2$	$17.0 \le x_3^5 \le 24.1$
C_4	$2651 \le x_4^1 \le 3026$	$2276 \le x_4^2 \le 2651$	$1901 \le x_4^3 \le 2276$	$1526 \le x_4^4 \le 1901$	$1151 \le x_4^5 \le 1526$
C_5	$93.0 \le x_5^1 \le 93.9$	$93.9 \le x_5^2 \le 94.8$	$94.8 \le x_5^3 \le 95.7$	$95.7 \le x_5^4 \le 96.6$	$96.6 \le x_5^5 \le 97.5$
C_6	$7651 \le x_6^1 \le 9075$	$6226 \le x_6^2 \le 7651$	$4802 \le x_6^3 \le 6226$	$3377 \le x_6^4 \le 4802$	$1953 \le x_6^5 \le 3377$
C_7	$55.1 \le x_7^1 \le 61.8$	$61.8 \le x_7^2 \le 68.5$	$68.5 \le x_7^3 \le 75.2$	$75.2 \le x_7^4 \le 81.9$	$81.9 \le x_7^5 \le 88.6$

Step 2: CTWF and the comprehensive clustering coefficient

The data obtained from the stakeholder groups were evaluated using CTWF. The grey classes were extended in two directions by adding classes V_0 and V_6 ("extra negative" and "extra positive", respectively), and their center-points λ_0 and λ_6 were determined. Therefore, there was a new sequence of center-points, λ_0, λ_1, λ_2, λ_3, λ_4, λ_5 and λ_6, as shown in Table 4.6 and Figure 4.4.

Table 4.6: Center-points of the extended grey classes in the case study.

Criteria	Center-points of the extended grey classes						
	Extra Negative impact (λ_0)	Very Negative impact (λ_1)	Negative impact (λ_2)	Normal impact (λ_3)	Positive impact (λ_4)	Very Positive impact (λ_5)	Extra Positive impact (λ_6)
C_1	572	651	729	808	886	965	1044
C_2	59.6	64.0	68.5	72.9	77.4	81.8	86.3
C_3	56.0	48.9	41.8	34.7	27.6	20.5	13.4
C_4	3213	2838	2463	2088	1713	1338	963
C_5	92.5	93.4	94.3	95.2	96.1	97.0	97.9
C_6	9788	8363	6939	5514	4090	2665	1241
C_7	51.7	58.4	65.1	71.8	78.5	85.2	91.9

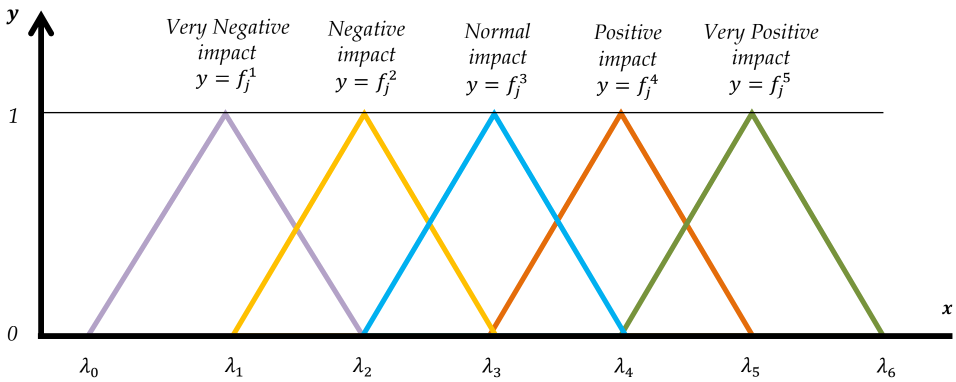

Figure 4.4: CTWF in the case study.

To illustrate, for the first criterion *C_1 (j=1)*, shown in the first row of Table 4.5 and Table 4.6, we first had the grey classes *V_1= [611; 690], V_2= [690; 768], V_3= [768; 847], V_4= [847; 926]*, and *V_5= [926; 1004]*, with their center-points being *λ_1=651, λ_2=729, λ_3=808, λ_4=886* and *λ_5=965*. The grey classes were then expanded in two directions by adding the grey classes *V_0= [533; 611]* and *V_6= [1004; 1083]*, with their center-points being *λ_0=572* and *λ_6=1044*. Thus, we obtained a new sequence of center-points: λ_0, *λ_1, λ_2, λ_3, λ_4, λ_5* and

λ_6. The values were substituted into Equation (4.1), and the CTWF of the five grey classes were then obtained. The results for the first criterion C_j $(j=1)$ are shown in Equations (4.12), (4.13), (4.14), (4.15) and (4.16):

$$f_1^1(x) = \begin{cases} 0, & x \notin [572, 729] \\ \dfrac{x-572}{79}, & x \in [572, 651] \\ \dfrac{729-x}{78}, & x \in [651, 729] \end{cases} \tag{4.12}$$

$$f_1^2(x) = \begin{cases} 0, & x \notin [651, 808] \\ \dfrac{x-651}{78}, & x \in [651, 729] \\ \dfrac{808-x}{79}, & x \in [729, 808] \end{cases} \tag{4.13}$$

$$f_1^3(x) = \begin{cases} 0, & x \notin [729, 886] \\ \dfrac{x-729}{79}, & x \in [729, 808] \\ \dfrac{886-x}{78}, & x \in [808, 886] \end{cases} \tag{4.14}$$

$$f_1^4(x) = \begin{cases} 0, & x \notin [808, 965] \\ \dfrac{x-808}{78}, & x \in [808, 886] \\ \dfrac{965-x}{79}, & x \in [886, 965] \end{cases} \tag{4.15}$$

$$f_1^5(x) = \begin{cases} 0, & x \notin [886, 1044] \\ \dfrac{x-886}{79}, & x \in [886, 965] \\ \dfrac{1044-x}{79}, & x \in [965, 1044] \end{cases} \tag{4.16}$$

The data was collated by means of a field study carried out in the area of influence of the mining project. The information from the stakeholder groups was gathered via direct interviews using a structured questionnaire based on the evaluation criteria and the grey classes established. The questions used in the questionnaire are presented in Table 4.7.

Table 4.7: Questions used in the questionnaire.

	Question	Grey classes				
		Very Negative (V1)	Negative (V2)	Normal (V3)	Positive (V4)	Very Positive (V5)
1	What effect would the project have on the economic income per person?	Decrease noticeably	Decrease	No effect	Increase	Increase noticeably
2	What effect would the project have on the employment rate?	Decrease noticeably	Decrease	No effect	Increase	Increase noticeably
3	What effect would the project have on the poverty rate?	Increase noticeably	Increase	No effect	Decrease	Decrease noticeably
4	What effect would the project have on the number of inhabitants per doctor (GP)?	Increase noticeably	Increase	No effect	Decrease	Decrease noticeably
5	What effect would the project have on the enrolment rate in primary education?	Decrease noticeably	Decrease	No effect	Increase	Increase noticeably
6	What effect would the project have on the number of reported crimes?	Increase noticeably	Increase	No effect	Decrease	Decrease noticeably
7	What effect would the project have on the access to drinking water?	Decrease noticeably	Decrease	No effect	Increase	Increase noticeably

Table 4.8 shows the overall results of the evaluation of the three stakeholder groups *(m = 3)* with respect to each criterion. The data were aggregated using arithmetic means (Aznar & Guijarro, 2012).

Table 4.8: Aggregated values for each criterion for groups G_1, G_2 and G_3.

Group	C_1	C_2	C_3	C_4	C_5	C_6	C_7
G_1	929	80.3	23	1777	95.9	4578	83
G_2	689	67.6	45	2324	94.7	6369	60
G_3	902	78.2	29	1788	95.2	5799	69

By way of illustration, for group G_1 the values of CTWF were calculated using Equations (4.12), (4.13), (4.14), (4.15) and (4.16). Subsequently, the comprehensive clustering coefficient (σ_i^k) was calculated for each stakeholder group using Equation (4.2). The values of CTWF and σ_i^k obtained for group G_1 *(m=1)* are shown in Table 4.9.

Table 4.9: Values of CTWF and σ_i^k for group G_1.

$f_j^k(x)$	C_1	C_2	C_3	C_4	C_5	C_6	C_7	σ_i^k
$f_j^1(x)$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$f_j^2(x)$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$f_j^3(x)$	0.00	0.00	0.00	0.17	0.23	0.34	0.00	0.11
$f_j^4(x)$	0.46	0.34	0.31	0.83	0.77	0.66	0.29	0.52
$f_j^5(x)$	0.54	0.66	0.69	0.00	0.00	0.00	0.71	0.37

Identical procedure was applied to the other groups in the case study.

Step 3: Percentage system

The social impact assessment for the case study was presented as a percentage system, defined by values a_1, a_2, a_3, a_4, and a_5, where $a_5=100$, $a_1=100/5=20$, $a_2=a_1+a_1=40$, $a_3=a_1+a_2=60$ and $a_4=a_1+a_3=80$, according to the grey classes established $(s=5)$. The results are given in Table 4.10. To illustrate, the values of social impact assessment for group G_1 were calculated using Equation (4.8), as shown in Table 4.11.

Table 4.10: The percentage system established in the case study.

Social impact class	Interval	α_k
Very negative	[20, 30]	20
Negative	[30, 50]	40
Normal	[50, 70]	60
Positive	[70, 90]	80
Very positive	[90, 100]	100

Table 4.11: Social impact assessment for group G_1.

Impact class	a_k	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Total
Very negative	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Negative	40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Normal	60	0.00	0.00	0.00	10.29	13.71	20.57	0.00	6.37
Positive	80	36.57	27.43	25.14	66.29	61.71	52.57	22.86	41.80
Very positive	100	54.29	65.71	68.57	0.00	0.00	0.00	71.43	37.14
		90.86	93.14	93.71	76.57	75.43	73.14	94.29	85.31
		Very positive	Very positive	Very positive	Positive	Positive	Positive	Very positive	Positive

The values of social impact assessment for groups G_2 and G_3 were obtained using the same procedure as for group G_1. A complete summary of all the results is shown in Table 4.12.

Table 4.12: Social impact assessment for groups G_1, G_2 and G_3.

Group	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Total	Impact class
G_1	90.86	93.14	93.71	76.57	75.43	73.14	94.29	85.31	Positive impact
G_2	29.71	36.00	29.71	47.43	48.00	48.00	25.71	37.80	Negative impact
G_3	84.00	84.00	76.00	76.00	60.00	56.00	52.00	69.71	Normal impact

Step 4: Entropy-weight method

We next proceeded to apply the entropy-weight method part. First, the criteria values shown in Table 4.12 were normalized using Equation (4.4), the normalized values are given in Table 4.13. Then, H_j, div_j and w_j were calculated using Equations (4.5), (4.6) and (4.7). The results are given in Table 4.14.

Table 4.13: Normalized values of SIA of groups G_1, G_2 and G_3.

Group	C_1	C_2	C_3	C_4	C_5	C_6	C_7
G_1	0.44	0.44	0.47	0.38	0.41	0.41	0.55
G_2	0.15	0.17	0.15	0.24	0.26	0.27	0.15
G_3	0.41	0.39	0.38	0.38	0.33	0.32	0.30

Table 4.14: Values of Hj, divj and wj for each criterion in the case study.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
H_j	0.92	0.94	0.92	0.98	0.98	0.99	0.89
div_j	0.08	0.06	0.08	0.02	0.02	0.01	0.11
w_j	0.21	0.16	0.21	0.05	0.04	0.04	0.29

Step 5: Objective assessment

The ECA was completed by calculating objective assessment for each stakeholder group *i, i=1, 2, 3,* for each criterion *Cj (j=1, 2, 3, 4, 5, 6, 7),* using Equation (4.10). The results are shown in Table 4.15.

Table 4.15: Objective assessment scores for each group in the case study.

Group	C_1	C_2	C_3	C_4	C_5	C_6	C_7
G_1	19.43	14.98	20.05	3.91	2.94	2.63	26.90
G_2	6.36	5.79	6.36	2.42	1.87	1.72	7.34
G_3	17.97	13.51	16.26	3.88	2.34	2.01	14.84

4.5 Results and Discussion

The results and discussion are presented below in accordance with the two main objectives of this article.

4.5.1 The case study

The detailed calculations for the case study produced three important findings, which we discuss below.

First, the IGCEW method helped to identify major tensions among the stakeholder groups. Figure 4.5 (based on Table 4.12) shows the score of social impact assessment for each stakeholder group: for group G_1 (urban population) the score was 85.31 (positive impact), for group G_2 (rural population) it was 37.80 (negative impact) and for group G_3 (specialists) it was 69.71 (normal impact). These results suggest a strong antagonism between groups G_1 and G_2, despite the specialists (G_3) expressing the opinion that the mining project would have an acceptable degree of social impact. The results for G_3 indicate that the mining project would not generate dramatic social problems, but the directly affected populations, as represented by groups G_1 and G_2, presented contradictory views of the project, the difference suggesting potential conflicts between G_1 and G_2 groups. In order to analyse and more fully understand the mechanisms and forces at play, we need to look at the specific criteria of conflict between G_1 and G_2, which points to our second important finding.

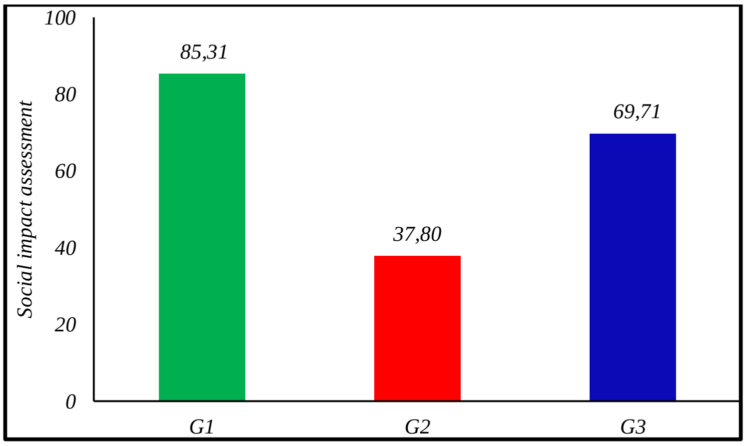

Figure 4.5: Total social impact assessment of G1, G2 and G3.

The second interesting finding in our case study analysis is that the behaviour of the criteria is considerably different across the affected groups. Figure 4.6, derived from Table 4.12, shows the results of social impact assessment for each criterion. For group G_1, the criteria C_1, C_2, C_3 and C_7 are placed in the range of “very positive impact” (90-100), and the criteria C_1, C_5 and C_6 occur in the range of “positive impact” (70-90). In addition, for group G_2, the criteria C_1, C_3 and C_7 are found in the range of “very negative impact” (20-30), and the criteria C_2, C_4, C_5 and C_6 in the range of “negative impact” (30-50). These results pose a need for a closer comparison of all these criteria in order to identify the most controversial ones among them.

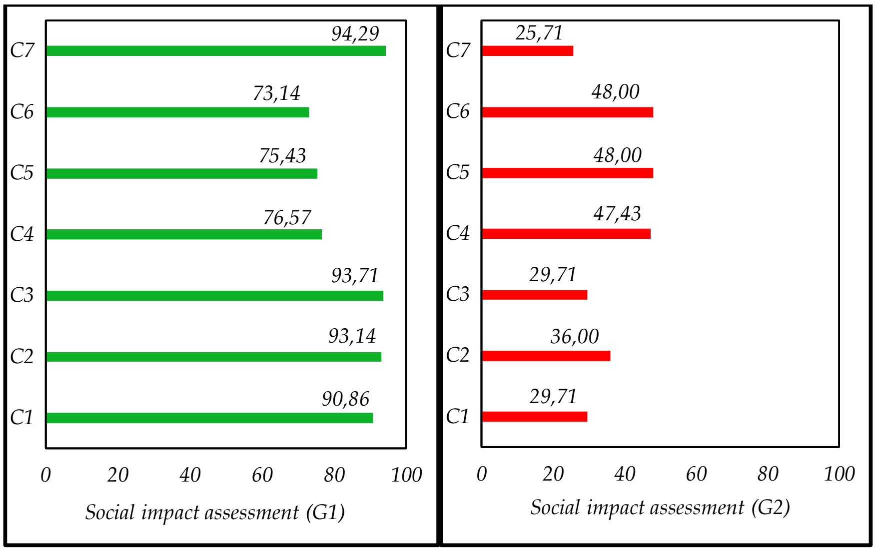

Figure 4.6: Social impact assessment for each criterion for groups G1 and G2.

It is at this stage that our third finding and the entropy-weight method proved useful. We were able to identify the most divergent criteria implying the most potential causes of conflict between the affected stakeholder groups. Figure 4.7, based on Table 4.15, shows that the stakeholder groups converge for criteria C_4 (number of inhabitants per doctor (GP)), C_5 (Enrolment rate in primary education) and C_6 (number of reported crimes), while they diverge for criteria C_1 (GDP per capita), C_2 (employment rate), C_3 (poverty rate) and C_7 (access to drinking water rate). The criteria with the greatest divergence are related to access to drinking water, poverty, GDP per capita and employment, in that order. It would thus appear that these four issues should first be taken into account when implementing measures to prevent environmental conflict over the mining project analysed. In addition, Figure 4.7 also shows that the criterion with the greatest divergence is related to access to drinking water (C_7). This very issue is especially problematic due to G_2's strongly expressed belief that the mining company's planned activity would contribute greatly to the contamination of the water sources.

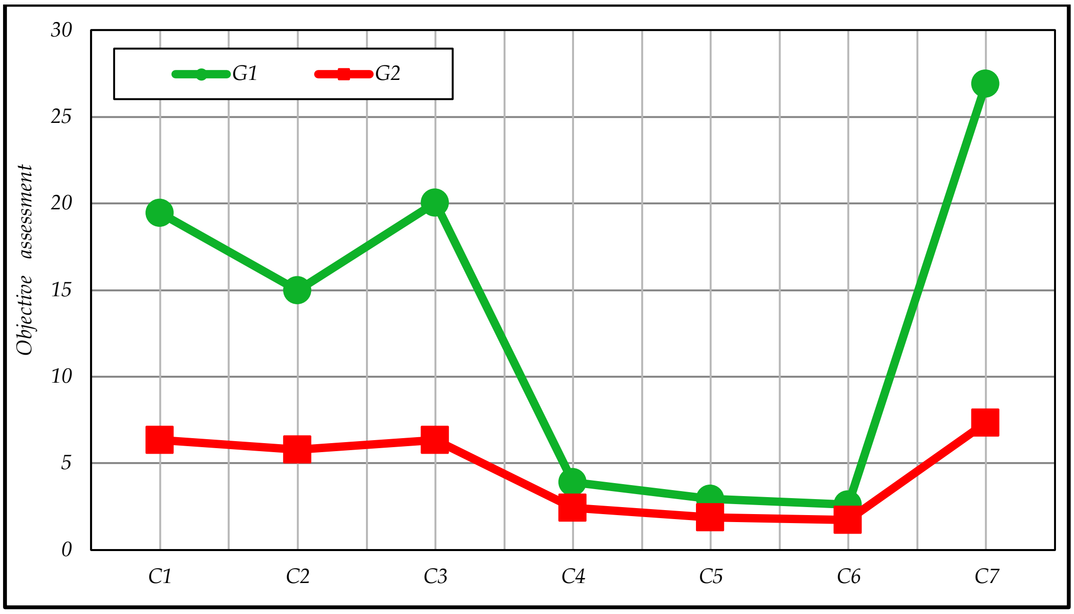

Figure 4.7: Objective assessment for each criterion for groups G1 and G2.

4.4.1.1 Sensitivity Analysis

The IGCEW method is flexible, versatile and adjustable due to the fact that the number of stakeholder groups and number of ECA criteria are determined according to the particularities of the project under scrutiny. In the case studied in this article, we determined seven criteria and three stakeholder groups.

The IGCEW method is sensitive to number and type of stakeholder groups. For example, in our case study, if we were to include the environmental advocacy stakeholder group, see Figure 4.8, the mining project would have very negative total impact, as in the opinion of this stakeholder group the mining project is completely non-viable (Sánchez, 2011). If we were to include the government stakeholder group or the company stakeholder group the mining project would have very positive total impact, as in the opinion of these stakeholder groups the mining project is completely viable (Knight Piésold, 2010; MINAM, 2011b). In this study, we excluded the environmental advocacy, government and company stakeholder groups, as these stakeholders groups distort the results; in addition, they are not the directly affected population (Wittmer et al., 2006).

Source: retrieved from ***(El Comercio, 2015)***

Figure 4.8: Environmental advocacy stakeholder group.

4.4.1.2 Analysis of diverging criteria

The mining project, commonly called Conga, consists of Newmont Mining Corporation (51.35%), *Compañía de Minas Buenaventura* (43.65%), and the World Bank's International Finance Corporation (5%). The planned duration of the mining process is 19 years, including 2 years of construction and 17 years in operation. The standard annual operation consists of the removal of overburden (topsoil and rocks) in order to obtain low-grade metal ores, which are then concentrated using a combination of physical and chemical processes that entail the very intense use of water (Silva-Macher & Farrell, 2014).

In order to establish some measures to prevent environment conflict in the mining project, we analyse the context of the diverging criteria below.

Access to drinking water

Access to drinking water is the most controversial criterion, in terms of the quantity and quality of the water supply to rural and urban areas. The mining project is placed at the headwaters of five important watersheds. In addition, the mining company plans to use four natural lagoons, the lagoon *El Perol* among them, see Figure 4.9. These lagoons will be emptied, the first two for mineralogical use and the last two for waste rock dumps (MINAM, 2011b). The mining company proposes building four water reservoirs, enough to replace the volumes of the natural lagoons and satisfy the demands of rural and urban areas (Knight Piésold, 2010).

Source: retrieved from ***(Celendín libre, 2015)***

Figure 4.9: Lagoon "El Perol", Cajamarca-Perú.

On the one hand, the urban stakeholder group strongly believes that there will be no problems with the quality and quantity of water for urban areas and the economic benefits to the city will be much more advantageous. On the other hand, the rural stakeholder group strongly believes that there will be problems with the quality and quantity of water for rural areas, as the mining company has caused serious environmental damage in previous projects developed in the area (Grufides, 2015), see Figure 4.10. In addition, the mining company conducted an environmental impact assessment (EIA) in 2010 (Knight Piésold, 2010), in order to show the viability of the project. However, the rural stakeholder group believes that it is not transparent, as the mining company hired a consulting company to conduct the EIA, even though this is permitted by Peruvian law. This perception was present in all controversial criteria.

Source: retrieved from (Red verde, 2011)

Figure 4.10: Water conflict on the channel "Quinua", Cajamarca-Peru.

Poverty

In the department of Cajamarca, about 68% of the population lives in rural areas, hence it is one of the most rural regions of Peru (De Echave & Diez, 2013). In addition, in the Sierra region of Peru, where the department of Cajamarca lies, poverty is 34.7%, higher than the average in the country, which stands at 23.9%. In the Sierra rural area poverty is 52.9% and in the Sierra urban area it is 16.2% (INEI, 2014).

The urban stakeholder group believes that the mining project will reduce the level of poverty, as it will generate direct and indirect economic income for families. While the rural stakeholder group, despite the fact that it has higher rates of poverty, believes the project will make them poorer, as it will destroy their economic base, which is based on agriculture and livestock.

GDP per capita

In the department of Cajamarca, in 1990, agricultural activity, with 42% of total production, was the mainstay of the regional economy, and mining accounted for only 5.9% of total production. In 2010 agricultural activity decreased to 20.1% and mining increased to 20.2%. In addition trade activities, hostelry and manufacturing also increased. This growth mainly benefited urban areas (De Echave & Diez, 2013).

The urban stakeholder group believes that the GDP per capita in the cities will grow, as there will be much more investment in trade activities and other activities in urban areas. The rural stakeholder group does not believe that the GDP per capita in the rural areas will grow, due to the fact that they do not have other economic alternatives to agriculture and livestock, which will be affected by the mining project.

Employment

In recent years mining in Peru has experienced notable growth due to government promoted reforms on investment in mining. However, this economic sector does not generate significant direct employment, as it requires specialized labour. However, the mining industry generates indirect economic movement in other areas such as trade and services, which provides indirect employment (De Echave & Diez, 2013).

The urban stakeholder group strongly believes that the mining project will generate employment in urban areas, as there will be growth in economic sectors such as trade and services; in addition, the mining company affirms that it will train and hire people from the villages around the project area (Knight Piésold, 2010). However, the rural stakeholders group believes that when the mining project ends, it will leave serious environmental damage, and it will not be possible to use the land for agriculture or livestock, which means job losses in the rural area.

Based on what is analysed above, we believe that in order to prevent environmental conflict the following measures could be implemented:

- Due to the fact that the rural population has lost confidence in the mining company and central government, we propose the implementation of a permanent committee of environmental and social monitoring, in which the rural population is represented.
- We propose a change in legislation, so that EIA is not conducted or contracted by the mining company and that EIA must be contracted by the government and with the agreement of the affected population and the mining company.
- The mining company should study and consider other alternatives, which do not involve the use of natural lagoons, due to the fact that they provide ecological balance in the area and also represent the main causes of conflict over water.
- Taxes collected by the implementation of the project should be invested in social development projects in the area of influence, so that the population is able to perceive the benefits of the project.
- Diversification of economic activities in rural areas in order to create jobs to improve agriculture and livestock and take advantage of opportunities in the context of mining.
- The mining company and the government should explain and demonstrate to the directly affected population, that environmental and social impacts will be mitigated when the mining project is finished.

4.4.2 The broader potential of the IGCEW method

ECA methods are mainly developed as part of qualitative and quantitative approaches. In order to discuss the potential of the IGCEW method, we compare it below with the qualitative methods and then with the quantitative methods.

First, we believe that the IGCEW method for ECA illustrated in this article could contribute to the improvement of the qualitative methods of ECA. For example, the study developed by (Griewald & Rauschmayer, 2014) or by (Prenzel & Vanclay, 2014), both conducted using qualitative methods, could be supplemented by applying the grey clustering method based on CTWF, which quantifies the qualitative information obtained from the stakeholder groups and then by a percentage system establishing a ranked order of social impact assessment for each stakeholder group. This knowledge can allow researchers to study environmental conflicts more accurately, because the procedure provides numerical information easy to analyse and to establish comparisons between the stakeholder groups involved in a given conflict.

Second, the IGCEW method for ECA applied in this article would also contribute to the improvement of the quantitative methods. For example, the study developed by (Al-Mutairi et al., 2008), conducted under a quantitative method, could be supplemented by applying the entropy-weight method, which identifies the criteria with the greatest divergence factor between the stakeholder groups, and thus helps to define the causes of environmental conflict more closely, enabling researchers to find more accurate measures of conflict prevention.

4.6 Conclusions

The application of the IGCEW method for ECA to the mining project in Peru has made it possible to quantify the qualitative information provided by the three stakeholder groups identified, allowing us to establish the values of social impact for each stakeholder group objectively. In addition, the application of the IGCEW method determined the divergent criteria most likely to produce environmental conflicts between the stakeholder groups. The specific results obtained, we believe, could help analysts in the mining company or in the Peruvian government to seek appropriate measures to prevent conflict over the mining project.

We also strongly believe that the IGCEW method for ECA described in this article could be applied as an extension to the qualitative and quantitative methods for ECA, as it provides quantitative information of social impact for each stakeholder group by applying the grey clustering method based on CTWF. In addition, the results from the entropy-weight method can show clearly the criteria most likely leading to environmental conflicts.

The limitations of the IGCEW method may be summarized as follows:

(1) It presents subjective aspects during information gathering and the establishment of limits of grey classes.
(2) The grey systems and Shannon entropy approaches are not widely diffused compared to approaches based on fuzzy logic or on statistics models.
(3) The calculations are a little tedious when processing data. This could be improved by implementing a computer system.
(4) As it is a new approach it needs to be validated in other contexts to improve its effectiveness.

In future research, the IGCEW method for ECA could be applied to other types of projects, such as water resources management, industrial projects, public construction projects, hydrocarbons exploitation projects, as well as be used to measure the social impact of public policies or governmental programs of conflict prevention.

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CHAPTER V

CASE STUDY: HYDROCARBON EXPLORATION IN SPAIN

5. Case study in Spain

Paper 3: Integrating social impact assessment and environmental conflict analysis on a hydrocarbon exploration project in the gulf of Valencia, Spain.

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Abstract

Social impact assessment (SIA) has become a key factor for environmental conflicts prevention, which makes necessary to integrate SIA and environmental conflict analysis (ECA). In this study, we integrate SIA and ECA using a method based on grey systems and Shannon entropy. A case study was conducted on a hydrocarbon exploration project located in the Sea of the Gulf of Valencia, Spain. Four stakeholder groups and four criteria were identified. The results revealed that for group of specialists the project would have negative social impact; and contrary perceptions were found between the group of those directly affected and the group of citizens in favour. It was also noted that the criteria most likely to generate environmental conflicts were the percentage of unemployment and GDP per capita. These results could help central and community governments to make the best decision on the project within of the use management of the gulf of Valencia, Spain. The method showed interesting results and could be apply to manage other projects or programs in coastal areas or ocean areas from point of view of social factors.

Keywords:
Social impact assessment
Environmental conflict analysis
Grey systems - Shannon entropy
Coastal and ocean management
Gulf of Valencia in Spain

5.1. Introduction

Social impact assessment (SIA) is an important factor to prevent environmental conflicts caused by implantation of investment projects (Prenzel & Vanclay, 2014). Qualitative methods are available for SIA, as evidenced by studies based on public participation (Tang, Wong, & Lau, 2008), or game theory (van der Voort & Vanclay, 2015). In addition, there are quantitative methods for environmental impact assessment and SIA, which can be found in studies based on fuzzy logic (Kim, Jang, & Lee, 2013; Peche & Rodríguez, 2011), or Delphi and fuzzy (Chang, Qisen, Zheng, & Zhang, 2009). In this study, we apply the grey clustering method (The GC method), which is based on grey systems theory, to conduce SIA.

The GC method is an approach that considers the uncertainty within its analysis, and also it enables the classification of observed objects into definable classes, called grey classes (S. Liu & Lin, 2010), as evidenced by the studies on a water rights allocation system (L. N. Zhang, Wu, & Jia, 2013), or the classification of innovation strategic alliances (Y. Zhang, Ni, Liu, & Jian, 2014). In this article, we argue that the GC method could benefit SIA, as SIA is a topic with high level of uncertainty.

Moreover, environmental conflict analysis (ECA) also is a key factor to prevent conflicts during planning and implementation of projects and programs, as evidenced by the studies on conflicts related to ecological tourism (Yang, Ryan, & Zhang, 2013), or water management (Bolin, Collins, & Darby, 2008; Saqalli, Thiriot, & Amblard, 2010). ECA has been mostly conducted using qualitative methods, as showed by the study on environmental conflict from an infrastructure project (Prenzel & Vanclay, 2014), which was based on the capability perspective. In addition, there are also quantitative methods for ECA, as evidenced by the study on environmental conflict over aquifer contamination (Al-Mutairi, Hipel, & Kamel, 2008), which was based on fuzzy logic. In this study, we apply the entropy-weight method (the EW method) to conduce ECA.

The EW method is based on Shannon entropy theory. Shannon entropy is a concept proposed as a measure of uncertainty (Zeleny, 1996). This determines a wide range of application for the EW method, as shown by the studies to resolve a software selection problem (Wang & Lee, 2009), or to asses a case of environmental pollution (Kou, Sun, & Peng, 2011). We believe that the EW method could contribute to ECA, as it would help to identify controversial criteria under the same philosophy of the GC method.

Furthermore, stakeholders are an important dimension of integrated assessment (Hamilton, ElSawah, Guillaume, Jakeman, & Pierce, 2015), and environmental conflicts are generated between stakeholder groups within affected population (Arun, 2008; Luyet, Schlaepfer, Parlange, & Buttler, 2012). This makes that SIA should first be conducted for each stakeholder group and then the differences between them should be determined in order to prevent possible environmental conflicts (Prenzel & Vanclay, 2014). In this study, we integrate SIA and ECA using the GC method and the EW method (The integrated method) (Delgado & Romero, 2015). Subsequently, in order to apply and test the IGCEW method, we conducted a study of SIA and ECA on a hydrocarbon exploration project in the Gulf of Valencia, Spain.

The specific objectives of this article are to:

1. Integrate SIA and ECA using the GC method and the EW method.
2. Apply the integrated method to the concrete context of the hydrocarbon exploration project in the Gulf of Valencia, Spain.

Section 5.2 provides details of the methodology to integrate SIA and ECA. In Section 5.3 the case study is described, followed by the results and discussion in Section 5.4. Conclusions are provided in Section 5.5.

5.2. Methodology

This section describes SIA using the GC method, ECA using the EW method, and provides the details of the integrated method for SIA and ECA.

5.2.1. SIA using the GC method

SIA is characterized by its high level of uncertainty (Wittmer, Rauschmayer, & Klauer, 2006). Therefore, SIA should be conducted by a method, which considers the uncertainly.

Some classical approaches of multi-criteria analysis, such as Delphi (Campos-Climent, Apetrei, & Chaves-Ávila, 2012; Landeta, 2002) or analytic hierarchy process (AHP) (Saaty, 1980; Sadeghi & Ameli, 2012), do not consider the uncertainty within their analysis, due to the fact that the importance degrees of criteria and the performance scores of alternatives are assumed to be known precisely (Baykasoğlu & Gölcük, 2015). Moreover, some options to model the uncertainly can be fuzzy logic approaches (Rouyendegh & Erkan, 2012), probabilistic approaches (Augustsson, Filipsson, Öberg, & Bergbäck, 2011) or grey systems approaches (S. Liu & Lin, 2010).

Grey systems theory established by Julong Deng focuses on the study of problems for which there are small samples or limited information available (Deng, 1985). In the real world, there are many uncertain systems with small samples or limited information, this fact determines a broad range of applicability of the grey systems. For example:

1. Geographical information systems (Wu, Lin, Peng, & Huang, 2012),
2. Health management (Yu, Wang, & Chengwu, 2013),
3. Optimization (Cui, Liu, Zeng, & Xie, 2013),
4. Safety management (Wei, Zhou, Wang, & Wu, 2015).

Approaches based on fuzzy logic, such as fuzzy analytic hierarchy process (FAHP) (Rouyendegh & Erkan, 2012; Zadeh, 1965), emphasize the investigation of problems with cognitive uncertainty, where the research objects possess the characteristic of clear intention and unclear extension. The focus of approaches based on grey systems theory is on the uncertainty problems, where the research objects possess the characteristic of unclear intention and clear extension (S. Liu & Lin, 2010). SIA has clear extension of the criteria on a determined study, for example, in a historic range of five years, we can know the minimum and maximum value of a social variable under analysis. In addition, affected population within a determined project could be clear about when things were good or bad: before or after project implementation (Delgado & Romero, 2015).

In turn, in statistical approaches the concept of large samples represents the degree of tolerance to incompleteness (S. Liu & Lin, 2010), and considering that one of the criteria for evaluating methods can be the cost (Wittmer et al., 2006), in this aspect an approach based in grey systems would have a lower cost with respect to a statistical approach, due to the fact that sample size influences on the cost during the field work. In addition, in 1994, Jiangping Qiu and Xisheng Hua established a comparison between statistical regression model and grey model on the deformation and leakage data of a certain large scale hydraulic dam. Their work showed that their grey model could provide a better fit than the statistical regression model (S. Liu & Lin, 2010).

Therefore, it could be argued that the GC method based on grey systems theory would benefit SIA, as it considers the uncertainty within its analysis. In addition, the grey clustering method would be more adequate than approaches based on fuzzy logic, as it considers clear extension for evaluation criteria. Furthermore, the GC method could be more effective and would have a lower cost than other statistical approaches during its application.

The GC method was developed to classify objects of observation into definable classes, and can be performed by means grey incidence matrices or whitenization weight functions. Whitenization weight functions are mainly used to test whether the objects of observation belong to predetermined classes. In this study, we use center-point triangular whitenization weight functions (CTWF), because typically people tend to be more certain about the center-points of grey classes in comparison with other points of the grey class. So, the conclusions based on this cognitive certainty could be more scientific and reliable (S. Liu & Lin, 2010).

The GC method based on CTWF can be described as follows (Delgado & Romero, 2015; S. Liu & Lin, 2010; Y. Zhang et al., 2014):

First, assume that there are a set of *m* objects, a set of *n* criteria, and a set of *s* grey classes, according to the sample value x_{ij} $(i=1, 2, \ldots, m; j=1, 2, \ldots, n)$. Then, the steps for the GC method based on CTWF can be developed as follows:

Step 1: The ranges of the criteria are divided into s grey classes, and then center-points $\lambda_1, \lambda_2, \ldots, \lambda_s$ of grey classes $1, 2, \ldots, s$ are determined.

Step 2: The grey classes are expanded in two directions, adding the grey classes 0 and (s+1) with their center-points λ_0 and λ_{s+1} respectively. The new sequence of center-points is $\lambda_0, \lambda_1, \lambda_2, \ldots, \lambda_s, \lambda_{s+1}$ see details in Figure 5.1. For the *k*th grey class, $k=1, 2, \ldots, s$, of the *j*th criterion, $j=1, 2, \ldots, n$, for an observed value x_{ij}, the CTWF is calculated by Equation (5.1).

$$f_j^k(x_{ij}) = \begin{cases} 0 \quad , & x \notin [\lambda_{k-1}, \lambda_{k+1}] \\ \dfrac{x - \lambda_{k-1}}{\lambda_k - \lambda_{k-1}}, & x \in [\lambda_{k-1}, \lambda_k] \\ \dfrac{\lambda_{k+1} - x}{\lambda_{k+1} - \lambda_k}, & x \in [\lambda_k, \lambda_{k+1}] \end{cases} \tag{5.1}$$

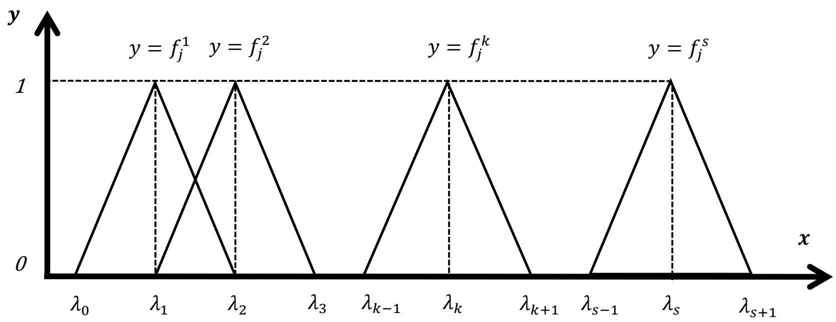

Figure 5.1: CTWF (S. Liu & Lin, 2010).

Step 2: The comprehensive clustering coefficient σ_i^k for object i, i=1, 2,…, m, with respect to the grey class k, k=1, 2,…, s, is calculated by Equation (5.2).

$$\sigma_i^k = \sum_{j=1}^{n} f_j^k(x_{ij}).\eta_j \quad (5.2)$$

where $f_j^k(x_{ij})$ is the CTWF of the *k*th grey class of the *j*th criterion, and η_j is the weight of criterion *j*.

Step 4: If $\max_{1\le k\le s}\{\sigma_i^k\} = \sigma_i^{k^*}$, we decide that object *i* belongs to grey class *k**. When there are several objects in grey class *k**, these objects can be ordered according to the magnitudes of their comprehensive clustering coefficients.

5.2.2. ECA using the EW method

ECA is a social topic, which also has high level of uncertainty. ECA could be conducted by classical multi-criteria methods (Wittmer et al., 2006), or by statistical approaches (S. Liu & Lin, 2010). However, classical multi-criteria methods do not consider the uncertainty within their analysis (Baykasoğlu & Gölcük, 2015). In addition, statistical approaches would have high cost during the field work (Wittmer et al., 2006).

A good option for ECA could be the EW method, which is based on Shannon entropy theory. Shannon proposed the concept of entropy as a measure of uncertainty in information, formulated in terms of probability theory (Shannon & Weaver, 1947). The concept of entropy is well suited to identify the contrast criteria for decision-making (Zeleny, 1996). This fact determines that Shannon entropy has made contributions to the resolution of problems, in areas such as:

- Pollution (Ainslie, Reuten, Steyn, Le, & Zidek, 2009),
- Water quality (L. Liu, Zhou, An, Zhang, & Yang, 2010),
- Management (Shemshadi, Shirazi, Toreihi, & Tarokh, 2011),
- Fault detection (Bafroui, Ohadi, Heidari Bafroui, & Ohadi, 2014).

ECA could be conducted by the EW method, as it considers uncertainty within its analysis, and under the same philosophy as the GC method. In addition, the EW method would benefit ECA, as it could help to researchers to determine the criteria for which there is divergence between stakeholder groups involved in a determined conflict (Kou et al., 2011).

The EW method can be developed as follows (Delgado & Romero, 2015; Fagbote, Olanipekun, & Uyi, 2014; Ji, Huang, & Sun, 2015):

First, assume that there are m objects for evaluation and n evaluation criteria, which form the decision matrix $Z = \{z_{ij};\ i = 1, 2, \dots, m; j = 1, 2, \dots, n\}$. Then, the steps of the EW method can be expressed as follows:

Step 1: The decision matrix $Z = \{z_{ij};\ i = 1, 2, \dots, m; j = 1, 2, \dots, n\}$ is normalized for each criterion *Cj (j=1, 2,..., n)*. The normalized values P_{ij} are calculated by Equation (5.3).

$$P_{ij} = \frac{z_{ij}}{\sum_{i=1}^{m} z_{ij}} \tag{5.3}$$

Step 2: The entropy H_j of each criterion Cj is calculated by Equation (5.4).

$$H_j = -k \sum_{i=1}^{m} P_{ij}\, ln(P_{ij}) \tag{5.4}$$

k is a constant, let $k = (ln(m))^{-1}$.

Step 3: The degree of divergence div_j of each criterion Cj is calculated by Equation (5.5).

$$div_j = 1 - H_j \tag{5.5}$$

Step 4: The entropy weight w_j of each criterion Cj is calculated by Equation (5.6).

$$w_j = \frac{div_j}{\sum_{j=1}^{n} div_j} \tag{5.6}$$

The combination of the GC method and the EW method could integrate SIA and ECA. Firs, the GC method assesses social impact by quantifying of information from stakeholders groups. And then, the EW method identifies criteria, for which, there is the most divergence between stakeholders groups within of project under scrutiny.

5.2.3. Integration of SIA and ECA using the IGCEW method

The IGCEW method consists of five steps, of which the first three correspond to SIA, which are based on the GC method; and the final two correspond to ECA, which are based on the EW method, as shown in Figure 5.2.

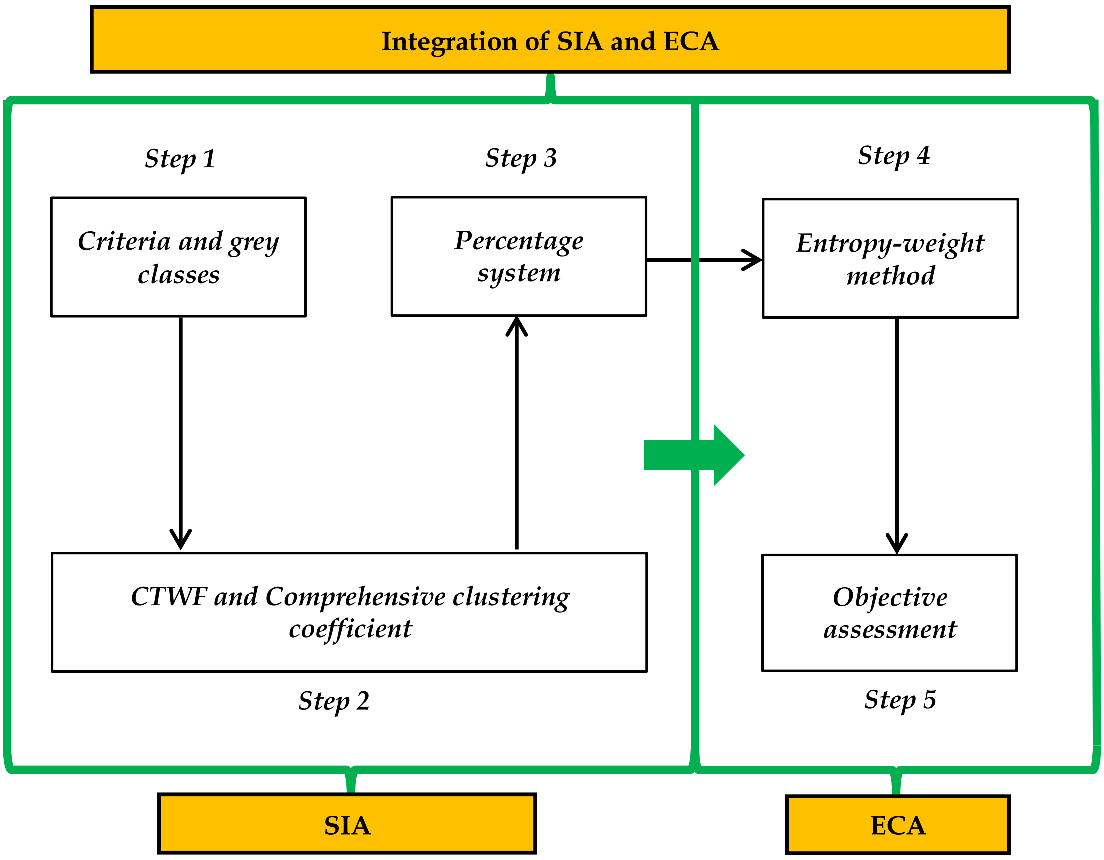

Figure 5.2: Schema of the integration of SIA and ECA.

First, the IGCEW method can be described by means the following sets (Delgado & Romero, 2015):

a. A set of *m* stakeholder groups called $G = \{G_1, G_2, \ldots, Gm\}$
b. A set of *n* criteria called $C = \{C_1, C_2, \ldots, Cn\}$
c. A set of *s* grey classes called $V = \{V_1, V_2, \ldots, Vs\}$
d. A set of evaluation values called $X = \{x_{ij}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n\}$ of G_i $(i = 1, 2, \ldots, m)$ with respect to the criterion C_j $(j = 1, 2, \ldots, n)$

Then, the steps of the IGCEW method are described as follows (Delgado & Romero, 2015):

Step 1: Criteria and grey classes

A set of *n* criteria for SIA, determined by C_j *(j=1, 2,…, n)*, is established; and a set of *s* grey classes, determined by V_k *(k=1, 2,…, s)*, is defined.

Step 2: CTWF and Comprehensive clustering coefficient

The CTWF values of each stakeholder group are obtained using Equation (5.1). Then, the comprehensive clustering coefficients σ_i^k for object *i*, *i=1, 2,…, m*, with respect to the grey class *k*, *k=1,…, s*, are calculated using Equation (5.2).

Step 3: Percentage system

SIA finishes with a percentage system (Chang et al., 2009; Delgado & Romero, 2015), defined by the values: $a_1, a_2, a_3, \ldots, a_s$, where *s* is the number of grey classes defined, $a_s=100$, $a_1=100/s$, $a_2=a_1+a_1$, $a_3=a_1+a_2$, …,and $a_{s-1}=a_1+a_{s-2}$. The results for each stakeholder group are given by Equation (5.7).

$$z_j^i = \sum_{k=1}^{s} f_j^k(x_{ij}).\alpha_k \tag{5.7}$$

where $f_j^k(x_{ij})$ is CTWF of the *k*th grey class of the *j*th criterion and α_k is the percentage value of each grey class. The results are represented by the matrix determined by Equation (5.8).

$$Z = z_j^i = \{z_{ij}, i = 1,2, \ldots, m; j = 1,2, \ldots, n\} \tag{5.8}$$

Step 4: Entropy-weight method

ECA is carried out by applying the EW method. First, using Equation (5.3), the normalized values P_{ij} of the matrix $Z = z_j^i = \{z_{ij}, i = 1,2, \ldots, m; j = 1,2, \ldots, n\}$

are calculated. Then, H_j, div_j and w_j are determined using Equations (5.4), (5.5) and (5.6).

Step 5: Objective assessment

The final step of ECA involves calculating the objective assessment (Delgado & Romero, 2015; Shemshadi et al., 2011) of each stakeholder group *i, i=1, 2,…, m,* for each criterion *Cj (j=1, 2,..., n)*, by means Equation (5.9).

$$Q_{ij} = w_j z_{ij} \tag{5.9}$$

where w_j is the entropy weight for each criterion *Cj* and z_{ij} is the result of SIA for each stakeholder group. The results are represented by the matrix defined by Equation (5.10).

$$Q_{ij} = \begin{bmatrix} w_1 z_{11} & w_2 z_{12} & \cdots & w_n z_{1n} \\ w_1 z_{21} & w_2 z_{22} & \cdots & w_n z_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_1 z_{m1} & w_2 z_{m2} & \cdots & w_n z_{mn} \end{bmatrix} \tag{5.10}$$

5.3. Case study

SIA and ECA were performed for a project located in the Gulf of Valencia in Spain, as shown in Figure 5.3. The concerned company proposes to conduct the hydrocarbon exploration by means a campaign of 3D seismic acquisition in zones B, G, AM-1 and AM-2, indicated on the map (Environmental Resources Management Iberia, 2012). Ultrasound technology was proposed to be used to determine the existence of hydrocarbon deposits in the marine subsoil. In this study, we conducted SIA and ECA of this project on the city of Valencia, located inside the zone of influence of the project.

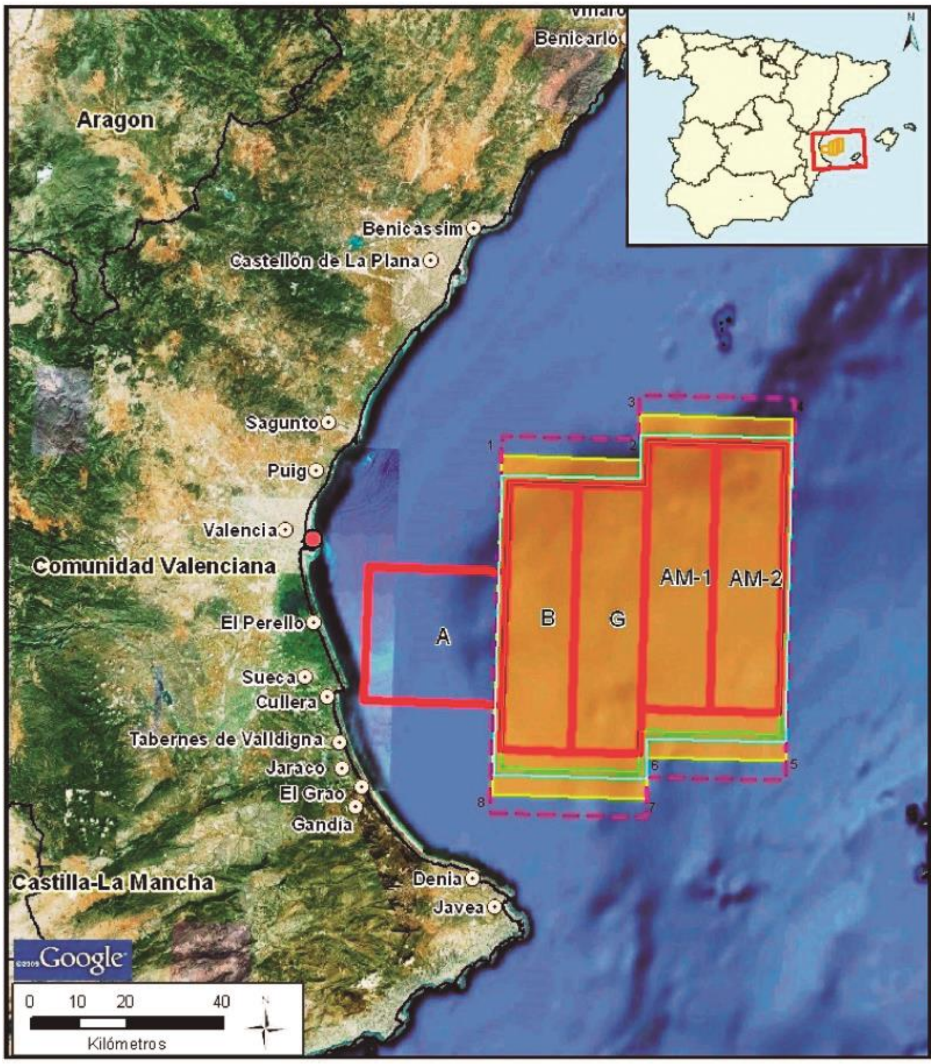

Figure 5.3: Project location (Environmental Resources Management Iberia, 2012).

5.3.1. Stakeholder Groups

During the field work, we identified four different stakeholder groups (*k*=4), the composition of these groups was determined according to similarities found during the overall assessment on the hydrocarbon exploration project (Delgado & Romero, 2015). The sample size in each group was determined by means the principle of saturation of discourse, which establish that information gathering should end when respondents do not produce new information relevant to object of study (Corbetta, 2007). The stakeholder groups were defined as follows:

5.3.1.1. Those directly affected (G_1)

This group was composed of those members of the population who are directly affected by the impacts of the project, consisting of people undertaking productive activities related to fishing or tourism (see Figure 5.4). This group was made up of thirty interviewees.

Figure 5.4: Those directly affected stakeholder group.

5.3.1.2. Those citizens opposed to the project (G_2)

This group was composed of citizens who generally have an adverse opinion of the project, mainly consisting of students with no links to productive activities related to fishing or tourism (see Figure 5.5). This group was made up of thirty interviewees.

Figure 5.5: Those citizens opposed to the project stakeholder group.

5.3.1.3. Those citizens in favour (G_3)

This group was composed of citizens who generally have a favourable opinion of the project, mainly consisting of retirees and people linked to the government of the day, who tended to stress during the interview the importance of private investment in the resolution of social problems (see Figure 5.6). This group was made up of fifteen interviewees.

Figure 5.6: Those citizens in favour stakeholder group.

5.3.1.4. Specialists (G_4)

This group was composed of experts from different fields who are familiar with the area of influence and the characteristics of the environmental and social impacts of hydrocarbon exploration projects, and who manifested an objective and neutral general assessment of the project (see Figure 5.7). This group was made up of eight interviewees.

Figure 5.7: Specialists stakeholder group.

5.3.2. Calculations using the integrated method

The calculations for the case study, based on the IGCEW method, are preceded as follows.

Step 1: Criteria and grey classes

a) Evaluation criteria

The criteria for the case study were established by taking into account to the economic and social situation of the city of Valencia and the characteristics of the project, and by consulting with experts. Four criteria were *(n=4)* were identified as shown in Figure 5.8.

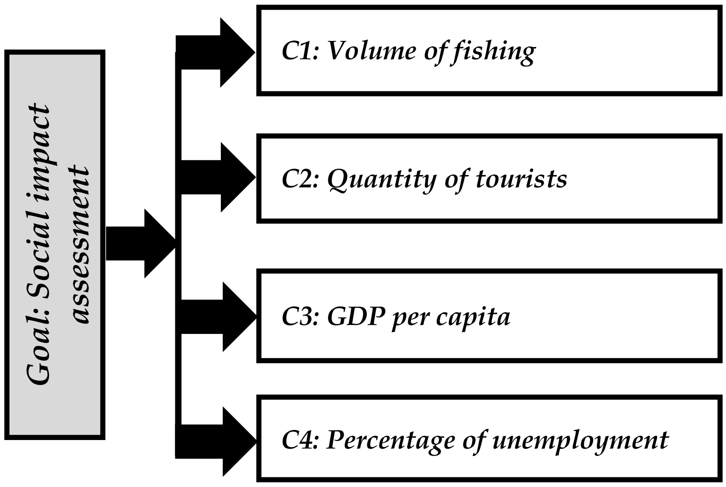

Figure 5.8: Criteria system of the case study.

The established criteria are described in Table 5.1.

Table 5.1: Evaluation criteria in the case study.

Criterion	Description
C1	This criterion measured the change in the volume of fishing in the *Comunitat Valenciana*, with the baseline figure being taken as the volume of fishing in 2013, which was 31,29 thousand tonnes of fish (INE-España, 2014).
C2	This criterion measured the change in the number of foreign tourists visiting the *Comunitat Valenciana*, with the baseline figure being taken as the number of foreign tourists in 2013, which was 5.97 million (INE-España, 2014).
C3	This criterion measured the change in quantity of GDP per capita in the *Comunitat Valenciana*, with the baseline figure being the GDP per capita in 2013, which was 19,500 euros per year (Datos Macro, 2014).
C4	This criterion measured the change in the percentage of unemployment in the *Comunitat Valenciana*, with the baseline figure being the unemployment rate in 2013, which was 28.05% (INE-España, 2014).

b) Grey classes

Five grey classes (s = 5) for the case study were established according to the historical information from 2009 to 2013 (Datos Macro, 2014; INE-España, 2014), and by the consultation with experts, in order to satisfy the need to reflect the characteristics of the specific region as accurately as possible (S. Liu & Lin, 2010). All the criteria had the same weight (ηj = 0.250), as they are social criteria (Corbetta, 2007). The grey classes established for each criterion are shown in Table 5.2.

Table 5.2: Grey classes for each criterion in the case study.

Criterion	Grey classes				
	Very Negative (V_1)	Negative (V_2)	Normal (V_3)	Positive (V_4)	Very Positive (V_5)
C1	$25.07 \leq x_1^1 \leq 27.56$	$27.56 \leq x_1^2 \leq 30.05$	$30.05 \leq x_1^3 \leq 32.54$	$32.54 \leq x_1^4 \leq 35.03$	$35.03 \leq x_1^5 \leq 37.52$
C2	$04.78 \leq x_2^1 \leq 05.26$	$05.26 \leq x_2^2 \leq 05.73$	$05.73 \leq x_2^3 \leq 06.21$	$06.21 \leq x_2^4 \leq 06.68$	$06.68 \leq x_2^5 \leq 07.16$
C3	$18.66 \leq x_3^1 \leq 19.00$	$19.00 \leq x_3^2 \leq 19.33$	$19.33 \leq x_3^3 \leq 19.67$	$19.67 \leq x_3^4 \leq 20.00$	$20.00 \leq x_3^5 \leq 20.34$
C4	$33.52 \leq x_4^1 \leq 37.16$	$29.87 \leq x_4^2 \leq 33.52$	$26.23 \leq x_4^3 \leq 29.87$	$22.58 \leq x_4^4 \leq 26.23$	$18.94 \leq x_4^5 \leq 22.58$

Step 2: CTWF and the comprehensive clustering coefficient

The data obtained from the stakeholder groups were processed using CTWF. The grey classes were extended in two directions by adding the grey classes V_0 and V_6 ("extra negative" and "extra positive", respectively), and with their center-points λ_0 and λ_6 being determined. Therefore, the new sequence of center-points was λ_0, λ_1, λ_2, λ_3, and λ_6, as shown in Table 5.3 and Figure 5.9.

Table 5.3: Center-points of the extended grey classes in the case study.

Criterion	Center-points of the extended grey classes						
	Extra negative impact (λ_0)	Very negative impact (λ_1)	Negative impact (λ_2)	Normal impact (λ_3)	Positive impact (λ_4)	Very positive impact (λ_5)	Extra positive impact (λ_6)
C1	23.82	26.31	28.80	31.29	33.78	36.27	38.76
C2	04.55	05.02	05.50	05.97	06.45	06.92	07.40
C3	18.50	18.83	19.17	19.50	19.84	20.17	20.51
C4	38.99	35.34	31.70	28.05	24.41	20.76	17.12

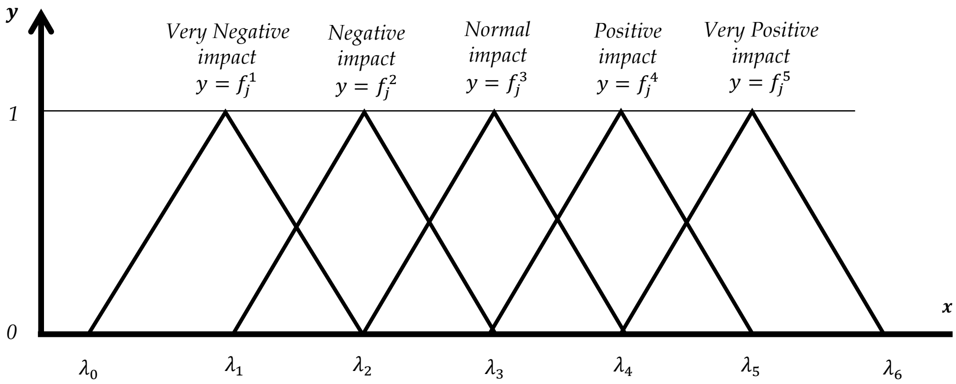

Figure 5.9: CTWF for the case study.

As illustration, for the first criterion C_1 *(j=1)* shown in the first row of Table 5.2 and Table 5.3, we have the grey classes: V_1= *[25.07; 27.56]*, V_2= *[27.56; 30.05]*, V_3= *[30.05; 32.54]*, V_4= *[32.54; 35.03]* and V_5= *[35.03; 37.52]*, with their center-points being λ_1=*26.31*, λ_2=*28.80*, λ_3=*31.29*, λ_4=*33.78* and λ_5=*36.27*. The grey classes were then expanded in two directions by adding the grey classes V_0= *[22.58; 25.07]* and V_6= *[37.52; 40.01]*, with their centres being λ_0=*23.82* and λ_6=*38.76*. Thus, we obtained a new sequence of centres: λ_0, λ_1, λ_2, λ_3, and λ_6. The values were substituted into Equation (5.1), to obtain the CTWF of the five grey classes. The results for the first criterion C_j*(j=1)* are shown in Equations (5.11), (5.12), (5.13), (5.14) and (5.15):

$$f_1^1(x) = \begin{cases} 0, & x \notin [23.82\,, 28.80] \\ \dfrac{x - 23.82}{2.49}, & x \in [23.82\,, 26.31] \\ \dfrac{28.80 - x}{2.49}, & x \in [26.31\,, 28.80] \end{cases} \tag{5.11}$$

$$f_1^2(x) = \begin{cases} 0, & x \notin [26.31\,, 31.29] \\ \dfrac{x - 26.31}{2.49}, & x \in [26.31\,, 28.80] \\ \dfrac{31.29 - x}{2.49}, & x \in [28.80\,, 31.29] \end{cases} \tag{5.12}$$

$$f_1^3(x) = \begin{cases} 0, & x \notin [28.80\,, 33.78] \\ \dfrac{x - 28.80}{2.49}, & x \in [28.80\,, 31.29] \\ \dfrac{33.78 - x}{2.49}, & x \in [31.29\,, 33.78] \end{cases} \tag{5.13}$$

$$f_1^4(x) = \begin{cases} 0, & x \notin [31.29\,, 36.27] \\ \dfrac{x - 31.29}{2.49}, & x \in [31.29\,, 33.78] \\ \dfrac{36.27 - x}{2.49}, & x \in [33.78\,, 36.27] \end{cases} \tag{5.14}$$

$$f_1^5(x) = \begin{cases} 0, & x \notin [33.78\,, 38.76] \\ \dfrac{x - 33.78}{2.49}, & x \in [33.78\,, 36.27] \\ \dfrac{38.76 - x}{2.49}, & x \in [36.27\,, 38.76] \end{cases} \tag{5.15}$$

The information from stakeholder groups was gathered by means of direct interviews using a structured questionnaire based on the evaluation criteria and grey classes established for the case study. The questions used are presented in Table 5.4.

Table 5.4: Questions used in the questionnaire for the case study.

Question		Grey classes				
		Very Negative (V1)	Negative (V2)	Normal (V3)	Positive (V4)	Very Positive (V5)
1	What effect would the project have on the volume of fishing?	Decrease noticeably	Decrease	No effect	Increase	Increase noticeably
2	What effect would the project have on the quantity of tourists?	Decrease noticeably	Decrease	No effect	Increase	Increase noticeably
3	What effect would the project have on the GDP per capita?	Decrease noticeably	Decrease	No effect	Increase	Increase noticeably
4	What effect would the project have on the percentage of unemployment?	Increase noticeably	Increase	No effect	Decrease	Decrease noticeably

Table 5.5 shows the overall results of the evaluation of the four stakeholder groups *(m = 4)* for each criterion. These data were aggregated using the arithmetic mean (Aznar & Guijarro, 2012).

Table 5.5: Aggregated values of each criterion for groups G_1, G_2, G_3 and G_4.

Group	**C_1**	**C_2**	**C_3**	**C_4**
G_1	26.81	05.16	18.85	34.98
G_2	26.89	05.59	19.53	26.96
G_3	30.13	05.88	19.92	22.22
G_4	27.87	05.61	19.42	27.14

Then, for group G_1, the values of CTWF were calculated using Equations (5.11), (5.12), (5.13), (5.14) and (5.15). Subsequently, the comprehensive clustering coefficient (σ_i^k) was calculated for each stakeholder group using Equation (5.2). The values of CTWF and σ_i^k obtained for group G_1 *(m=1)* are shown in Table 5.6.

Table 5.6: Values of CTWF and σ_i^k for group G_1.

$f_j^k(x)$	C_1	C_2	C_3	C_4	σ_i^k
$f_j^0(x)$	0.8000	0.7000	0.9333	0.9000	0.8333
$f_j^1(x)$	0.2000	0.3000	0.0667	0.1000	0.1667
$f_j^2(x)$	0.0000	0.0000	0.0000	0.0000	0.0000
$f_j^3(x)$	0.0000	0.0000	0.0000	0.0000	0.0000
$f_j^4(x)$	0.0000	0.0000	0.0000	0.0000	0.0000

Step 3: Percentage system

The final stage of SIA for the case study involved the employment of a percentage system defined by the values a_1, a_2, a_3, a_4 and a_5, where $a_5=100$, $a_1=100/5=20$, $a_2=a_1+a_1=40$, $a_3=a_1+a_2=60$ and $a_4=a_1+a_3=80$, according to five grey classes established, as shown in Table 5.7. Then, the results of SIA for group *G1* were calculated using Equation (5.7), as presented in Table 5.8.

Table 5.7: The percentage system determined in the case study.

Impact class	Interval	α_k
Very negative	[20, 30]	20
Negative	[30, 50]	40
Normal	[50, 70]	60
Positive	[70, 90]	80
Very positive	[90, 100]	100

Table 5.8: Results of SIA for group G_1.

Impact class	a_k	C_1	C_2	C_3	C_4	Total
Very negative	20	16.00	14.00	18.67	18.00	16.67
Negative	40	08.00	12.00	02.67	04.00	06.67
Normal	60	00.00	00.00	00.00	00.00	00.00
Positive	80	00.00	00.00	00.00	00.00	00.00
Very positive	100	00.00	00.00	00.00	00.00	00.00
		24.00	26.00	21.33	22.00	23.33
		Very negative	Very Negative	Very negative	Very negative	Very negative

The values of SIA for groups G_2, G_3 and G_4 were obtained using the same procedure as for group *G1*. The results for all stakeholder groups are presented in Table 5.9.

Table 5.9: Results of SIA for groups G_1, G_2, G_3 and G_4.

Group	C_1	C_2	C_3	C_4	Total	Impact class
G_1	24.00	26.00	21.33	22.00	23.33	Very negative
G_2	24.67	44.00	62.00	66.00	49.17	Negative
G_3	50.67	56.00	85.33	92.00	71.00	Positive
G_4	32.50	45.00	55.00	65.00	49.38	Negative

Step 4: Entropy-weight method

ECA for the case study was carried out by applying the EW method. First, the criteria values shown in Table 5.9 were normalized using Equation (5.3), the normalized values are shown in Table 5.10. Then, H_j, div_j and w_j were calculated using Equations (5.4), (5.5) and (5.6). The results are shown in Table 5.11.

Table 5.10: Normalized results of SIA for groups G_1, G_2, G_3 and G_4.

Group	C_1	C_2	C_3	C_4
G_1	0.182	0.152	0.095	0.090
G_2	0.187	0.257	0.277	0.269
G_3	0.384	0.327	0.382	0.376
G_4	0.247	0.263	0.246	0.265

Table 5.11: Values of H_j, div_j and w_j for each criterion.

	C_1	C_2	C_3	C_4
H_j	0.964	0.976	0.932	0.930
div_j	0.036	0.024	0.068	0.070
w_j	0.182	0.123	0.343	0.353

Step 5: Objective assessment

ECA for the case study was completed by calculating objective assessment of each stakeholder group *i, i=1, 2, 3, 4,* for each criterion *Cj (j=1, 2, 3, 4)*. The results were obtained using Equation (5.9), as shown in Table 5.12.

Table 5.12: Objective assessment scores for each group.

Group	C_1	C_2	C_3	C_4
G_1	04.36	03.20	07.31	07.76
G_2	04.48	05.41	21.24	23.28
G_3	09.21	06.89	29.23	32.45
G_4	05.91	05.53	18.84	22.92

5.4. Results and Discussion

The results and discussion, according to objectives in this study, are presented below.

5.4.1 The potential of the integrated method to integrate SIA and ECA

In this article, we proposed to conduct SIA by means the GC method based on grey systems, as it can analyse problems with high level of uncertainty, which could be an advantage with respect to classical multi-criteria methods as Delphi o AHP (Baykasoğlu & Gölcük, 2015). In addition, the GC method can be applied to problems with clear extension, which could help to collect information from stakeholder groups, this fact could be an advantage with respect to approaches based on fuzzy logic (S. Liu & Lin, 2010). Furthermore, the GC method uses small samples, which could have lower cost during its application than other statistical approaches (Wittmer et al., 2006).

In turn, ECA was carried out by means the EW method based on Shannon entropy, which is a method that also considers the uncertainty within its analysis (Zeleny, 1996). Therefore, the EW method could integrate SIA and ECA under the same philosophy of the GC method, identifying controversial criteria between stakeholder groups.

The main advantages of the integrated method could be summarized as follows:

- The integrated method could be more effective than other classical multi-criteria methods, as it considers uncertainty within its analysis.
- The integrated method could be more appropriate than other approaches based on fuzzy logic, as it considers clear extension of criteria within its analysis.
- The integrated method could have a lower cost than other statistical approaches during its application.
- The integrated method integrates SIA and ECA, performing an analysis of stakeholders, which is a dimension of integrated assessment.

The main limitations of the integrated method could be summarized as follows:

- The approaches based on grey systems or Shannon entropy are not widely diffused compared to approaches based on multi-criteria analysis, fuzzy logic or statistics models.
- The integrated method presents still subjective aspects, during information gathering and the establishment of limits of grey classes.

- The calculations are still tedious during the application of the integrated method. However, this could improve by implementing a computer system.

5.4.2 The case study

5.4.2.1 Analysis of findings from calculations

The calculations for the case study produced three important findings, which are discussed below.

First, the major tensions among stakeholder groups were identified. Figure 5.10 (based on Table 5.9) shows a strong antagonism between groups G_1 (*those directly affected*) and G_3 *(those citizens in favour)*, despite the fact that the specialists (G_4) expressed the opinion that the project would have a negative social impact. The results indicate that G_1 and G_3, presented contradictory views on the project, these differences suggest potential conflicts between G_1 and G_3 groups. In order to analyse and more fully understand the mechanisms and forces at play, we need to look at the specific criteria of conflict between G_1 and G_3, which points to our second important finding.

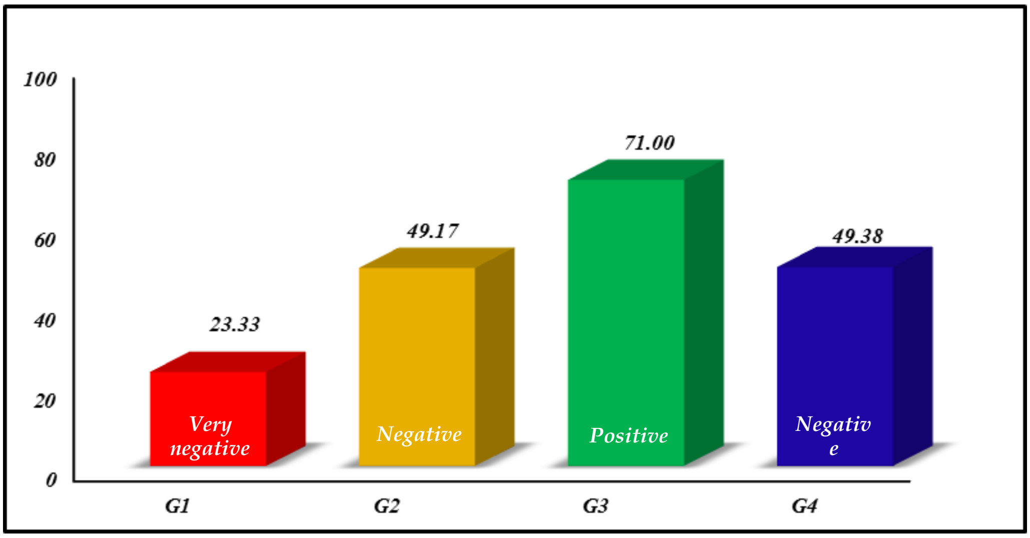

Figure 5.10: Values of SIA of each group.

Second, Figure 5.11 based on Table 5.9 shows the behaviour of the criteria for G1 and G3 groups: for group G1, all the criteria are in the "very negative" range; for group G3, C1 and C2 are placed in the range of "normal", C3 is found in the range of "positive", and C4 is in the range of "very positive". These results suggest a specific comparison of all these criteria, in order to identify the most controversial criteria among them.

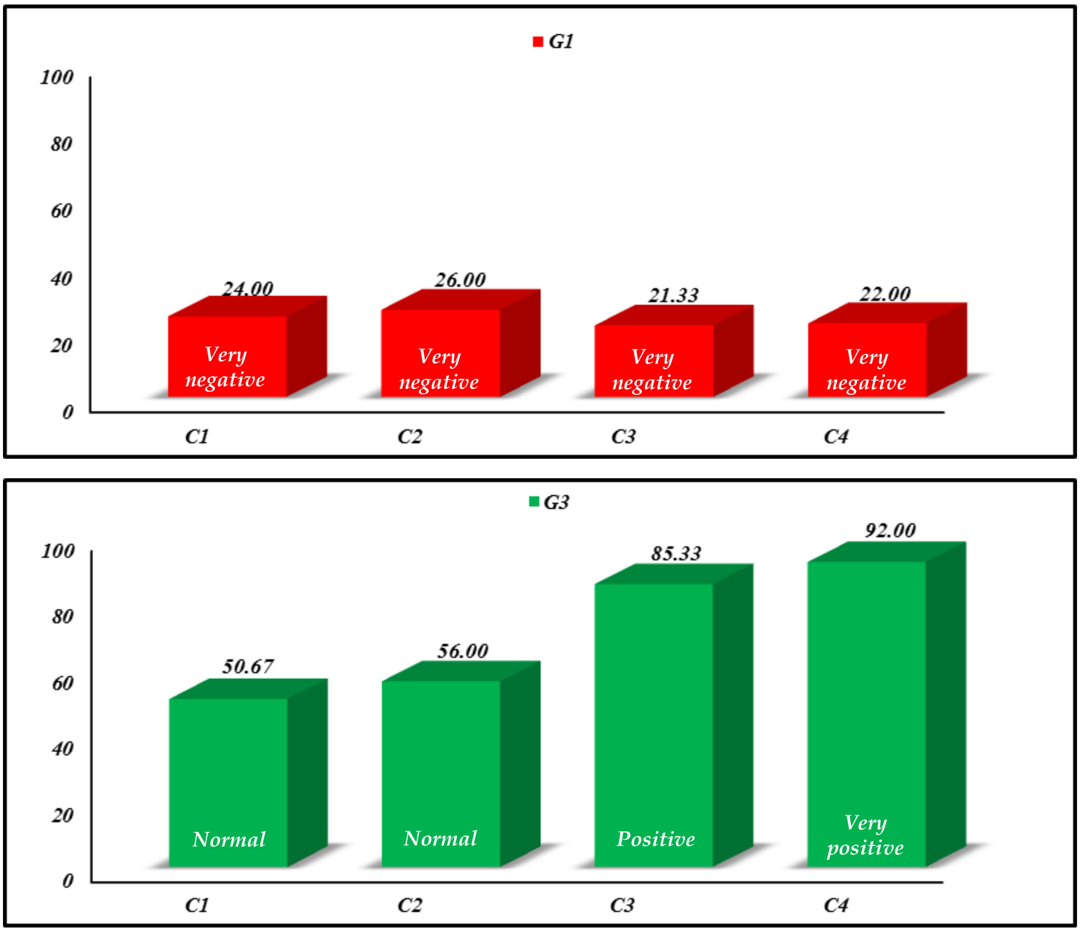

Figure 5.11: Values of SIA of each criterion for groups G1 and G3.

Third, the most divergent criteria between the stakeholder groups, which could imply potential causes of conflicts, were identified. Figure 5.12, which is based on Table 5.12, shows that the stakeholder groups converge for criteria C1 (volume of fishing) and C2 (quantity of tourists) and diverge for criteria C3 (GDP per capita) and C4 (percentage of unemployment). The convergent criteria can be considered as strengths and the divergent criteria as threats in a possible environmental conflict. The criterion with the greatest divergence is related to unemployment, followed by GDP per capita. Therefore, these issues should be taken into account when implementing measures to prevent environmental conflicts on the hydrocarbon exploration project.

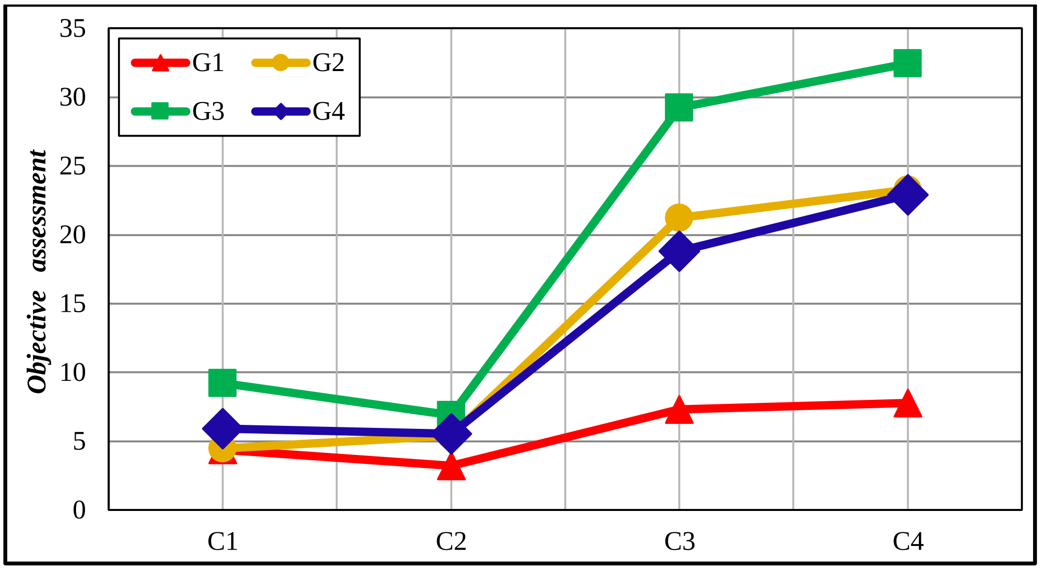

Figure 5.12: Objective assessment for each group.

5.4.2.2 Analysis of diverging criteria

The hydrocarbon exploration project in the Gulf of Valencia consists of the application of ultrasound technology, in order to determine the existence of hydrocarbon deposits in the marine subsoil (Environmental Resources Management Iberia, 2012). The company presented environmental impact assessment (EIA) to Spain government in 2012, but at the present (2015) this project is paused due to the fact that a part of the population of Valencia city manifests opposition to the implementation of the project. In order to propose some measures to prevent environmental conflicts on the project, the context of the divergent criteria is analysed.

a) Percentage of unemployment

The unemployment is a social problem in Spain, which increased since year 2009, for example in Valencia in 2009 was 20.76%, and in 2013 was 28.05% (INE-España, 2014). This is due to the fact that the economic crisis in Europa and particularly in Spain impacts on the employment.

The group G3 *(those citizens in favour)* believe that the project will generate direct and indirect employment, as the hydrocarbon industry demands supplies that would increase the employment in all economic sectors. However, the group G1 (*those directly affected*), in concordance with the groups G2 *(those citizens opposed to the project)* and G4 *(Specialists)*, strongly believe that the project will destroy the employment in sensitive sectors, such as tourism and fishing. Therefore, this fact generates discomfort on a part of the population in Valencia (see Figure 5.13).

Figure 5.13: Opposed citizens to the project.

b) GDP per capita

In the *Comunitat Velenciana*, the GDP per capita has been decreased according to increasing of economic crisis since 2009, for example in 2009 was 20170 euros per year, and in 2013 was 19500 euros per year (INE-España, 2014). This is due to the fact that the employment and the salary have decreased notably.

The group G3 believe that the project will increase the GDP per capita, as there will be investment from the company that will impulse other sectors of the economy. However, for groups G1, G2 and G4, the project will affect to the more important economic sectors of Valencia, which are tourism and fishing. For example a part of group G1, the fishing cooperative of Valencia strongly believes that the project will affect their economic income, considering the context of lack of employment (see Figure 5.14).

Figure 5.14: Fishing cooperative of Valencia.

According to what was analysed above, the following measures could be implemented in order to prevent environmental conflicts on the project:

- As three of four stakeholder groups are not according to the project. This project would not be feasible, due to the fact that it is located within sensitive ecological area. In addition, this project could affect important economic sectors in Valencia City.

- However, if the central government or the company insist on implementing the project, they should demonstrate the benefits of the project to affected population.
- In addition, in order to prevent possible environmental conflict, the central and community governments should listen to the suggestions from the affected population, which are related with the tourism and fishing activities.

5.5. Conclusions

The integrated method applied in this article made possible to integrate SIA and ECA. SIA was conducted by means the GC method, which quantified the qualitative information collected from stakeholder groups. In turn, ECA was performed by means the EW method, which identified the controversial criteria. The results obtained on the hydrocarbon exploration project in the Sea of the Gulf of Valencia, Spain, could help to central government or authorities of the community to make the best decision to manage the use of the Gulf of Valencia.

In addition, the integrated method could be applied in future studies to other types of programs or projects in ocean areas or coastal areas. The number of stakeholder groups and of criteria could be determinate according to each type of project or program and the concrete social situation of the zone of influence.

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CHAPTER VI

CONCLUSIONS

6. General discussion and conclusions

In this section the general discussion and conclusions on this thesis are descripted; as well as, the contributions and limitations of the thesis, and the future research lines are presented.

6.1 Discussion of the thesis

According to objectives of this thesis, a general discussion is presented below:

6.1.1 Discussion on the proposed integrated method

The proposed methodology in this thesis is a combination of the grey clustering method and the entropy-weight method. The grey clustering method was used to quantify the information obtained from stakeholder groups, with which, social impact assessment for each stakeholder group was determined. In turn, the entropy-weight method was used to identify controversial criteria between stakeholder groups, with which, environmental conflict analysis was performed. Consequently, the combination of both methods was able to integrate social impact assessment (SIA) and environmental conflict analysis (ECA).

Some alternative to assess social impact studied in this thesis were classical methods of multi-criteria analysis such as the Delphi method and the AHP method. The grey clustering method would be more convenient than these classical methods of multi-criteria analysis, because, the grey clustering method includes uncertainty within its analysis. This aspect is not present in classical methods of multi-criteria analysis as the Delphi method and the AHP method (Baykasoğlu & Gölcük, 2015).

Other alternative to assess social impact developed in this thesis was the FAHP method, which is based on fuzzy logic theory. The grey clustering method would be more appropriate than the FAHP method, as the grey clustering method considers unclear intention and clear extension for research objects (S. Liu & Lin, 2010). This fact facilitates data collection from stakeholder groups, as the affected population within a determined project is clear about when things were good or bad: before or after project implementation.

The grey clustering method, which is based on grey systems theory, also showed that would be more convenient and accuracy than other methods based on statistical approaches. First, the grey clustering method would be more convenient, as it would have less cost due to the fact that sample size affects the cost during the field work (Wittmer et al., 2006). Second, the grey clustering method would be more accuracy, as shown by studies of Jiangping Qiu and Xisheng Hua on the deformation and leakage data of a certain large scale hydraulic dam (S. Liu & Lin, 2010).

In turn, the entropy-weight method, which is based on Shannon entropy theory, is an approach that considers uncertainty within its analysis. In addition, the concept of entropy is well suited to measuring the relative intensities of contrast criteria (Zeleny, 1996). Therefore, the entropy-weight method is a good option to analyse environmental conflict, as it would help to identify controversial criteria between stakeholder groups involved into a determined environmental conflict. As a result, the entropy-weight method was combined with the clustering method, both under the same philosophy, in order to integrate social impact assessment and environmental conflict analysis.

6.1.2 Discussion on the application to a project in Peru

The first application of proposed method in this thesis was on a mining project, which is located in northern Peru. The mining company is trying to expand its exploitation in the area since 2010 (Knight Piésold, 2010; MINAM, 2011b). This fact has generated a lot of conflicts between effected populations. In this study, three stakeholder groups were identified: urban population, rural population, and specialists. In addition, seven criteria were established: GDP per capita, employment rate, poverty rate, number of inhabitants per doctor (GP), enrolment rate in primary education, number of reported crimes, and access to drinking water rate.

The results showed that for specialists stakeholder group the project would have a normal social impact. However, for the urban stakeholder group the project would have a positive impact, and for the rural stakeholder group would have a negative social impact. This antagonism is due to the fact that the rural population believes that their main economy activities, which are agriculture and livestock, will strongly be affected. While, the urban stakeholder group believes that the project will generate welfare and economic development for urban population.

The main controversial criterion was the access to drinking water rate. The rural population strongly believes that the project will contaminate their water sources, and their economic income will decrease notably. In contrast, the urban population believes that the amount of water available will increase, due to the fact that the mining company will construct water reservoirs. Other minor controversial criteria were poverty rate, GDP per capita, and employment rate.

6.1.3 Discussion on the application to a project in Spain

The second application of proposed method in this thesis was on a hydrocarbon exploration project, which is located in the gulf of Valencia in Spain. The company is planning to explore hydrocarbon since 2012 (Environmental Resources Management Iberia, 2012). This fact has generated environmental conflicts between effected populations in Valencia City. In this study, four stakeholder groups were identified: those directly affected, those citizens opposed to the project, those citizens in favour and the specialists. In addition, four criteria were established: volume of fishing, quantity of tourists, GDP per capita, and percentage of unemployment.

The results showed that for specialists stakeholder group the project would have a negative social impact, for those citizens opposed to the project stakeholder group would have a negative social impact. In addition, for those directly affected stakeholder group the project would have a very negative social impact, and for those citizens in favour stakeholder group would have a positive social impact. This antagonism is due to the fact that those directly affected believe that their main economy activities, which are tourism and fishing, will strongly be affected by the project. While, those citizens in favour believe that the project will generate a lot of direct and indirect employment.

The main controversial criterion was the percentage of unemployment. Those citizens in favour strongly believe that the project will generate a lot of direct and indirect employment, and consequently, it will generate economic development. In contrast, those directly affected believe that the project will destroy the employment existing. Other minor controversial criterion was GDP per capita.

6.1.4 Discussion on the potential to be applied in other contexts

As was argued above, the proposed integrated method in this thesis showed much flexibility, as it was able to be applied to two different contexts, as are the Peruvian context and the Spanish context. This fact would demonstrate that the integrated method could be applied to other contexts without major inconvenient.

In addition, the proposed method is able to adapt to each type of project, in other words, the criteria number and the stakeholder groups number are defined according to particularities of project and the decision of project coordinators.

The proposed method is also able to be applied to different alternatives of a determined project; this is, if a company or an organization, which proposes a project, presents alternatives within of EIA, then the integrated method can be applied for each alternative.

As additional information, the integrated method could also be applied to assess the impact on other environmental factors, which have high level of uncertainty or subjectivity, as for example the impact assessment on the landscape.

6.2 Conclusions of the thesis

1. Social impact assessment and environmental conflict analysis were integrated by combination of the grey clustering method and the entropy-weight method.

2. The proposed integrated method in this thesis showed to be effective and flexible during its application on the mining project in northern Peru.
3. The proposed integrated method in this thesis showed to be effective and flexible during its application on the hydrocarbon exploration project in the gulf of Valencia in Spain.
4. The proposed integrated method showed a great potential to be applied to other contexts and other types of programs or projects.

6.3 Contributions and limitations of the thesis

The main contributions of this thesis may be summarized as follows:

- Social impact assessment and environmental conflict analysis are integrated for first time using the grey clustering method and the entropy-weight method; both approaches consider uncertainty within their analysis.
- A new methodology to assess social impact and analyse environmental conflict on hydrocarbon project is proposed in this thesis.
- This thesis provides a new methodology for social impact assessment and environmental conflict analysis of mining projects.
- This thesis provides a methodological alternative for social impact assessment and environmental conflict analysis, which could be applied to other contexts and other types of programs and projects.

The main limitations of this thesis may be summarized as follows:

- The grey systems and Shannon entropy are not approaches sufficiently diffused in comparison with other approaches based on fuzzy logic or statistics model.

- As the proposed method is a new approach, it needs to be applied to other project, in order to test its effectiveness.
- The calculations during the application of proposed method are a little tedious; this fact could change implementing a computer system.

6.4 Future research lines

The future research lines generate from results of this thesis could be summarized as follows:

- To apply the proposed method for social impact assessment and environmental conflict analysis to other contexts and other projects and programs. Such as water resources management, industrial projects, public construction projects, etc. As well as be used to measure the social impact of public policies or governmental programs.
- To apply the proposed method to assess the impact of other environmental factors, in which there is high level of uncertainty or subjectivity, such as the assessment of impact on landscape.
- To develop informatics systems to simplify the procedure during the application of proposed method.

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Annexes

Annexe 1: Questionnaire used in paper 1

Please, according to information sent to evaluate the criteria and the alternatives for SIA, perform your evaluation using the following comparison table:

Scale	*Numerical rating*	*Reciprocal*
Extremely recommended	*9*	*1/9*
Very strong to extremely	*8*	*1/8*
Very strongly preferred	*7*	*1/7*
Strongly to very strongly	*6*	*1/6*
Strongly preferred	*5*	*1/5*
Moderately to strongly	*4*	*1/4*
Moderately preferred	*3*	*1/3*
Equally to moderately	*2*	*1/2*
Equally preferred	*1*	*1*

The criteria and the alternatives for SIA are:

Criterion
C1: Quantification
C2: Robustness
C3: Standardization

Alternative
A1: The Delphi method
A2: The AHP method
A3: The FAHP method
A4: The grey clustering method

Put your score, first between criteria, and then the comparison of the alternatives for each criterion.

	Score
C1-C2	
C1-C3	
C2-C3	

	C1	***C2***	***C3***
A1-A2			
A1-A3			
A1-A4			
A2-A3			
A2-A4			
A3-A4			

Annexe 2: Questionnaire used in paper 2

Indicaciones:

Con fines de investigación (Tesis), se está desarrollando una valoración del impacto social del proyecto de exploración de reservas de hidrocarburos en el mar del Golfo de Valencia, la empresa ejecutora del proyecto usará la técnica de ultrasonido para determinar los depósitos de hidrocarburos para su posible explotación en el futuro. De manera objetiva se solicita marcar la opción que considere adecuada, de acuerdo a la escala mostrada en la tabla, agregando sus comentarios correspondientes.

Criterios de Evaluación	Impacto Muy Negativo	Impacto Negativo	Impacto Normal	Impacto Positivo	Impacto Muy Positivo	Comentario
¿Con el proyecto, el volumen de pesca?	*Disminuye notablemente*	*Disminuye*	*Se mantiene*	*Aumenta*	*Aumenta notablemente*	
¿Con el proyecto, la cantidad de turistas?	*Disminuye notablemente*	*Disminuye*	*Se mantiene*	*Aumenta*	*Aumenta notablemente*	
¿Con el proyecto, el PIB per cápita?	*Disminuye notablemente*	*Disminuye*	*Se mantiene*	*Aumenta*	*Aumenta notablemente*	
¿Con el proyecto, la tasa de paro?	*Aumenta notablemente*	*Aumenta*	*Se mantiene*	*Disminuye*	*Disminuye notablemente*	

Gracias por su colaboración.

Annexe 3: Questionnaire used in paper 3

Indicaciones:

Con fines de investigación (Tesis), se está desarrollando una valoración del impacto social del proyecto minero Conga, ubicado en el departamento de Cajamarca en Perú, la empresa planea expandir su explotación. De manera objetiva se solicita marcar la opción que considere adecuada, de acuerdo a la escala mostrada en la tabla, agregando sus comentarios correspondientes.

Criterios de Evaluación	***Impacto Muy Negativo***	***Impacto Negativo***	***Impacto Normal***	***Impacto Positivo***	***Impacto Muy Positivo***	***Comentario***
¿Con el proyecto, el ingreso económico por persona?	*Disminuye notablemente*	*Disminuye*	*Se mantiene*	*Aumenta*	*Aumenta notablemente*	
¿Con el proyecto, la tasa de empleo?	*Disminuye notablemente*	*Disminuye*	*Se mantiene*	*Aumenta*	*Aumenta notablemente*	
¿Con el proyecto, el porcentaje de pobreza?	*Aumenta notablemente*	*Aumenta*	*Se mantiene*	*Disminuye*	*Disminuye notablemente*	
¿Con el proyecto, el número de habitantes por médico?	*Aumenta notablemente*	*Aumenta*	*Se mantiene*	*Disminuye*	*Disminuye notablemente*	
¿Con el proyecto, la tasa de matrícula en educación primaria?	*Disminuye notablemente*	*Disminuye*	*Se mantiene*	*Aumenta*	*Aumenta notablemente*	
¿Con el proyecto, los incidentes delictivos?	*Aumenta notablemente*	*Aumenta*	*Se mantiene*	*Disminuye*	*Disminuye notablemente*	
¿Con el proyecto, el acceso al agua potable?	*Disminuye notablemente*	*Disminuye*	*Se mantiene*	*Aumenta*	*Aumenta notablemente*	

Gracias por su colaboración.

Annexe 4: Images from stakeholder groups of case study in Peru

G_1: Urban population

G_2: Rural population

G_3: Specialists

Annexe 5: Images from stakeholder groups of case study in Spain

G_1: Those directly affected.

G_2: Those citizens opposed to the project

G_3: Those citizens in favour

G₄: Specialists

Annexe 6: Products derived of the thesis

6.1 Scientific articles

1. **Delgado, Alexi; Romero, I. (2015).** Selection of a method for social impact assessment using AHP. Revista ECIPerú. 12 (1): 84-91.
   OPEN ACCESS.

2. **Delgado, Alexi; Romero, I. (2016).** Environmental conflict analysis using an integrated grey clustering and entropy-weight method: A case study of a mining project in Peru. ***Environmental modelling and software***. 77, 108-121.
   doi: http://dx.doi.org/10.1016/j.envsoft.2015.12.011.
   Editorial: ELSEVIER.

3. **Delgado, Alexi; Romero, I. (2016).** Integrating social impact assessment and environmental conflict analysis on a hydrocarbon exploration project in the gulf of Valencia, Spain. ***Ocean & Coastal Management***. Under review.
   Editorial: ELSEVIER.

6.2 Documents presented to congress

1. **Delgado, Alexi; Romero, I. (2014).** Ponencia: Modelo matemático para la valoración del impacto ambiental social. Encuentro Científico Internacional 2014 de invierno. Lima-Perú. 30 julio – 01 agosto, 2014.

2. **Delgado, Alexi; Romero, I. (2015).** Ponencia: Selección de un método para la evaluación del impacto social usando AHP. Encuentro Científico Internacional 2015 de invierno. Lima-Perú. 30 julio – 01 agosto, 2015.

3. **Delgado, Alexi; Romero, I. (2016).** Poster: Social impact assessment of hydrocarbon exploration project in the gulf of Valencia using grey clustering and Shannon entropy. The International Society for Ecological Modelling Global Conference 2016. Towson University, Baltimore, MD, USA. 08 -12 May, 2016. Abstract accepted.

6.3 Copyright

1. **Delgado, Alexi; Romero, I. (2014).** Copyright: Modelo cuali-cuantivativo para la valoración del impacto ambiental social. Oficina europea de copyright. Cod: DEP635393794353951250.