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Applying Grey Systems and Shannon Entropy to Social Impact Assessment and Environmental Conflict Analysis

Alexi Delgado* **and I. Romero[1]**

**Universidad de Ciencias y Humanidades, Av. Universitaria 5175 – Lima 39 – Peru*
Universidad Nacional de Ingeniería, Av. Túpac Amaru s/n, Rimac, Lima 25, Peru.
*(*Corresponding author)*
Orcid Id: 0000-0003-0470-8535

[1]Research Institute of Water and Environmental Engineering (IIAMA),
Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain.

Abstract

Social impact assessment (SIA) is an important factor to prevent environmental conflicts, in this way, it is very necessary to integrate SIA and environmental conflict analysis (ECA). In this work, we propose to integrate SIA and ECA by means of an integrated method based on grey systems and Shannon entropy. A case study was conducted on a hydrocarbon exploration project located in the Gulf of Valencia, Spain. Three stakeholder groups and four evaluation criteria were established. The results revealed that for group of affected directly population (G1), the project would have very negative social impact; for group of academic population (G2), the project would have negative social impact; and contrary perception was found in the group of retirees (G3), who opined the project would have positive social impact. In addition, it was also noted that the criteria most likely to generate environmental conflict were the percentage of unemployment (C4) and the GDP per capita (C3). The results obtained in this study could help to central and local authorities to make the best decision on the project. The integrated method showed interesting results and could be applied to assess social impacts and to analyse environmental conflicts from other type of projects.

Keywords: Grey systems, Shannon entropy, Social impact assessment, Environmental conflict analysis.

INTRODUCTION

On the one hand, social impact assessment (SIA) is a key factor to prevent environmental conflicts, due to the fact that implantation of investment projects, which exploit natural resources [1]. SIA has been mainly conducted by qualitative methods, as evidenced by studies based on public participation [2], or game theory [3]. In this work, we apply a quantitative method for SIA, the grey clustering method, which is based on grey systems theory. In addition, SIA is characterized by its high level of uncertainty [4]; therefore, SIA should be conducted by a method, which considers the uncertainly. In fact, the grey clustering 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 [5], as evidenced by the studies on a water rights allocation system [6], or the classification of innovation strategic alliances [7]. On the other hand, the grey systems theory, which was established by Julong Deng, focuses on the study of problems with small samples or limited information available [8]. In various practical problems, there are many uncertain systems with small samples or limited information, this fact determines a broad range of applicability of the grey systems; such as, geographical information systems [9], health management [10], optimization [11], or safety management [12].

In addition, environmental conflict analysis (ECA) also is used to prevent conflicts during planning and implementation of projects or programs, as evidenced by the studies on conflicts related to ecological tourism [13], or water management [14], [15]. ECA has been mostly conducted using qualitative methods, as showed by the study on environmental conflict from an infrastructure project [1], which was based on the capability perspective. In this study, we apply a quantitative method for ECA, the entropy-weight method, which is based on the Shannon entropy theory. Shannon proposed the concept of entropy as a measure of uncertainty in information, formulated in terms of probability theory [16]. The concept of entropy is well suited to identify the contrast criteria for decision-making [17]. Subsequent, research on Shannon entropy has contributed to the resolution of problems on different topics such as pollution [18], water quality [19], management [20], or fault detection [21].

In turn, stakeholders are an important dimension for integrated assessment [22], and environmental conflicts are main generated between stakeholder groups within affected population [23], [24]; therefore, first SIA should be conducted for each stakeholder group, and then by ECA, the differences between them can be determined, in order to prevent possible environmental conflicts [1]. This fact makes that SIA and ECA should be integrated. A good option to integrate SIA and ECA is the grey clustering method and the entropy-weight method;

as the grey clustering method assesses social impact by quantifying of information from stakeholder groups, and the entropy-weight method identifies criteria, for which, there is the most divergence between stakeholder groups within of project under scrutiny.

Therefore, in order to apply the integrated method, we conducted SIA and ECA on a hydrocarbon exploration project in the Gulf of Valencia, Spain. This project consists of the application of ultrasound technology, in order to determine the existence of hydrocarbon deposits in the marine subsoil [25]. Consequently, the specific objectives of this article are to:

1. Apply the integrated method to the concrete context of the hydrocarbon exploration project in the Gulf of Valencia, Spain.
2. Analyse the potential of the integrated method.

In this work, Section 2 provides details of the methodology to integrate SIA and ECA. In Section 3, the case study is described, followed by the results and discussion in Section 4. Conclusions are provided in Section 5.

METHODOLOGY

In this section the grey clustering method, the entropy-weight method, and the integrated method for SIA and ECA, are described.

A. The grey clustering method

The grey clustering method was developed to classify objects of observation into definable classes, and can be performed by means grey incidence matrices or whitenization weight functions. In this work, we apply the center-point triangular whitenization weight functions (CTWF), as typically people tend to be more certain about the center-points of grey classes in comparison with other points of the grey class; therefore, the conclusions based on this cognitive certainty could be more scientific and reliable [5].

The CTWF method can be described as follows: 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 ,…, m; j=1, 2, …, n); then, the steps of the CTWF method can be developed as follows [5], [7], [26]:

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, …, 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 1. For the kth grey class, k=1, 2,…, s, of the jth criterion, j=1, 2,…, n, for an observed value x_{ij}, the CTWF values are calculated by Eq. (1).

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

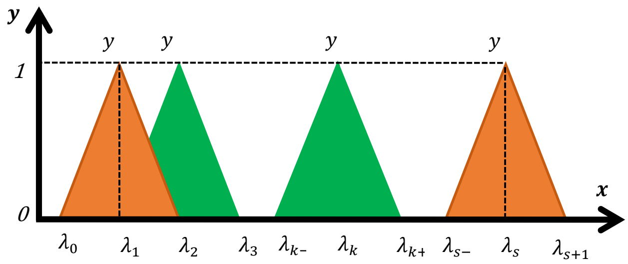

Figure 1: CTWF [5]

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, 2,…, s, is calculated by Eq. (2).

$$\sigma_i^k = \sum_{j=1}^{n} f_j^k(x_{ij}).\eta_j \tag{2}$$

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.

B. The entropy-weight method

The entropy-weight method can be developed as follows: first; assume that there are m objects for evaluation and n evaluation criteria, which form the 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 [26]–[28]:

Step 1: The decision matrix $Z = \{z_{ij};\ i = 1, 2, \ldots, m; j = 1, 2, \ldots, n\}$ is normalized for each criterion C_j (j=1, 2,..., n). The normalized values P_{ij} are calculated by Eq. (3).

$$P_{ij} = \frac{z_{ij}}{\sum_{i=1}^{m} z_{ij}} \tag{3}$$

Step 2: The entropy H_j of each criterion C_j is calculated by Eq. (4).

$$H_j = -k \sum_{i=1}^{m} P_{ij} \, ln(P_{ij}) \quad (4)$$

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

Step 3: The degree of divergence div_j of each criterion C_j is calculated by Eq. (5).

$$div_j = 1 - H_j \quad (5)$$

Step 4: The entropy weight w_j of each criterion C_j is calculated by Eq. (6).

$$w_j = \frac{div_j}{\sum_{j=1}^{n} div_j} \quad (6)$$

C. The integrated method

The integrated method for SIA and ECA consists of five steps, of which the three first steps correspond to SIA, and the two final steps correspond to ECA, as shown in Figure 2.

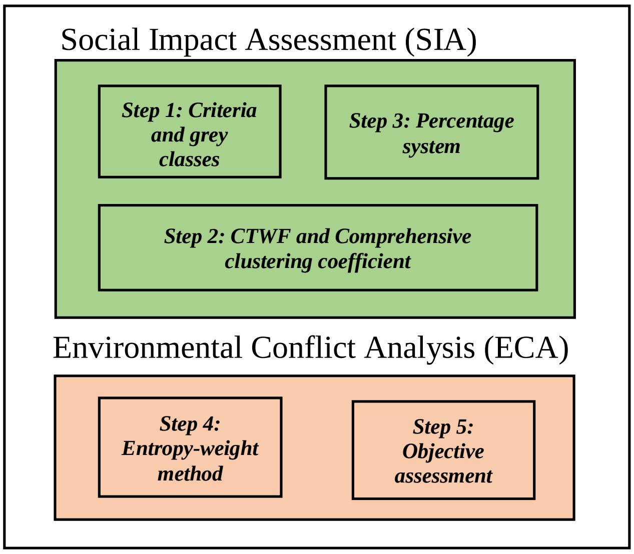

Figure 2: Schema of the integrated method.

The integrated method can be described by means of the following sets [26]:

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 object or stakeholder group are obtained using Eq. (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 Eq. (2).

Step 3: Percentage system

SIA finishes with a percentage system [26], [29], defined by the values α_1, α_2, α_3,…, and α_s, where α_s=100, α_1=100/s, $\alpha_2=\alpha_1+\alpha_1$, $\alpha_3=\alpha_1+\alpha_2$, …, and $\alpha_{s-1}=\alpha_1+\alpha_{s-2}$; s is the number of grey classes defined. The results for each stakeholder group are given by Eq. (7).

$$z_j^i = \sum_{k=1}^{s} f_j^k(x_{ij}).\alpha_k \quad (7)$$

where $f_j^k(x_{ij})$ is 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 the matrix determined by Eq. (8).

$$Z = z_j^i = \{z_{ij}, i = 1, 2, \dots, m; j = 1, 2, \dots, n\} \quad (8)$$

Step 4: Entropy-weight method

ECA is carried out by applying the entropy-weight method. First, using Eq. (3). The normalized values P_{ij} of the matrix $Z = z_j^i = \{z_{ij}, i = 1, 2, \dots, m; j = 1, 2, \dots, n\}$ are calculated. Then, H_j, div_j and w_j are determined using Eqs. (4)-(6).

Step 5: Objective assessment

The final step of ECA involves calculating the objective assessment [20], [26] of each stakeholder group i, i=1, 2,…, m, for each criterion C_j (j=1, 2,..., n). The objective assessment value is defined by Eq. (9).

$$Q_{ij} = w_j z_{ij} \quad (9)$$

where w_j is the entropy weight for each criterion C_j and z_{ij} is the result of SIA for each stakeholder group.

CASE STUDY

The integrated method was applied for SIA and ECA on a hydrocarbon project located in the Sea of the Gulf of Valencia in Spain, as shown in Figure 3. The project proposes to conduct the exploration by means of a campaign of 3D seismic acquisition in zones B, G, AM-1 and AM-2 [25]. Ultrasound technology was proposed to be used to determine the existence of hydrocarbon deposits in the marine subsoil. This study was conducted on the city of Valencia, located into the influence area of the project.

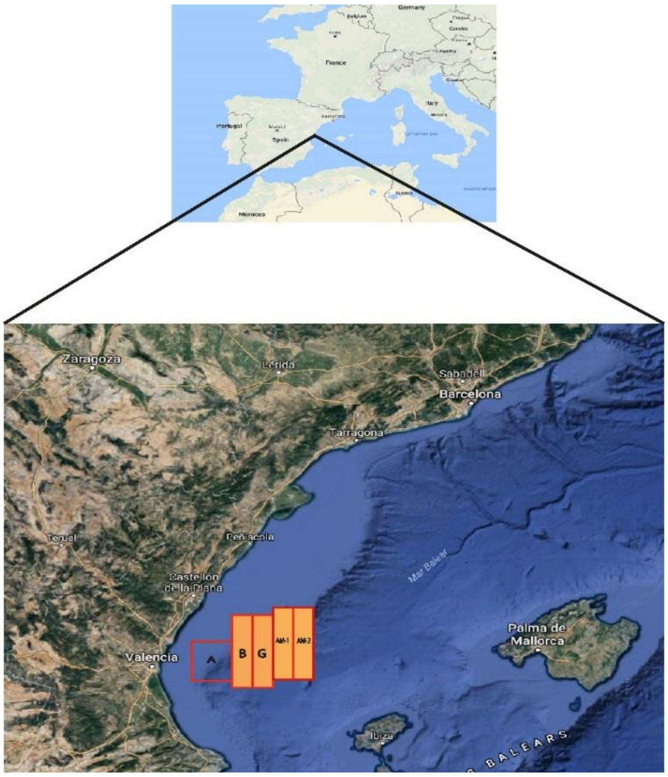

Figure 3: Hydrocarbon project location [25]

A. Stakeholder Groups

During the field work, we identified three different stakeholder groups (k=3), the composition of these groups was determined according to similarities found during the overall assessment on the hydrocarbon exploration project [26]. 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 [30]. The stakeholder groups are presented in Table 1:

Table 1: Stakeholder groups in the case study

Stakeholder group	Description
G1: affected directly population	It was composed of those members of the population who are directly linked with the impacts of the project, consisting of people undertaking productive activities related to fishing or tourism (see Figure 4a). This group was made up of thirty interviewees.
G2: Academic population	It was composed of students and teachers with no links to productive activities related to fishing or tourism (see Figure 4b). This group was made up of thirty interviewees.
G3: Retirees	It was composed of retirees (see Figure 4c). This group was made up of fifteen interviewees.

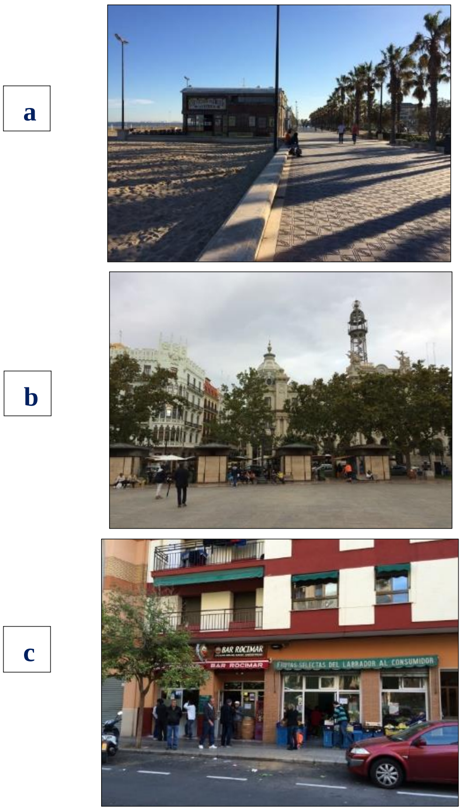

Figure 4: Stakeholder groups.

B. Calculations using the integrated method

The calculations for the case study, based on the integrated 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. The social criteria are directly linked to the economic criteria, due to the fact that social conflicts in Spain are related to the economic crisis facing the country [31]. Four criteria (n=4) were identified as shown in Table 2.

Table 2: Criteria in the case study

Criterion	Name
C1	Volume of fishing
C2	Quantity of tourists
C3	GDP per capita
C4	Percentage of unemployment

b. Grey classes

Five grey classes (s = 5) for the case study were established according to the scale of Likert [32], and by the consultation with experts, in order to satisfy the need to reflect the characteristics of the specific region as accurately as possible [5]. All the criteria had the same weight ($\eta_j = 0.250$), as they are social criteria [30]. The grey classes established for each criterion are shown in Table 3.

Table 3: Grey classes for each criterion in the case study

Criterion	Grey classes				
	Very Negative	**Negative**	**Normal**	**Positive**	**Very Positive**
C1	$0\leq x_1^1 < 2$	$2\leq x_1^2 < 4$	$4\leq x_1^3 < 6$	$6\leq x_1^4 < 8$	$8\leq x_1^5 \leq 10$
C2	$0\leq x_1^1 < 2$	$2\leq x_1^2 < 4$	$4\leq x_1^3 < 6$	$6\leq x_1^4 < 8$	$8\leq x_1^5 \leq 10$
C3	$0\leq x_1^1 < 2$	$2\leq x_1^2 < 4$	$4\leq x_1^3 < 6$	$6\leq x_1^4 < 8$	$8\leq x_1^5 \leq 10$
C4	$0\leq x_1^1 < 2$	$2\leq x_1^2 < 4$	$4\leq x_1^3 < 6$	$6\leq x_1^4 < 8$	$8\leq x_1^5 \leq 10$

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 "extra negative" and "extra positive", respectively; with their center-points λ_0 and λ_6. Therefore, the new sequence of center-points was λ_0, λ_1, λ_2, λ_3, and λ_6, as shown in Table 4 and Figure 5.

Table 4: Center-points of the extended grey classes

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	0	1	3	5	7	9	10
C2	0	1	3	5	7	9	10
C3	0	1	3	5	7	9	10
C4	0	1	3	5	7	9	10

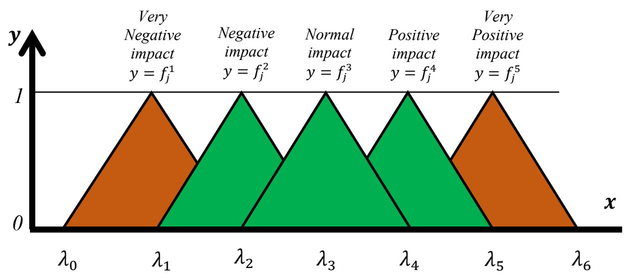

Figure 5: CTWF for the case study

As illustration, for the first criterion C1 (j=1) shown in the first row of Table 4, we have the center-points: $\lambda_0=0$, $\lambda_1=1$, $\lambda_2=3$, $\lambda_3=5$, $\lambda_4=7$, $\lambda_5=9$, and $\lambda_6=10$. The values were substituted into Eq. (1), to obtain the CTWF of the five grey classes. The results for the first criterion C1 are shown in Eqs. (10)-(14):

$$f_1^1(x) = \begin{cases} 0, & x \notin [0\,,3] \\ \dfrac{x-0}{1}, & x \in [0\,,1] \\ \dfrac{2-x}{2}, & x \in [1\,,3] \end{cases} \tag{10}$$

$$f_1^2(x) = \begin{cases} 0, & x \notin [1\,,5] \\ \dfrac{x-1}{2}, & x \in [1\,,3] \\ \dfrac{5-x}{2}, & x \in [3\,,5] \end{cases} \tag{11}$$

$$f_1^3(x) = \begin{cases} 0, & x \notin [3\,,7] \\ \dfrac{x-3}{2}, & x \in [3\,,5] \\ \dfrac{7-x}{2}, & x \in [5\,,7] \end{cases} \tag{12}$$

$$f_1^4(x) = \begin{cases} 0, & x \notin [5\,,9] \\ \dfrac{x-5}{2}, & x \in [5\,,7] \\ \dfrac{9-x}{2}, & x \in [7\,,9] \end{cases} \tag{13}$$

$$f_1^5(x) = \begin{cases} 0, & x \notin [7\,,10] \\ \dfrac{x-7}{2}, & x \in [7\,,9] \\ \dfrac{10-x}{1}, & x \in [9\,,10] \end{cases} \tag{14}$$

The information from stakeholder groups was gathered by means 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.

Table 5: Questions used in the questionnaire for the case study

Question		Grey classes				
		Very Negative	**Negative**	**Normal**	**Positive**	**Very Positive**
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 6 shows the overall results of evaluation from four stakeholder groups (m = 3) for each criterion. These data were aggregated using the arithmetic mean [34].

Table 6: Aggregated values of each criterion for groups G1, G2, and G3

Group	C1	C2	C3	C4
G1	1.20	1.30	1.07	4.90
G2	1.23	2.20	3.10	2.70
G3	2.53	2.80	4.27	1.40

Then, for group G1, the values of CTWF were calculated using Eqs. (10)-(14). Subsequently, the comprehensive clustering coefficient (σ_i^k) was calculated for each stakeholder group using Eq. (2). The values of CTWF and σ_i^k obtained for group G1 (m=1) are shown in Table 7.

Table 7: Values of CTWF and $\boldsymbol{\sigma_i^k}$ for group G1

$f_j^k(x)$	C1	C2	C3	C4	σ_i^k
$f_j^0(x)$	0.8000	0.7000	0.9333	0.9000	0.8000
$f_j^1(x)$	0.2000	0.3000	0.0667	0.1000	0.2000
$f_j^2(x)$	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 [35] defined by the values α_1, α_2, α_3, α_4, and α_5; where α_5=100, α_1=100/5=20, $\alpha_2=\alpha_1+\alpha_1$=40, $\alpha_3=\alpha_1+\alpha_2$=60, and $\alpha_4=\alpha_1+\alpha_3$=80; according to five grey classes established, as shown in Table 8. Then, SIA for group G1 was calculated using Eq. (7). The results are presented in Table 9.

Table 8: The percentage system 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 9: Results of SIA for group G1

Impact	α_k	C1	C2	C3	C4	Total
Very negative	20	16.00	14.00	18.67	18.00	16.67
Negative	40	8.00	12.00	2.67	4.00	6.67
Normal	60	0.00	0.00	0.00	0.00	0.00
Positive	80	0.00	0.00	0.00	0.00	0.00
Very positive	100	0.00	0.00	0.00	0.00	0.00
	SIA	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 G2 and G3 were obtained using the same procedure as for group G1. The results for all stakeholder groups are presented in Table 10.

Table 10: Results of SIA for groups G1, G2, and G3

Group	C1	C2	C3	C4	Total	Impact
G1	24.00	26.00	21.33	22.00	23.33	Very negative
G2	24.67	44.00	62.00	66.00	49.17	Negative
G3	50.67	56.00	85.33	92.00	71.00	Positive

Step 4: Entropy-weight method

ECA for the case study was carried out by applying the entropy-weight method. First, the criteria values shown in Table 10 were normalized using Eq. (3). The normalized values are shown in Table 11. Then, H_j, div_j, and w_j were calculated using Eqs. (4)-(6). The results are shown in Table 12.

Table 11: Normalized results of SIA for groups G1, G2, G3 and G4

Group	C1	C2	C3	C4
G1	0.24	0.21	0.13	0.12
G2	0.25	0.35	0.37	0.37
G3	0.51	0.44	0.51	0.51

Table 12: Values of H_j, div_j and w_j for each criterion

	C1	C2	C3	C4
H_j	0.94	0.96	0.89	0.88
div_j	0.06	0.04	0.11	0.12
w_j	0.18	0.12	0.34	0.36

Step 5: Objective assessment

ECA for the case study was completed by calculating objective assessment of each stakeholder group i, i=1, 2, 3; for each criterion C_j (j=1, 2, 3, 4). The results were obtained using Eq. (9), as shown in Table 13.

Table 13: Objective assessment scores for each group

Group	C1	C2	C3	C4
G1	4.33	3.20	7.25	7.85
G2	4.45	5.42	21.06	23.55
G3	9.14	6.90	28.98	32.83

RESULTS AND DISCUSSION

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

A. The case study

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

First, From Figure 6 (based on Table 10), we can see stakeholder group G2 opined that the project would have negative social impact. However, the major tension among stakeholder groups was identified, Figure 6 shows a strong antagonism between groups G1 (affected directly population) and G3 (retirees). The results indicate that G1 and G3, presented contradictory views on the project, these differences suggest potential conflicts between G1 and G3 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 G1 and G3, which points to our second important finding.

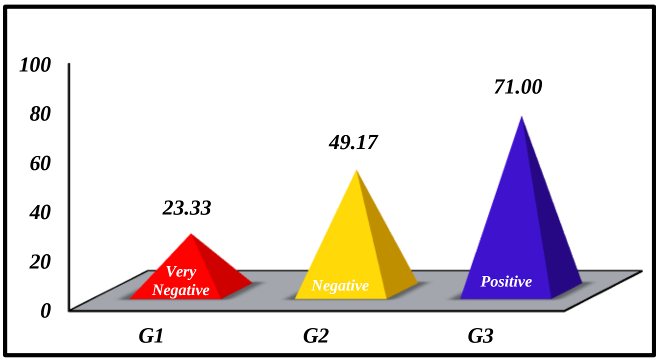

Figure 6: Values of SIA in each group

Second, Figure 7 based on Table 10 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.

Third, the most divergent criteria between the stakeholder groups, which could imply potential causes of conflicts, were identified. Figure 8, which is based on Table 13, 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).

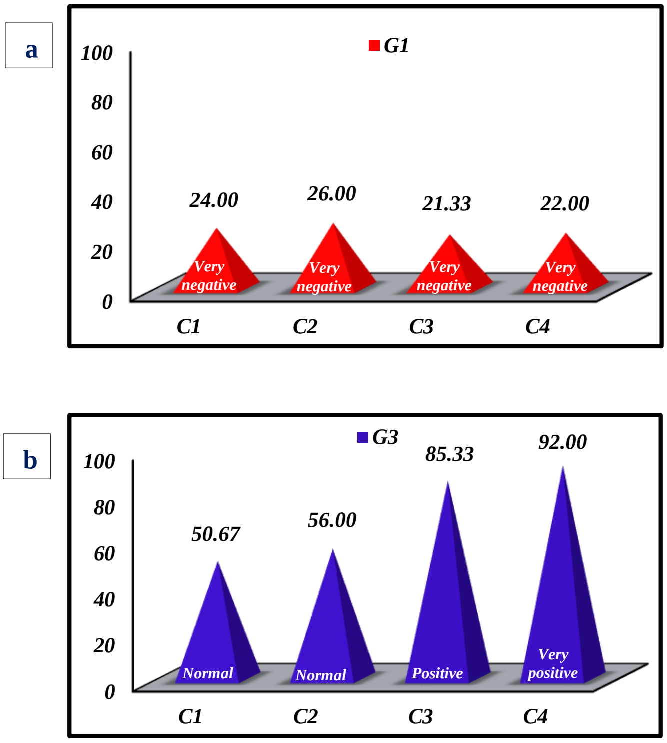

Figure 7: Values of SIA of groups G1 and G3

In addition, 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.

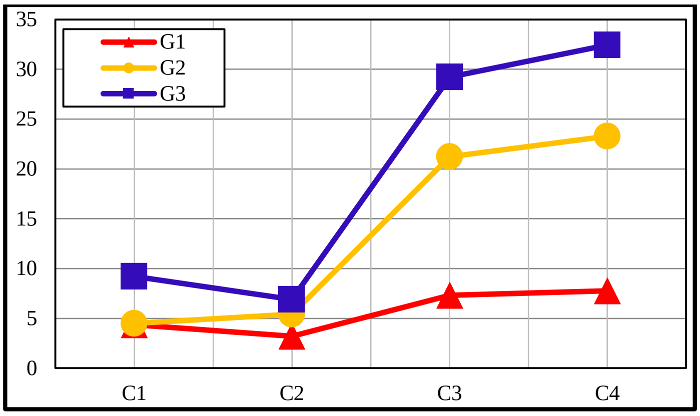

Figure 8: Objective assessment for each group

The divergent criteria are analysed below:

a. Percentage of unemployment (C4)

The group G3 (retirees) 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 (affected directly population), in concordance with the groups G2 (academic population), 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, as unemployment is a social problem in Spain, which increased since year 2009, due to the fact that the economic crisis in Europe and particularly in Spain impacts on the unemployment; for example, in Valencia in 2009 was 20.76%, and in 2013 was 28.05% [32].

b. GDP per capita (C3)

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 and G2 (see Figure 9), 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. This fact could be understudied, as 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 [32]. This is due to the fact that the employment and the salary have decreased notably.

Figure 9: Stakeholder groups who were opposed of the project

B. The potential of the integrated method

On the one hand, SIA is a topic with high level of uncertainty; therefore, it should be analysed by methods, which consider the uncertainty within its analysis. Some classical approaches of multi-criteria analysis, such as Delphi [36], [37] or analytic hierarchy process (AHP) [38], [39], do not consider the uncertainty within their analysis, due to the fact that the importance degrees of criteria and performance scores of alternatives are assumed to be known precisely [40]. On the other hand, some options to model the uncertainly can be fuzzy logic approaches [41], probabilistic approaches [42] or grey systems approaches [5].

In turn, Approaches based on fuzzy logic, such as fuzzy analytic hierarchy process (FAHP) [41], [43], emphasize the investigation of problems with cognitive uncertainty, which 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, which the research objects possess the characteristic of unclear intention and clear extension [5]. SIA has clear extension of the criteria on a study determined; 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 of a determined project could be clear about when things were good or bad: before or after project implementation [26].

In addition, in statistical approaches the concept of large samples represents the degree of tolerance to incompleteness [5], and considering that one of the criteria for evaluating methods can be the cost [4], 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 [5].

Consequently, it could be argued that the grey clustering 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 grey clustering method could be more effective and would have a lower cost than other statistical approaches during its application.

Moreover, ECA is a social topic, which also has high level of uncertainty. ECA could be conducted by classical multi-criteria methods [4], or by statistical approaches [5]. However, classical multi-criteria methods do not consider the uncertainty within their analysis [40]. In addition, statistical approaches would have high cost during the field work [4]. Therefore, ECA could be carried out by means the entropy-weight method based on Shannon entropy, which is a method that also considers the uncertainty within its analysis [17].

CONCLUSIONS

The integrated method applied in this study made possible to integrate SIA and ECA. SIA was conducted by means the grey clustering method, which quantified the qualitative information collected from stakeholder groups, and ECA was performed by means the entropy-weight method, which identified the controversial criteria. The results obtained on the hydrocarbon exploration project in the Gulf of Valencia, Spain, could help to central government or local authorities to make the best decision about the project.

The main advantages of the integrated method could be summarized as follows: the integrated method would be more effective than other classical multi-criteria methods, as it considers uncertainty within its analysis; would be more appropriate than other approaches based on fuzzy logic, as it considers clear extension of criteria within its analysis; and would have a lower cost than other statistical approaches during its application.

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; and the calculations are still tedious during the application of the integrated method, this fact could be improved by implementing a computer system.

Finally, the integrated method could be applied, in future studies on social impact assessment or environmental conflict analyses from other types of programs or projects. The number of stakeholder groups and criteria could be determinate according to each type of project or program and the concrete social situation of the influence area.

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