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Effectiveness of environmental impact statement methods: A Colombian case study

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ABSTRACT

The effectiveness of impact assessment (IA) methods has been a neglected topic in procedural effectiveness research, which has placed higher relevance on the quality of Environmental Impact Statements (EISs) and the environment impact assessment (EIA) process in general. This study analysed the effectiveness of methods used in IA in Colombia to demonstrate that they have been used in compliance with the Terms of Reference (ToR) but did not analyse their effectiveness. A total of 131 EIS were analysed using a revised version of the Effectiveness Index for Environmental Impact Assessment Methods (EIM) proposed by Caro and Toro (2016). It is concluded that, even if the environmental authority has accepted the EIS as a requirement for obtaining an environmental license, most of the methods that have been used in these technical documents, obtained a medium or low degree of effectiveness. The parameters regulated for the law have a higher percentage of compliance. The analysis suggests that the guidelines provided for the law, related to the design and implementation of the methods, should be improved to develop an effective EIA.

1. Introduction

Environmental impact assessment (EIA) focusses on the decision-making process regarding environmental impacts that can be generated from projects, works and activities. Considered a technical tool (Pereira et al., 2018), an environmental impact statement (EIS) incorporates methods[1] for the identification, prediction and significance addressing of environmental impacts that should be used in prevention and mitigation proposals included in the enhancement plan (Glasson et al., 2012; Morris and Therivel, 2009; Morrison-Saunders, 2018; Wood, 2003).

EIA effectiveness has become in an emerged field because of the need to improve understanding of the process, generate quality control, and promote its progress (Ross et al., 2006). There are four dimensions that analyse EIA effectiveness: substantive, transactive, normative and procedural effectiveness (Chanchitpricha and Bond, 2013; Pope et al., 2018). According to Cashmore et al. (2004), procedural effectiveness has received more attention. Although studies related to procedural effectiveness have been focussed on the legal framework, good practices of EIA or the quality of EIS (Cashmore et al., 2002; Duarte and Sánchez, 2020; Sadler, 1996), studies of EIA effectiveness tend to focus on the process in general (the decision-making process) and not on the impact assessment (IA) methodologies and methods (Loomis and Dziedzic, 2018; Lyhne et al., 2017).

EIA needs to present reliable results with limited evaluator subjectivity and parameters that support final decisions (Martínez et al., 2019). Impact prediction uses methods of moderate or low technical rigour, however, that enhance the involuntary omission of some IA features; an

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[1] There are authors who use the terms "methodologies" and "methods" indiscriminately in the literature for the identification and evaluation of environmental impacts, however, epistemologically they are different. Elkatawneh (2016) and McGregor and Murnane (2010) describe methodologies as the approach that shapes the body of knowledge of a particular subject of study, in this case IA, which can be qualitative or quantitative, and a method applied to the technical procedures for a particular analysis.

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EIS can therefore lose effectiveness and become a tool of limited range. In Colombia, guidelines called the Terms of Reference (ToR) are established by law, and do not include a general or specific method for project or activity assessment.

EIS methods have been used according to the criteria of the project proponent (Toro et al., 2010), generating moderately reliable results, because the IA has been developed based on compliance with the minimum EIS requirements defined in the ToR (Official Journal of the Colombian Government, 1993; Official Journal of the Colombian Government, 2015). Although official guidance used by the environmental authority to assess EIS recommends developing an effective analysis, the law does not establish methodological guidelines to evaluate the effectiveness of the process (Toro et al., 2010; Vargas et al., 2020).

This paper presents an analysis of the effectiveness of the methods of impact prediction used in Colombia, through the evaluation of weighted parameters related to the characteristics and application of the methods. Below we elaborate a review of EIA effectiveness, a description of IA methods and finally a discussion about the proposed analysis.

2. Effectiveness of the environmental impact assessment

Effectiveness in the EIA process refers to "setting the right targets and meeting them with the right means in the process of implementing a project or a plan with environmental caretaking" (Elling, 2009, p.125). In IA, effectiveness is analysed based on many aspects, such as the purpose of the process, the expectations of stakeholders, the interest of the decision-makers, and policy management (Chanchitpricha and Bond, 2013). However, the intention to verify that EIA produces reliable results that improve the ability to make appropriate decisions regarding impacts of the activities on the ecosystems is not clear (Leu et al., 1996; Sadler, 1998; Wood, 2003).

2.1. Research on EIA effectiveness

To illustrate the variety of studies focussed on EIA effectiveness, Chanchitpricha and Bond (2013) explain the concept of effectiveness based on the categories established by Sadler (1996), who divided effectiveness according to the purpose of the process: substantive, procedural and transactive effectiveness. Substantive effectiveness focuses on achieving objectives and the results of the process (performance); procedural effectiveness refers to the provisions and principles established to develop the EIA (practice), and transactive effectiveness addresses the process in terms of time and cost (proficiency). Baker and McLelland (2003) incorporated a new category into this conceptual framework: normative effectiveness (purpose), defined as the achievement of normative goals which are related to social and individual norms. Bond et al. (2015) also propose two aspects for analysis: knowledge and learning, which refer to the conceptual framework of effectiveness and hence improvement in governance over time; and pluralism, related to the value systems and perspectives on the effectiveness process.

Different topics have been developed, focusing on effectiveness categories: procedural analysis, legal framework and international principles of best practices (Canter and Sadler, 1997; IAIA and IEA-UK, 1999); substantive and transactive outcomes of the EIA process (Cashmore et al., 2004; Theophilou et al., 2010) and the conceptualisation and perspective of EIA effectiveness (Baker and McLelland, 2003; Chanchitpricha and Bond, 2013; Loomis and Dziedzic, 2018; Lyhne et al., 2017; Pope et al., 2018). Research effort has focused on the procedural effectiveness; however as against substantial effectiveness, a less explored topic of study (Cashmore et al., 2004; Lyhne et al., 2017).

2.2. Effectiveness and quality in EIS

Studies of the quality and effectiveness of EISs are part of research into the procedural dimension of EIA effectiveness. The EIS is a representation of the EIA in practice. It allows mechanisms to be proposed to facilitate decision-making and meet the objectives proposed in the EIA, based on quantitative and qualitative analyses (Loomis and Dziedzic, 2018), and it is also the only part of the EIA that is published (Cashmore et al., 2002). Several investigations address the concepts of quality and effectiveness in EISs, however, this topic has not been considered as extensively as the effectiveness of the EIA. Even less relevant has been the Analysis of the methods used in the identification, prediction, and significance determination of impacts. Lawrence (2005) recognises the complexity of the stepwise process of impact assessment (IA) and suggests the creation of an EIA sub-field that establishes good practice in this process.

Some current research is related to significance determination on environmental assessments (Ehrlich and Ross, 2015), and the quality of EISs (Ross et al., 2006; Wende, 2002). Assessment packages have also been designed to review EIS information, such as those developed by Lee et al. (1999), the European Commission (2001), and Glasson et al. (2012). Other authors have designed systems to analyse whether significant impacts are addressed coherently in EISs (Duarte and Sánchez, 2020), proposed methods to reduce sources of uncertainty in significance evaluation (Martínez et al., 2019; Toro et al., 2013) and evaluate the effectiveness of the methods used in predicting impacts (Caro and Toro, 2016).

3. Impact assessment methods

An EIS presents the findings of the EIA focused on individual assessments of environmental components, mitigation proposals, and enhancement plans (Morris and Therivel, 2009). This document involves relevant information from impacts related to projects, civil works, or activities, and is the main tool used in environmental decision-making (Toro et al., 2010). The IA includes scoping, identification, prediction, and evaluation.

The scoping stage presents all the possible impacts of a project, including those that are potentially significant and should be studied in detail and those that are minor (Glasson et al., 2012). The environmental impact identification confirms the scoping hypotheses and establishes the potential impacts, considering the particularities of the project and the time frame. In the prediction of impacts, their dimensions are defined in each environmental component (Anjaneyulu and Manickam, 2011), and finally, the natural resources that will be affected are specified in the significance determination, based on the predictions made in the previous stage and the baseline information (Duarte and Sánchez, 2020).

Many methods have been designed to enable the work of evaluators. The first methods used in EISs were designed for use in specific projects, such as Batelle and Leopold's methods (Dee and Baker, 1973; Leopold et al., 1971). Over time, these were generally adapted to other types of projects, omitting details that could generate subjective results. Bojórquez-Tapia and García (1998) and Therivel and Wood (2018) clarify that the aim of the EIA process is not to eliminate subjectivity, but to establish limits or guidelines aimed at ensuring sustainable development. However, given the impossibility of making objective judgements, it has been shown that fuzzy logic can convert subjective perceptions into qualitative values that can be implemented in the decision-making process authors (Ruíz-López et al., 2012).

Several methods develop a unidirectional analysis of the connection between activities and environmental factors, ignoring complex multidirectional interactions between activities, environmental factors and impacts (Martínez et al., 2019). Despite this, there is a considerable diversity of methods for identifying, predicting, and evaluating environmental impacts. The methods and techniques included in the EIS to assess the significance of IA, can be classified into multiple methodologies with a qualitative approach that are based on the perceptions, attributes, criteria and meanings of IA, and a quantitative approach related to numerical analysis and measurement (McGregor and

Murnane, 2010).

The selection of methods or techniques to analyse environmental impacts is a critical issue in EIS, but it is difficult to define one or several generic methods due to the complexity of the environment and the particularities of the activity. For this reason, it is recommended that methods and techniques be chosen according to the nature of the project and the environmental characteristics of the area of influence, to recognise the advantages and disadvantages of each one. However, this choice is not easy. One of the main weaknesses of IA is the inadequate explanation of the methods used to predict impacts and their difficulty in quantifying the characteristics of the impact (Cashmore et al., 2002). When predicting impacts, any method that is chosen to carry out this task must estimate the possible uncertainties associated with scenarios without a project (Morris and Therivel, 2009). Furthermore, the lack of data and the discontinuities between cause and effect mean that impact prediction is not an exact science (Glasson et al., 2012).

The principle of the selection and implementation of IA methods should be to set limits on subjectivity and reduce uncertainty in the terms proposed (Bojórquez-Tapia and García, 1998; De Jongh, 1988; Martínez et al., 2019; Pereira et al., 2018; Zhang et al., 2018). Also, to reduce the possibility of manipulation of the results due to the flexibility of the methods and the subjective perception of the evaluators (Ehrlich and Ross, 2015). Innovative proceedings are currently being developed to predict impacts (checklists, matrices, and complex mathematical models), however the lack of auditing predictive techniques limits feedback on the effectiveness of methods (Glasson et al., 2012) affecting the procedural effectiveness of the EIA process.

4. Colombian case

To execute works, projects or activities that have any effect on the state of natural resources, the Environmental Authority grants an environmental license based on the EIA. This process is regulated by Colombian law through decrees (from Decree 1753 of 1994 to Decree 1076 of 2015) that set the guidelines with which productive sectors and project proponents must comply. The decrees have been modified since 2002, however, simplifying the requirements for the preparation of an EIS. The Environmental Authority establishes the ToR for the preparation of EIS (presentation of information, baseline, components to evaluate), but it is flexible in the selection and implementation of IA methods (Pereira et al., 2019; Toro et al., 2010; Vargas et al., 2020). If a lack of regulation of IA methods and techniques increases the uncertainty of the results, and the manipulation of data favours the interests of the proponents (Loomis and Dziedzic, 2018; Sadler, 1996), then the EIA would be less effective.

5. Methodology

Several investigations stand out among the studies that address the IA stages and the analysis of EISs. Julien et al. (1992) presented a method to optimise the identification of impacts using past environmental evaluations; Buckley (1991) audited the accuracy of environmental impact predictions in Australia, Duarte and Sánchez (2020) focused on the determination of significance and Cashmore et al. (2002) analysed the variables that affect the quality of EISs in Greece. Even so, the literature shows that the analysis of the methods used in an IA is a less explored topic.

The approach proposed by Caro and Toro (2016) was adopted to estimate the effectiveness of the methods used in the IA. This proposal involves the Effectiveness Index of Methodologies (EIM) based on a series of indicators to analyse the variables that can affect the effectiveness of the methods. This index establishes a relationship between the uncertainty and the effectiveness of the methodology. If the uncertainty of the results is reduced, the methods will have greater effectiveness. In order to determine the effectiveness more precisely, some significant modifications are made to this tool in this analysis.

5.1. Effectiveness index for EIS methods

The EIM estimates the effectiveness of methods based on the calculation of structural and operational values. The values obtained from weighted indicators provides a percentage (%) based on the degree of effectiveness. The EIM expressed in Eq. (1) consists of the structural parameters value (S_{PV}) and operative parameters values (O_{PV}), also two weighing factors (α and β) equivalent to the representation of the structural and operative parameters in the equation and a random uncertainty factor (R_{UF}). S_{PV} and O_{PV} are determined from mathematical expressions, whereas the R_{UF} and all the weighing factors were determined through the application of the Delphi method with a group of experts in Colombia (Caro and Toro, 2016). Information about structural and operative indicators is provided in the Appendix

$$EIM = [(\alpha \times S_{PV} - R_{UF}) + \beta \times O_{PV}] \times 100 \quad (1)$$

S_{PV} refers to the method design (Eq. (2)), and the good practices proposed by Sadler (1996), which were subsequently included in the work of the IAIA (1999) and Pereira et al. (2018). It includes parameters related to impact prediction and the baseline conditions of objectivity (*Ob*), totality (*To*), rigour (*Rg*) and pertinence (*Pt*). Each parameter **is** evaluated based on indicator values. The S_{PV} (α = 0.7) represents 70% of the result due to the difficulty of modifying the IA method once its use has been defined, because one change in its structure becomes extremely complex. Any modification in the method can also be interpreted as a strategy to manipulate the results of the assessment.

$$S_{PV} = \gamma \times Ob + \delta \times To + \varphi \times Rg + \theta \times Pt \quad (2)$$

where:

$\gamma = 0.4$; $\delta = 0.1$; $\varphi = 0.3$; $\theta = 0.2$;

$Rg = UT_S \times SU_T$; UT_S: Use of technical-scientific procedures required by the environmental authority or the features of the project or activity. SU_T: Suitability of techniques used.

O_{PV} is related to the available resources to execute the methods and their optimisation (Eq. (4)), based on efficiency definition (Elling, 2009). It includes three analysis parameters: interdisciplinary (It), expertise (Ex) and participation (Pa). The weighting factor O_{PV} (β = 0.3) indicates that operative parameters represent 30% of the effectiveness, because once an operative flaw is detected in the implementation of the method, decisions for changing can be easily affected.

$$O_{PV} = \rho \times It + \gamma \times Ex + \sigma \times Pa \quad (4)$$

where.

γ = 0.4; ρ = 0.35; σ = 0.25.

$Ex = RECA \times LFE$; RECA: Relationship between specialties or education of evaluators and component analysis. LFE: Approximate educational background of evaluators.

RUF (0.05) represents the uncertainty of the process and the impossibility of having exact results in the IA. Methods therefore cannot be completely effective because an impact cannot be predicted with exactitude given the complexity and dynamics of the environment (Martínez et al., 2019). This relates to the random or exogenous uncertainty in the EIA (Tennøy et al., 2006) or the occurrence of natural variations in the ecosystem that cannot be controlled or dissipated when collecting more information.

5.2. Classification of the EIM

Considering that the terms $(\alpha \times S_{PV} - R_{FU})$ and $(\beta \times V_{PO})(\beta \times O_{PV})$ obtain values between 0 to 0.65 and 0 to 0.3, respectively, the EIM value will variate between 0% and 95%, as presented in Fig. 1. This means that the effectiveness of a method ranges between a minimum of 0%, where it is not effective, to a maximum of 95%. This work presents a modification of the original range of values proposed in the study by Caro and Toro (2016) because there is no clear difference in the previous

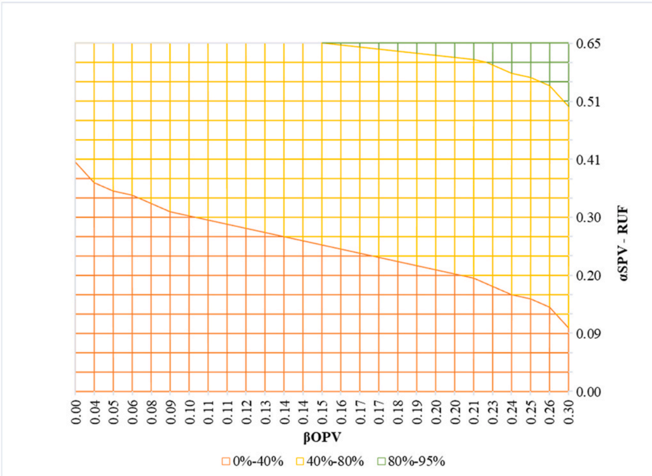

Fig. 1. Relationship between the values of the EIM, $(\alpha S_{PV} - R_{UF})$ and.(βO_{PV})

classification between each type of method and the potential effects in the EIA results. Table 1 shows the proposed value scale, as well as the characteristics of the methods placed in each category. This classification facilitates the identification of the failures that must be corrected to increase the effectiveness of the methods. This proposal takes the recommendations made by IAIA (1999) and Sadler (1998), directed towards the proper development of IA.

Based on this new classification (Figs. 1), 513 possible results were found for the EIM. 42.6% (219) are placed on the interval of low effectiveness, 53.2% (273) of the results represent medium effectiveness, and 4.09% (21) are placed in the high effectiveness interval. Due to the use of non-random variables that represent the interpretation of qualitative variables and become quantitative variables, the results of Shapiro–Wilk test conclude that the data does not come in regular distribution (Fig. 2).

Table 1
Value scale for the interpretation of EIM results.

Effectiveness degree	Range	Description
Low	≤40%	**The method is not effective.** Assessment results are not reliable; the method does not integrate basic elements to properly assess environmental impacts, presenting a low probability of behaving according to the result of the EIS. The enhancement plans will not be accurate because the measurements do not correspond with the impact significance. The residual impacts will be a threat to ecosystems and communities. The method must be restated entirely, or major adjustments made in the variables, indicators and weighing factors that have a low value affecting the qualification of the EIM.
Medium	≥40%–80%	**The method is effective.** Assessment results are reliable because, even if it integrates several basic elements to assess the impact in an accurate manner, it presents moderate probabilities of behaving according to the result of the EIS. The method presents a solid structure but must still improve several aspects, especially those that have low qualifications in the EIM, to generate reliable results.
High	>80%–95%	**The method is effective in the established trust interval (95%).** Assessment methods are reliable, and the impact represents a high probability of behaving according to the final EIS result. However, the application of the enhancement plans must be considered in the context of uncertainties regarding predictive methods and the precautionary principle: "damage to the environment can be irreversible or remediable only at considerable expense and over long periods, and therefore one must not wait for proof of harmful effects before taking action." (Hanson, 2017).

5.3. *Application of the EIM*

The study sample was determined considering the productive sectors that applied for an environmental license in Colombia in the years 2012–2014 (hydrocarbons, mining, energy, civil works[2] and was approved. In this period, 285 EIS were presented applying for an Environmental License. In reviewing the documents, a final sample of 131 studies was selected, meeting the inclusion criteria (46% of the total of EIS presented in those three years). EISs associated with importing or the transportation of chemical substances were not included because they do not require an Environmental License (Fig. 3).

EISs in Colombia are considered public documents with open access and were provided by the National Environmental Licensing Authority (ANLA). These documents have a similar structure due to the regulations established in the methodology for the presentation of environmental studies (Zapata and Londoño, 2010). Typically, information about the team of evaluators and their credentials can be found on the front pages of these documents. Data for analysing structural parameters and participation can be found in the chapters related to the identification and evaluation of impacts; information that precedes the management plans.

6. Results

The review of the EIS shows a strong tendency to use methods with a qualitative approach (Information about qualitative and quantitative methods are provided in the Appendix). The most used methods are the RAM method (Ecopetrol, 2008), the method proposed by Arboleda (2003), the method proposed by Conesa (2010) and its adjusted version. In the oil sector, the use of the RAM method is predominant, probably because it is an adaptation that the oil union made to the Conesa method, to include the probability of occurrence as an evaluation attribute. On the other hand, the method proposed by Conesa (2010) and its adjusted version are used due to their flexibility to include attributes in the impact evaluation according to the characteristics of the project. The use of a mixed methods is highlighted in three EIS. Those methods integrate qualitative elements of the method proposed by Conesa (2010) and the method proposed by Barrantes and Di Mare (2001) and use quantitative and qualitative indicators to establish the current state of resources and their possible impact on the development of the project. The civil works and energy sector frequently uses the method proposed by Arboleda (2003), also known as the EPM method. Most of the few EIS presented by the energy and mining sector carry out impact assessments following the guidelines of the Conesa method and its modified version (Fig. 4).

6.1. *Analysis of structural parameters (αSPv)*

6.1.1. *Objectivity*

This indicator is related to the characteristics of the methods and the possibility of subjective judgments without any limits or guidelines in the established terms (Bojórquez-Tapia and García (1998). The value of objectivity is determined by considering the use of methods that mandatorily include parameters or indicators related to the state of the

[2] The temporality of the sample does not affect the objective of this work, because the application aims to analyse the behaviour and scope of the proposed method, being applicable at any time. From this period to the present (2020), the law has not established official methodologies or methodological guidelines.

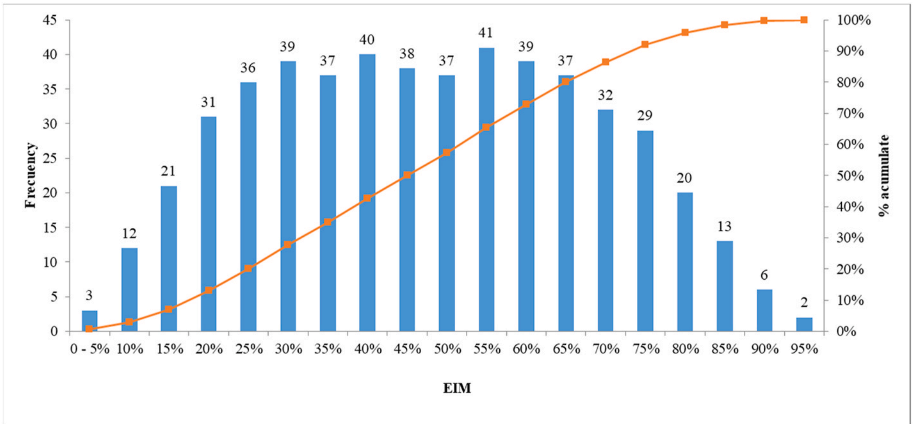

Fig. 2. Distribution of EIM values.

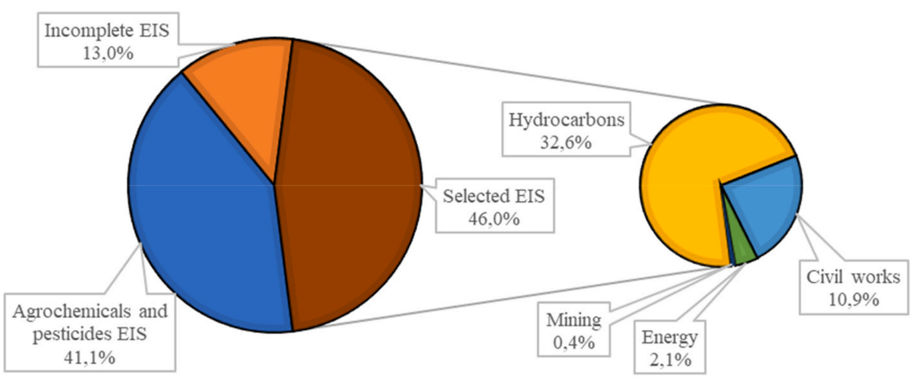

Fig. 3. EIS selected for the application of the EIM.

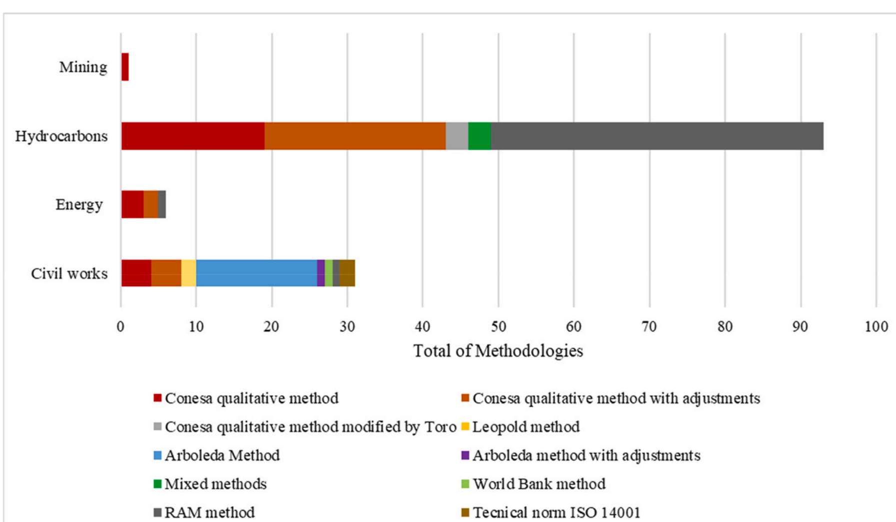

Fig. 4. EIS methods by productive sector.

environment, the project characteristics and low dependency on the evaluators' criteria. An increased number of methods (91.6%) have minimum values (0) in the objectivity qualification because the final evaluation of impact significance is not based on established parameters. This could be related to misleading results, and the rejection of potential impacts. Any method for predicting impacts would be of minimal value in assessing objectivity if the evaluator does not set indicators to demonstrate that the decision is not arbitrary and establish ranges in their value judgement.

The categories to qualify the magnitude of the impact and establish ranges of grading depending on the environmental component are justified; it therefore presents medium values (0.5). 6.11% of the sample uses the RAM method (Ecopetrol, 2008) or the Conesa method modified by Toro et al. (2013). 2.29% of the methods obtained a higher score (1); those that integrated the qualitative and quantitative elements of the method proposed by Conesa (2010) and the methods proposed by

Barrantes and Di Mare (2001). This mixed approach uses indicators related to the state of natural resources and determines environmental damage before and after project execution through a mathematical expression.

6.1.2. Totality

Totality (To) represents the inclusion of all the environmental components and factors that may be affected by the project. An IA would therefore lose its integrity and the characterisation of the possible alterations generated from the development of the project would be distorted. 98.47% of the methods include all the environmental components required in the ToR to develop the IA. The accomplishment of this requirement addresses the request made by the environmental authorities to present an EIS that considers the type of work, project, or activity.

6.1.3. Rigour

Rigour (Rg) evaluates the use of accurate techniques, standardised and replicable, that adjust to the purpose of the EIS. The evaluation of this parameter considers the technique or method generated within a rigorous study process, endorsed by academia, or specialised institutions so that it can be replicated. Due to the requirement of the environmental authority to include replicable procedures in the making of the EIS (Zapata and Londoño, 2010), 99.24% of the methods have high rigour. These results show the correlation between the effectiveness of the methods and the compliance of the ToR established by the authority. When establishing clear guidelines in terms of the design and application of the methods, effectiveness can therefore be guaranteed.

6.1.4. Pertinence

Pertinence (Pt) determines whether a method is accurate, appropriate, or relevant to the accomplishment of the objectives related to the IA. Some methods use a qualitative approach to predict and evaluate the significance of the impact. The impact prediction could generate uncertainties that affect the assessment of the impact significance if is made through the score of attributes, without a theoretical or conceptual point of view (Toro et al., 2013). The technical pertinence of a method would be severely affected if the following attributes are included:

- *Moment (Mo)* qualified by considering the time between the start of the action and the time when the factor begins to be affected.
- *Effect (Ef)* is qualified considering the cause-effect relationship in the impact affecting the environmental factor.
- *Recovery (Rc), Preventability (Pv), Mitigability (Mi) and Compensability (Co)*. These attributes of intentionality or technical viability assess the intentionality of the proponent to implement the Environment Management Plan, but they do not evaluate whether the management measurement is going to be executed, nor the danger or the impact.
- *Probability of occurrence (Po)* is an attribute whose calculation, in scenarios without a project, is extremely difficult considering the stochasticity of the environment and the need for an analysis of a historical series of the frequency of the appearance of an event.

Only one of the analysed methods obtained the highest score for this parameter. This value was obtained because the structure of the method excludes non-recommended attributes and uses attributes representing a significant input to the IA. Of the remaining methods, 32.82% used two of the irrelevant or non-recommended attributes and 58.02% used three or four of these attributes; therefore, the lowest score was assigned for this parameter.

6.2. Analysis of operational parameters (O_{PV})

6.2.1. Interdisciplinarity

Interdisciplinarity represents the incorporation of results from several disciplines with different schemes of conceptual analysis that are compared for final integration (Elio and Termini, 2017; Macleod and Nagatsu, 2018). An interdisciplinarity group that is optimal to assess environmental impacts must therefore include at least six professionals, and each of them must represent a field in the IA. The number of disciplines and professionals involved in the implementation of the prediction method were determined through the application of the Delphi method with a group of experts in Colombia. Of the evaluator groups, 96.18% include more than six professionals or fields of knowledge, 3.05% include five or six specialists and 0.76% include three professionals.

6.2.2. Expertise

This parameter refers to the coherence between the academic education of the professionals constituting the work team and the component being analysed. Each specialist must recognise their own ability to develop a task and its suitability to produce a specialised concept. The fact that it portrays a function for which it was not educated is an uncertainty factor since the judgment produced lacks reliability due to the reputation of the correspondent specialty. In 70% of the evaluator groups, at least 50% of the professionals have complementary education or experience of more than three years in EIS development.

6.2.3. Public participation

Public participation (Pa) represents the inclusion of stakeholders in an IA (Glasson et al., 2012; Therivel and Wood, 2018; Wathern and Wathern, 2009). The purpose of participation is to include public opinion regarding a project, avoid the appearance of distrust and new conflicts between the parties (Tripp and Alley, 2003), and providing higher legitimacy to the results (Wilkins, 2003). 4.58% of the methods include participation from communities in each impact score and possible further management measurements. 95.42% do not consider community opinion, omitting the guidelines of the environmental authority. According to the Ministry of the Environment, Housing and Territorial Development (2010) it is mandatory to inform the community regarding the features of the project and to implement the contributions received during this process in the EIS.

As can be seen in Fig. 5, only one method obtained a high degree of effectiveness (>80%), and a considerable number of methods presented a medium and low degree of effectiveness, 90 and 40, respectively.

The data strongly confirms that methods used in impact assessment in Colombia during the period 2012–2014 are of low effectiveness, and only one of them obtained high levels of effectiveness, due to the implementation of good practices (Cashmore et al., 2002; Sadler, 1996). The highest percentage in the sample refers to methods classified as of medium effectiveness (68.7%) because of the inclusion of elements used to enrich and manage the impact prediction. 30.53% of the methods are of low effectiveness, characterized by flaws either in the statement or in their implementation; consequent results may decrease the importance of the potentially significant impacts and generate loss regarding resources designated for mitigation or prevention.

Methods with a higher degree of effectiveness were used in one EIS of the hydrocarbons sector, integrating elements from the method proposed by Conesa (2010), and the method of Barrantes and Di Mare (2001), as discussed previously. Data obtained in the parameter evaluation revealed that no indicator had minimum values (0), for the following reasons:

- The weighted indicators were related to an impact by an environmental component, reducing the manipulation risk of the method results.
- The techniques and procedures implemented use reference studies and scientific publications and evaluate all environmental components.

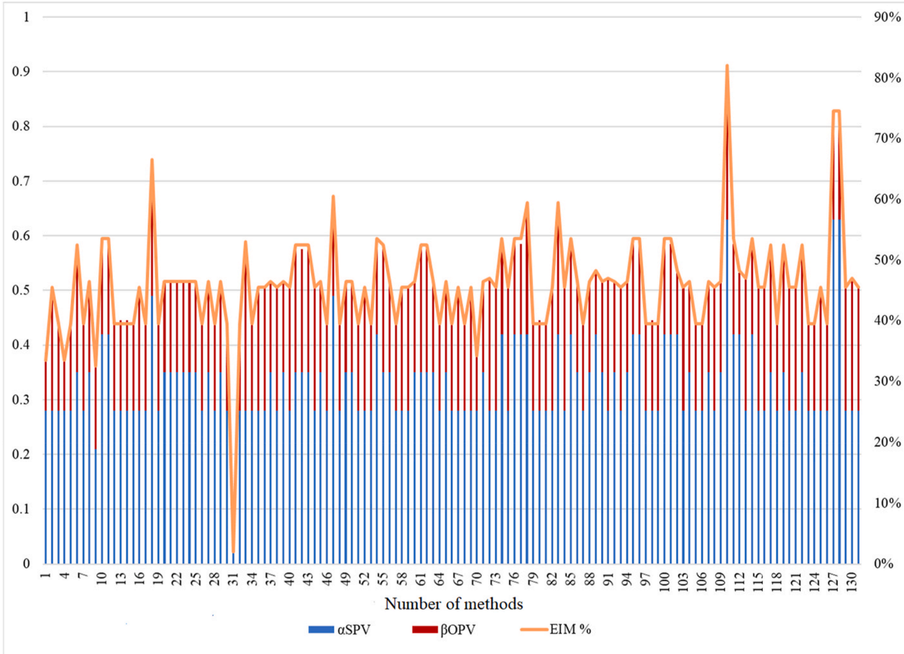

Fig. 5. Ranges of values obtained for αS_{PV} and βO_{PV}.

- The method was implemented by a team of professionals with different specialties, 50% of whom have complementary studies and at least three years of experience.
- The community feedback for the identified impacts is integrated into the IA results.

Methods with a medium degree of effectiveness used some basic elements that enhanced the correct assessment of the impact. The impact thus has a diminished probability of behaving as predicted. These methods can present minimum values (0) in a maximum of two (2) of the indicators related to the αS_{PV} and until one (1) of the indicators related to the βO_{PV} manifests in acceptable results of the EIM; the data thus reflects flaws presented in the statement of the method and its implementation. Even though 68.7% of the methods were qualified as being of medium effectiveness, this does not imply that the EIA process was satisfactory. Flaws in the identification and assessment of the environmental impact could result in an excessive use of resources oriented to minor impacts or irrelevant issues, decreasing the relevance of potentially significant impacts that, when not properly managed, could risk ecosystems and communities (Jalava et al., 2010).

The methods with a low percentage of effectiveness represent 30.53% of the sample and are characterized by the exclusion of elements that provide solidity to the assessment and non-integration of basic elements so as to accurately assess environmental impacts and present low probabilities, which generates results that adjust to a real environmental impact. The data suggests that the methods present minimum values (0) in the assessment of two (2) or three (3) indicators related to the αS_{PV} and one (1) to three (3) indicators of the βO_{PV}. Although some of the medium effectiveness methods can accomplish this rule, the expertise (γEx) attribute makes a difference, having superior values (0.4) compared with the low effectiveness methods (0.0–0.2).

7. Discussion

This article proposes a modification of the categories established in the EIM to assess the effectiveness of methods used in EIS. Although the index was tested in an early stage by Caro and Toro (2016), there was a striking difference in the results due to the value scale for the effectiveness degree proposed in this study. Caro and Toro (2016), presents five categories to evaluate the effectiveness of the method used in EIS (high, medium-high, medium, low and very low). In this study, effectiveness has been classified according to three intervals: low effectiveness, medium effectiveness, and high effectiveness.

An analysis of objectivity revealed that most of the IA methods used in Colombia have a qualitative approach. It is remarkable how irrelevant attributes are integrated into the selected methods to assess the impact, thus represents a disproportional qualification (positive or negative) of the impact and an inefficient assessment with subjective results. The combined use of qualitative and quantitative elements from different methodologies suggests that the evaluators have the tools to justify their final decisions about the prediction, increasing the level of effectiveness. Technically complex methods using a quantitative approach tend to be more consistent (Lawrence, 2005), but integrating a qualitative approach could facilitate community involvement and avoid technical biases.

Based on the assumption that the IA process should involve a multidisciplinary, experienced team and all the stakeholder groups in final decisions (Cashmore et al., 2002), interdisciplinarity, expertise and public participation parameters reveal that most of the methods (70%) have a work team made up of specialists who carry out tasks according to their academic training. The data suggest that 95.42% of the EIS do not include feedback from the community in IA results, however, which is interpreted as one of the main flaws in the EIA system due to the possibility of generating short-term conflicts that would in turn generate new socio-economic impacts that would not have been estimated in the IA. Finally, the data confirms that most of the methods to predict impacts used in impact assessment in Colombia during the period 2012–2014 are low effectiveness.

The evidence points to the possibility that in many cases, the results of low effectiveness methods do not correspond to the probable impacts that could be generated, because of the lack of elements to validate them. Irregular implementation also generates a disorderly and low-reliability process; method does therefore not accomplish the purpose for which it was originally designed and will be a waste of resources for the stakeholders. If the EIS does not involve accurate results, wrong decisions will be made regarding the management of natural resources in the area of influence, and potential impacts may be minimised. Consequent environmental impacts could be irreversible because enhancement plans based on misleading results could generate residual, significant and irreversible impacts. By ignoring the impacts associated with their work, project, or activity, the actors involved loss the opportunity to reduce them and to optimise the associated processes (Duarte and Sánchez, 2020).

We found evidence to suggest that IA in Colombia have significant flaws, specifically in the prediction of impacts. The results seem to indicate that there is no correlation between compliance with the ToR in the EIS and their effectiveness, because the law does not include methods to evaluate it. Nowadays, EIS are developed following the ToR of the environmental authority (ANLA, 2018), but nonetheless IA effectiveness is not considered in a conclusive manner. Impact evaluations are therefore developed based on the legality of the process, but not on their effectiveness as a determining factor.

8. Conclusions

Prior works have analysed the procedural effectiveness of EIA, but a considerable number of studies have been focused on EIS quality and methods to review EIS information, placing less relevance on IA methods, and impact prediction. We analysed the effectiveness of 131 impact prediction methods used in 46% of the EISs presented between 2012 and 2014 in Colombia. We used the EIM (Caro and Toro, 2016) because it values the structural and operational parameters of the methods based on weighted indicators, however, the evaluation scales of the degrees of effectiveness were modified to establish significant differences between each of them.

This work reveals the non-existent relationship between compliance and effectiveness, which is a consequence of the lack of regulations for using methods to evaluate the effectiveness of impact assessment. This suggests that the effectiveness of the methods that will be implemented in the future depends on a change in the legal framework that regulates the design and presentation of the EIS. Unfortunately, the decrees that regulate EIA in Colombia increasingly restrict requests for information from the EIS and the monitoring of management proposals, giving greater autonomy to project proponents for IA development. As explained (Toro et al., 2010), the effectiveness of EIS criteria and methods must be unified regarding legal and administrative support in the Colombian system to eliminate the possibility of biased results that would make the system less effective.

This study contributes to the analysis of the effectiveness of IA methods, a topic that has been moderately addressed. Our results provide relevant information about procedural effectiveness in the EIA system in Colombia, as a novelty in this research field. Some limitations are worth noting, however, many EISs do not provide enough information to analyse their effectiveness. Effectiveness analysis should consider the EIA features in each country, and it is therefore proposed that the EIM be adapted to include specific aspects of the EIA process in countries where this analysis could be replicated.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Indicators used to evaluate the S_{PV} (Caro and Toro, 2016)

Parameter	Indicator	Description	Value
Objectivity: Use of methodologies with a qualitative or quantitative approach	Number of methodologies of different nature with previously defined evaluation parameters (N_{MCP}).	Use of an exclusive methodology of a qualitative or quantitative nature without parameters to execute the evaluation.	0
		Exclusive use of a methodology of qualitative or quantitative nature with justified parameters for impacts assessment.	0.5
		Use of two or more methodology of different nature with justified parameters for impacts assessment.	1
Totality: Consideration of all the environmental components and factors that may be affected.	Components or environmental factors included in environmental assessment (C_{AI})	Omission of one or several environmental components or factors proposed by an environmental authority according to the characteristics of the location site for the project or activity.	0
		Inclusion of all the environmental components or factors proposed by an environmental authority according to the characteristics of the location site for the project or activity.	1
Rigour: Use of adequate techniques, standardised and replicable, which adjust to the purpose of the analysis	Use of technical- scientific procedures required by environmental authority or the features of the project or activity. (UTs).	The required protocols and techniques required by the authority or the characteristics of the project are not adopted.	0
		The required protocols and techniques required by the authority or the characteristics of the project are adopted.	1
	Suitability of used techniques (SU_T).	The technique is not replicable and is not part of an academic study.	0
		The technique has been approved by the academy or official specialised institutions, but it is not supported by scientific literature.	0.5
		The technique has been evaluated academically and has been supported by a systematic research and scientific literature.	1
Pertinence: Definition of attributes relevant to impact assessment.	Number of irrelevant attributes includes in the assessment of environmental impacts (N_{IA}).	Inclusion of three or more of the following attributes in the assessment of environmental impacts or their equivalents: moment (Mo), effect (Ef), recoverability (Rb) and probability of occurrence (Po).	0
		Inclusion of one or two of the following attributes of environmental impact assessments or their equivalents: Mo, Ef, Rb and Po.	0.5
		Exclusion of the attributes of environmental impact assessments or their equivalents: Mo, Ef, Rb and Po.	1

Appendix B. Indicators to evaluate the O_{Pv} (Caro and Toro, 2016)

Parameter	Indicator	Description	Value
Interdisciplinarity: Inclusion of specialists in different Disciplines	Number of areas of knowledge represented by professionals of different specialties constituting the team evaluator. (N_{PET})	Number of fields of knowledge less than three	0
		Between three and four fields of knowledge	0.5
		More than four fields of knowledge	1
Expertise: Coherence between the evaluator's action field and the work to be executed.	Relationship between the specialties or education of the evaluators and the component of analysis (RECA)	One or more specialties or education not corresponding with the component of study.	0
		All the specialties or education are coherent with the component of study.	1
	Level of formation of the evaluators (LFE)	The evaluators do not have postgraduate degrees or complementary education, minimum experience of three years; relates to the represented specialty.	0
		50% of the evaluators have post-graduate degrees or complementary education, minimum experience of three years related to the represented specialty.	0.5
		More than 50% of the evaluators have postgraduate degrees or complementary education, minimum experience of three years related to the represented specialty.	1
Public participation: Inclusion of the community in decision making.	Participation of the community in impact assessments (P_{CA})	There is no degree connecting the impact assessment to suggestions or observations from the community.	0
		There is some degree connecting the impact assessments to suggestions or observations from the community.	1

Appendix C. Methods of impact prediction used in Colombia

Method	Description
Conesa (2010)	The environmental impact is qualitatively assessed through the qualification of attributes that describe in detail the environmental impact using qualitative scales or adjectives (such as high, medium, low, etc.) to which a numerical value has been assigned.
Conesa modified by Toro et al. (2013)	Modification of Conesa's methodology (2008), due to the incorporation of importance indexes of the activity and environmental vulnerability indexes to evaluate environmental impacts
Conesa with adjustments	Modification of Conesa's methodology that excludes some attributes originally proposed according to the evaluator's criteria
Barrantes and Di Mare (2001)	Estimation of the state of conservation of the environment after environmental damage has occurred using indicators and expert judgement to assign a value to each indicator
Arboleda (2003)	An environmental mark is given to the impact through the classification of five evaluation criteria, like Conesa's methodology (2010)
Arboleda with adjustments	Modification of the methodology of Arboleda (2003) in which some attributes originally proposed are excluded according to the evaluator's criteria
Risk assessment matrix (Ecopetrol, 2008)	Method based on the consequences and probability of occurrence of the environmental impact.
Leopold et al. (1971)	It consists of a double entry matrix in which are arranged in the rows, the environmental factors that can be affected and, in the columns, the activities that will take place in a project
ISO 14001 (Technical norm)	It is a standard that provides the requirements for an environmental management system, and does not require the definition of environmental impacts but of environmental aspects, defined as those elements of the activities, products or services of an organization that can interact with the environment

Appendix D. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2021.113659.

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