Environmental impacts of hydropower plants in Brazil: identification guide

Impactos ambientais de hidrelétricas no Brasil: guia de identificação

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ABSTRACT

This paper presents a guide for the identification of environmental impacts of hydroelectric enterprises. The qualitative research used the following methods: case studies, systematic literature review (SLR), content analysis, and consultation with experts. Four sources of information were used, including: Environmental Impact Statements (EISs), scientific articles, best practice guides, and expert consultation. All EISs of hydroelectric plants submitted to the Brazilian federal Environmental Licensing between 2010 and 2020 (8 EISs) were analyzed. RSL identified 68 scientific papers eligible for analysis and collection of impacts. The results were compared with Canadian practice and discussed in a virtual workshop of 15 experts. The guide has 90 impacts and can be used by environmental consulting firms and environmental agencies in the preliminary identification of environmental impacts of hydroelectric dams, contributing to the improvement of planning carried out in the EIA scoping stage of future environmental studies of this type.

Keywords: EIA. EIS. Environmental Impact. Hydroelectric power plants. Guide.

RESUMO

Este trabalho apresenta um guia para identificação de impactos ambientais de empreendimentos hidrelétricos. A pesquisa qualitativa utilizou como métodos: estudos de caso, revisão sistemática *da literatura (RSL), análise de conteúdo e consulta a especialistas. Foram usadas quatro fontes de informação, sendo elas: Estudos de Impacto Ambiental (EIA), artigos científicos, guias de boas práticas e consulta a especialistas. Foram analisados todos os EIAs de hidrelétricas submetidos ao Licenciamento Ambiental federal brasileiro, entre 2010 e 2020 (8 EIAs). A RSL identificou 68 artigos científicos elegíveis para análise e coleta dos impactos. Os resultados foram cotejados com a prática canadense e discutidos em um workshop virtual com a participação de 15 especialistas. O guia apresenta 90 impactos e poderá ser utilizado por empresas de consultoria e órgãos ambientais na identificação preliminar de impactos ambientais de hidrelétricas, contribuindo para o aprimoramento do planejamento realizado na etapa de escopo da Avaliação de Impacto Ambiental (AIA) de futuros estudos ambientais dessa tipologia.*

Palavras-chave: *AIA. EIA. Impacto ambiental. Hidrelétricas. Guia.*

1 INTRODUCTION

Brazil is the country with the largest availability of water on the planet and its main source of energy generation are hydroelectric plants, which account for about 62% of all electricity produced in the country (ANEEL, 2021). This characteristic represents an advantage of this type of project, since it is a cheap, reliable and renewable energy source (TOLMASQUIM; GUERREIRO; GORINI, 2007). However, the construction of hydroelectric developments causes potentially significant Environmental Impacts (EI) that must be considered (HUANG et al., 2018; ZHANG; HAN; SONG, 2020).

In this context, the Environmental Licensing and the Environmental Impact Assessment (EIA) are deemed as instruments of environmental planning and management capable of preventing and mitigating the EIs of projects (BRASIL, 1981; SÁNCHEZ, 2020). Since the publication of Conama Resolution No. 1/1986, the EIA has been linked to the Environmental Licensing process through the requirement of the Environmental Impact Statement (EIS) for the Environmental Licensing of activities that cause significant EI. Thus, it became necessary to prepare an EIS for hydroelectric projects with installed capacity greater than 10 MW (BRASIL, 1986).

Since then, "the EIS has become the most important document of the entire impact assessment process, as main decisions for the feasibility of a project are made based on the EIA process" (SÁNCHEZ, 2020, p. 136). However, often the EISs are submitted to the environmental agency without presenting adequate information to support the decision-making process regarding the environmental feasibility of the project (ALMEIDA; MONTAÑO, 2017; VERONEZ; MONTAÑO, 2017).

Another characteristic of the Brazilian context is the preparation of studies using an exhaustive approach, without adequate planning and containing an excess of compiled data about the study area, much of it useless for the analysis of project feasibility (SÁNCHEZ, 2020). This reality does not meet international best practice in EIA, which indicates that the preparation of an EIS should be the result of good planning, which guides the preparation of baseline studies focused on important factors for decision making (IAIA; IEA, 1999). Therefore, the first activity in the preparation of an EIS should be the preliminary identification of the EIs, carried out in the EIA planning stage. Such planning will guide the procedures in order to identify the relevant issues in the field (GLASSON; THERIVEL; CHADWICK, 2012).

Given the information gaps presented in the EISs, which can compromise the effectiveness of the EIA and Environmental Licensing processes, it is up to the environmental agency to require additions to environmental studies. In this sense, the World Bank (2008) has described the Environmental Licensing process as an obstacle to the construction of new hydroelectric plants in Brazil, and among the main reasons for the slowness of the process is the time it takes to define the Terms of Reference (TOR) and the low quality of the environmental studies. However, the proposals of simplification can have serious consequences for the Brazilian Environmental Licensing (BRAGAGNOLO et al., 2017). Moreover, scientific research points to the significant impacts of hydropower projects, even the smallest ones, having a potential to threaten the provision of ecosystem services, river connectivity, biodiversity conservation, and the lives of indigenous and traditional communities (ATHAYDE et al., 2019).

The importance of the preliminary identification of impacts and the planning of the EIA, which occurs in the scoping stage, is then highlighted, serving as a basis for planning the subsequent stages. If impacts are not identified correctly in this initial planning stage, it will not be possible to direct the baseline studies to the identification of important data, which compromises the environmental prognosis and consequently the proposition of mitigation measures. Therefore, the absence of an adequate preliminary identification in the planning stage can compromise the preparation of baseline studies and negatively interfere in all stages of the preparation of an EIS, undermining the effectiveness of the EIA process (GLASSON; THERIVEL; CHADWICK, 2012).

Given the importance of the EIA planning stage (BORIONI; GALLARDO; SÁNCHEZ, 2017), this paper presents a guide for the preliminary identification of EI caused by hydroelectric developments, thus contributing to the improvement of the EIA process of these developments

2 METHODOLOGY

In order to prepare the guide, multiple sources of information were used, as recommended by Sánchez (2020). Hydropower EISs and scientific articles were analyzed to compose a list of EIs that was compared with Canadian practice and discussed at an expert consultation workshop.

Using a predominantly qualitative approach, the research was divided into four steps, related to each of the information sources researched. Figure 1 represents the methodological procedures used in each step.

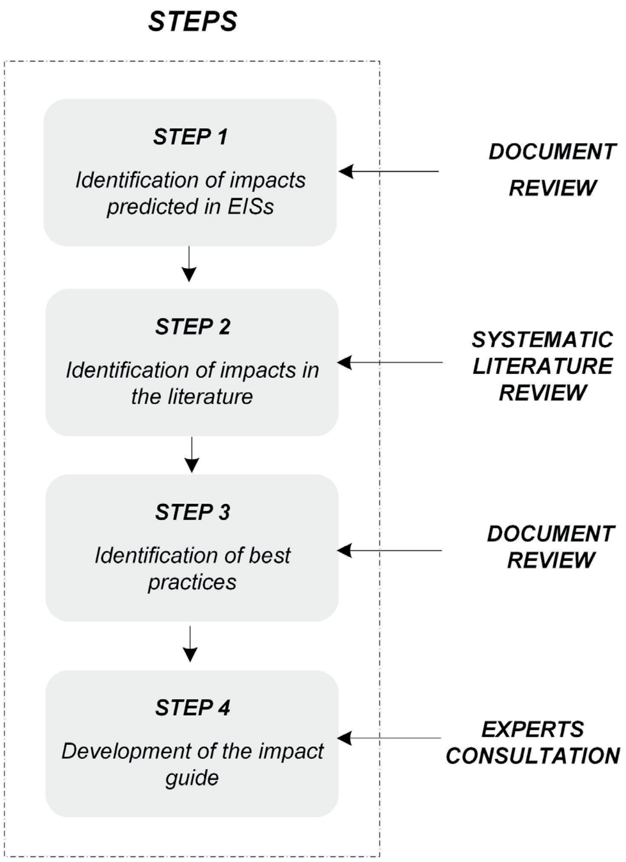

Figure 1 | Methodological steps and procedures used in the research.

Source: Elaborated by the authors.

2.1 IDENTIFICATION OF IMPACTS PREDICTED IN EISs

For the identification of the EI foreseen, the EISs of hydroelectric projects licensed at the federal level were used as study objects. These EISs are available on the website of the federal environmental agency of Brazil - Brazilian Institute of Environment and Renewable Natural Resources (Ibama). In this step, the data collection methods were document review in a multiple case study (YIN, 2009), and as an analysis method the content analysis (KRIPPENDORFF, 2004). Figure 2 illustrates the methodological flowchart used to identify the impacts described in the EISs (Step 1).

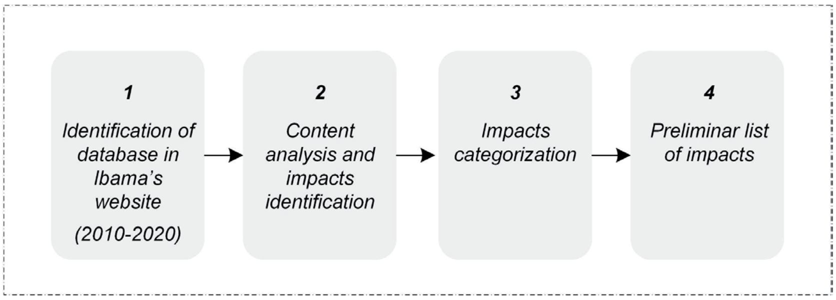

Figure 2 | Methodological flowchart used to identify the impacts predicted in the EISs.

Source: Elaborated by the authors.

A total of 35 EISs in Ibama's database (available at: https://www.ibama.gov.br/laf/consultas), were identified. The study focuses on the most recent studies, considering a time frame of 10 years. Box 1 presents the main characteristics of the 8 EISs analysed.

Box 1 | Environmental Impact Studies analysed.

EIS	*Year*	*Project*	*Implementation location*
EIS 1	2011	Itaocara Hydroelectric Power Plant	Minas Gerais/Rio de Janeiro
EIS 2	2012	Davinópolis Hydroelectric Plant	Minas Gerais/Goiás
EIS 3	2012	Pai Querê Hydroelectric Plant	Santa Catarina/Rio Grande do Sul
EIS 4	2012	Cabuí Small Hydroelectric Plant	Minas Gerais/Rio de Janeiro
EIS 5	2013	Caiçara Small Hydroelectric Plant	Minas Gerais/Bahia
EIS 6	2013	Gavião Small Hydroelectric Plant	Minas Gerais/Bahia
EIS 7	2014	São Luís dos Tapajós Hydroelectric Plant	Pará
EIS 8	2019	Tabajara Hydroelectric Plant	Rondônia

Source: Elaborated by the authors.

The EIS chapters on identification and evaluation were reviewed. The impacts were identified and extracted into Microsoft Excel spreadsheets, where they were organised and grouped. The organisation was done according to (i) the phase of the project in which they were foreseen (planning, implementation, and operation), (ii) the environment in which they have a direct impact (physical, biotic, or anthropic), and (iii) the nature of the impact (negative or positive). All spreadsheets were integrated into a single list of EIs, following the coding process suggested by Berg (2001). In this step, EIs whose statements were different, but their descriptions pointed to the same EI, were grouped. The grouping was performed considering the perceived characteristics or attributes (CORBIN; STRAUSS, 2008).

2.2 IMPACTS IDENTIFIED IN THE LITERATURE

A Systematic Literature Review (SLR) was used to identify the EIs mentioned in the literature. This method allows to produce results with greater reliability, reducing errors and researcher bias. For that reason, it was chosen to achieve better search results (SAMPAIO; MANCINI, 2007). Further, RSL is a particularly useful method for integrating information from a set of studies conducted separately on a given subject (SAMPAIO; MANCINI, 2007).

RSL was performed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Prisma) protocol, created with the goal of improving the reporting of systematic reviews (MOHER et al., 2015). The protocol was initially developed for randomized clinical trials, but Prisma can also be used as a basis for reporting systematic reviews of other types of research (MOHER et al., 2015). Prisma has been widely used in research on the environmental field, achieving satisfactory results (LIQUETE et al., 2013; SIERRA-CORREA; CANTERA KINTZ, 2015; TALAMINI et al., 2017). Based on the Prisma protocol, the RSL followed the following steps: identification, selection, eligibility, and inclusion, as illustrated in Figure 3 and described below.

The RSL started with the identification of scientific articles. The RSL was performed on 10/20/2021, using the bibliographical databases in Scopus. This database has a multidisciplinary scope and is the largest database of abstracts and citations in the literature, with peer review. The search process was performed using a string, ensuring greater applicability of the search (Box 2).

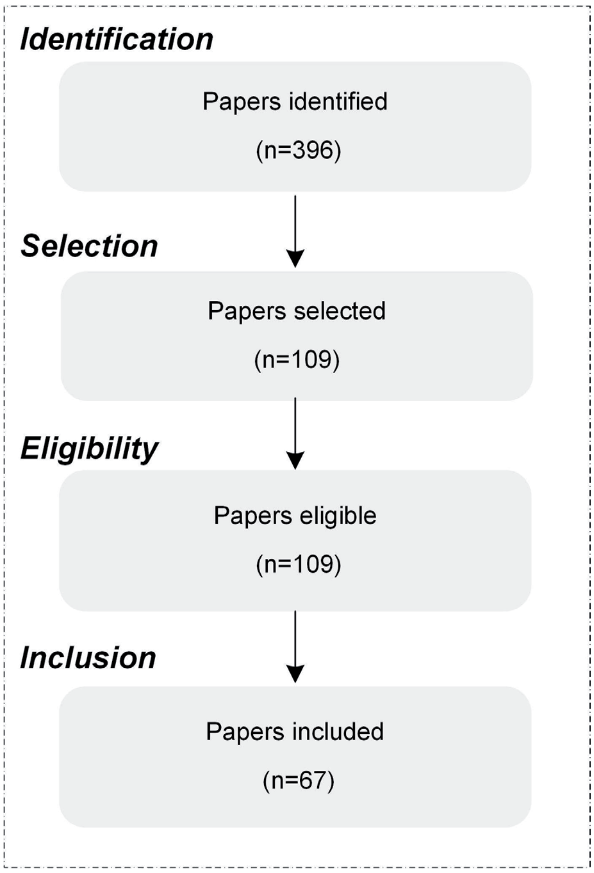

Figure 3 | RSL Methodological Flowchart.

Source: Elaborated by the authors based on Prisma Flowchart (MOHER et al., 2015).

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Box 1 | Search string used in Scopus database

String	*Explanation of the filters*
TITLE (dams OR hydropowerplants OR "hydropower plants" OR "hydroelectric power" OR "hydroelectric complex" OR reservoirs OR hidreletric OR reservatório*) AND TITLE (impact*) AND ABS (environment*) AND (EXCLUDE (SUBJAREA, "MEDI") OR EXCLUDE (SUBJAREA, "COMP")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE, "ch")) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013) OR LIMIT-TO (PUBYEAR, 2012) OR LIMIT-TO (PUBYEAR, 2011) OR LIMIT-TO (PUBYEAR, 2010)) AND (LIMIT-TO (LANGUAGE, "English") OR LIMIT-TO (LANGUAGE, "Portuguese"))*	• The search considered that at least one of the following descriptors should be in the title: dams, hydropowerplants, Hydropower Plants, hydroelectric power, hydroelectric complex, reservoirs, hydreletric* or reservoir*.
	• The title should also include some description derived from the term impact*, and the abstract should include some derived from environment*.
	• Medicine and Computer Science Studies were excluded.
	• Only book chapter and articles from journals and congresses were included.
	• Year of publication: From 2010 to 2021.
	• The search was limited to, studies written in English and Portuguese.

Source: Elaborated by the authors.

A total of 396 articles was selected on the basis of the following parameters: (i) title; (ii) abstract; (iii) keywords. In addition to the criteria already established in the search (being scientific articles, written in Portuguese or English, related to research published between 2010 and 2021, and identifying EIs from hydroelectric projects), theoretical and literature review papers were excluded. This selection was made using the Rayyan Intelligent Systematic Review (https://www.rayyan.ai). This is a tool to assist the RSL, which receives the importation of the search results from the databases (in the case of this research the files were imported in CSV format). In this online program you can perform peer-reviewed RSL, analyzing and categorizing each article, titles and abstracts. It is also possible to search by keywords as an aid to the categorization process. The analysis was performed by two researchers and resulted in 109 articles eligible for full reading. In the eligibility process no article was discarded, and all were forwarded to the next step.

From the complete reading of the 109 articles, always using the same selection criteria described above, only 67 scientific articles were included as a result of the RSL. These articles were re-read to identify and extract the cited EIs.The eligibility and inclusion steps were performed using the Mendeley reference manager. EIs were grouped and organised in a Microsoft Excel table, forming a preliminary list of the EIs mentioned in the articles. The grouping and organisation of the EIs was performed taking into account their perceived characteristics or attributes (CORBIN; STRAUSS, 2008).

2.3 IDENTIFICATION OF BEST PRACTICES

In this step, technical guides prepared for Canadian EISs were consulted. The choice of Canada was motivated by the fact that it is one of the pioneer countries in the implementation of the EIA process, already having a consolidated and well-structured system, which implies a good quality of environmental studies (SÁNCHEZ, 2020). It is worth noting that the EIA process in Canada takes into account sustainability, transparency, social and health impacts, liability, and climate change. The Government of Canada has adopted a law that also reflects the best practices recommended by the International Association for Impact Assessment (IAAC, 2021). The comparison with Canadian practice aimed to learn about the best practices applied internationally and to refine the lists of EIs identified in steps 1 and 2. At the end of this third step, the extracted EIs were assembled into a single list.

2.4 DEVELOPMENT OF THE IMPACT GUIDE

This step aims to suggest a guide for preliminary identification of hydroelectric projects EI based on the results of the previous steps and consultation of experts who work in different fronts of the EIS of hydroelectric projects.

Initially a pilot workshop was conducted, prior to the consultation with experts (main workshop). This pilot workshop consisted of two online meetings (on 07/08/2021 and 07/16/2021), totaling six hours of group analysis. Six experts participated in the pilot workshop. The meetings aimed to analyse each EI, whose description was adjusted, when necessary, for a better understanding of the experts during the main workshop (MATTHEWS; ROSS, 2010). It was also possible to define the data collection procedures during the main workshop.

The main workshop was also held in the online modality, on 10/18/21. A total of 33 IA specialists participated in the study: of them, 15 were from federal (Ibama) and provinces (State Institute of Environmental and Water Resources of Espírito Santo - Iema) governments, and from an environmental consulting company. The expert consultation process started by reading and discussing each EI on the list. During this process, some descriptions were modified and EIs were included (no impacts were excluded). The event was recorded, which allowed a later analysis to verify the considerations made by the experts. After consolidating the information, the final product of this step was elaborated, which is a guide to identify the hydroelectric projects EI.

3 RESULTS AND DISCUSSION

The four steps used in this research allowed the construction of a guide for identifying hydropower plant EIs, based on prior knowledge from different sources including EISs, articles, best practice and expert opinion.

The option to separately analyse the list of EI cited in each EIS allowed us to learn what EISs say about the hydropower plants EIs and understand the peculiarities of the typology, which might vary according to the context in which the project is intended to be implemented. The EI list that emerged from the EISs counted 76 different EIs. It is to be noted that some EI were described differently among the studies, although they had the same meaning. The statements of the EIs were sometimes dubious, vague, or very specific. It was also possible to identify conceptual errors in the wording of the EI that were sometimes confused with environmental aspects. For example, vegetation suppression and job creation appear as EIs in some studies. Regarding the classification of EIs, it is worth noting that there is divergence among the EISs concerning the environment affected by some EIs. For example, the EI "Interference from mining activities" was mentioned in one EIS as occurring in the physical environment, while three others refer to the anthropic environment. Conceptual and information gaps about EIs described in EISs are mentioned in the literature (ALMEIDA; MONTAÑO, 2017; VERONEZ; MONTAÑO, 2017). At the end of the EIS analysis, a preliminary list (Step 1) was drawn up, adjusting the description of each EI to make them more synthetic, self-explanatory, and to describe the meaning of the changes (SANCHEZ, 2020).

In the second step, the 67 articles coming from the RSL refer to 35 different EIs. Eight of them were unknown to the experts consulted at the workshop. It is worth noting that EIs "Degradation of estuarine ecosystems" and "Loss of coastal biodiversity" are associated with sediment retention in reservoirs (EZCURRA et al., 2019). It is also worth mentioning the EI "Mercury contamination of the food chain" due to the degradation of organic matter in the reservoirs by methylating bacteria (LIU et al., 2019). After the analysis of the articles and the collection of the EIs cited in practical research, the results obtained (Step 2) were added to the list drawn up in the previous step.

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When analysing the Canadian practice, it was found that the environmental agency prepares specific guidelines for each EIS. In general, the organisation of the information is given in a very different way than in Brazil. EIs are not presented associated with the environmental aspects of each activity, but rather with the environmental factors impacted. The list of EIs prepared by the interaction between steps 1 and 2, was compared to the document "Draft Environmental Assessment Report", prepared for the "Tazi Twé Hydroelectric" enterprise (available at: https://iaac-aeic.gc.ca/050/documents/p80031/101642E.pdf). Results show that all the factors were included in the list drawn up in this research. Regarding the organisation of the information, the guide is presented in the format: activity - environmental aspect - environmental impact, more common in Brazilian practice.

In addition to the confirmation of the list of impacts, 23 environmental impacts were added during the workshop. Most of them are associated with the anthropic environment. The final guide consists of 90 EIs, shown in Tables 1, 2 and 3. Results reveal that 31 EIs were identified in the EISs and articles, 36 were only identified in the EISs, and 10 only in the articles. In the guide, EIs are divided into three project phases: planning, installation, and operation. The indication of the environment (anthropic, biotic or physical) considered the action of the direct impacts. Further, tables 1, 2, and 3 describe the nature of the EI and its frequency (which indicates the number of EISs/articles that mentioned the EI). It is worth pointing out that these tables represent a fragment of the final product, which is organised by macro activity and environmental aspects related to each EI. For space reasons the guide has been adjusted and focuses on the main information in this paper.

Table 1 presents the EIs associated with the project's planning phase, when the economic feasibility studies, the environmental studies, the public hearings, the disclosure of the project, the preparation of the engineering designs, and the first field works are conducted. At this point, the local population is informed about the implementation of the project, thus initiating the first discussions regarding the potential EIs that may occur. Twelve EIs related to the planning phase were identified, among which only one does not belong to the anthropic environment: "Pressure on natural resources". The analysis of the articles included only one EI that had not been identified in the EISs: "Rising prices of goods and services" (OLIVEIRA et al., 2016; TAJZIEHCHI et al., 2013). Oliveira et al. (2016) also highlight, as a negative EI, the "Increase in disorderly land occupation". This EI is similarly written by half of the EISs analysed. The consultation with specialists added two EIs that had not been mentioned in the EISs and scientific articles, namely: "Real estate development" and "Pressure on natural resources". Overall, the most cited EI was "Loss of quality of life of the population," cited by all EISs and validated in the expert consultation.

The construction of the work itself begins in the implementation phase. Activities that are executed in this phase include: releasing areas, opening access roads, mobilising and operating the support infrastructure, diverting the river and building the main work, and cleaning the area to be occupied by the reservoir. During the construction, there is an increase in the influx of people attracted by job generation, which reflects in changes in the local socio-economy and in land use and occupation patterns, and induces the occurrence of the environmental impacts as shown in Table 2. It is worth highlighting that it is during the implementation phase that most of the EIs occur and in a more expressive way (BATISTA et al., 2012).

Table 1 | Environmental impacts expected during the planning stage.

Activity	Impact	Frequency		Workshop	Environment	Nature
		EIS	Papers			
Execution of preliminary studies	Loss of public quality of life	8		x	A	N
	Increase in the market for goods and services	2		x	A	N
	Creation of negative expectations, insecurity and apprehension	5		x	A	N
	Creation of positive expectations in the population	5		x	A	P
	Rising price of real estate			x	A	N
	Increase in disorderly land occupation	4	1	x	A	N
	Rising prices of goods and services		2	x	A	N
	Stimulating the mobilization and organization of civil society	4		x	A	N
	Increased scientific knowledge about the biotic environment	3		x	A	P
	Increased scientific knowledge about the physical environment	1		x	A	P
	Increased scientific knowledge of the anthropic environment	1		x	A	P
	Increased pressure on natural resources			x	B/F	N

Legend: Environment: A (Anthropic); B (Biotic); F (Physical)

Nature: N (Negative); P (Positive)

Source: Elaborated by the authors.

Table 2 show that 54 different EIs were identified in the different activities of the implementation phase, and only four of them were mentioned in all the EISs including: "Loss of quality of life", "Increase in fish mortality", "Deterioration of water quality", and "Induction of erosive processes''. The last three EIs were also the most cited in the articles (ALP; AKYÜZ; KUCUKALI, 2020; BAOLIGAO et al., 2016; ESPA et al., 2019). Von Sperling (2012) also refers to these EIs as being the most significant associated with the implementation of hydroelectric dams. During the installation phase, the main EIs occur in the local population. A total of 35 impacts was identified as affecting the anthropic environment. With regard to nature, 51 EIs are negative, and three are positive. These are always associated with the anthropic environment. The vast majority of EIs that occur during the construction phase are negative in nature and remain in a long term. The few positive EIs are mostly temporary.

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Table 2 | Environmental impacts expected during the implementation phase.

Activity	*Impact*	*Frequency*		*Workshop*	*Environment*	*Nature*
		EIS	*Papers*			
Area Release	Creation of negative expectations, insecurity and apprehension	5		x	A	N
	Compulsory relocation of families	2	2	x	A	N
	Increased social vulnerability			x	A	N
	Loss of productive areas	3	6	x	A	N
	Loss of social equipment			x	A	N
	Rising price of real estate			x	A	N
	Interference in mining activities	4	1	x	A	N
	Rupture of social relations			x	A	N
Earthmoving	Degradation of the speleological heritage	1		x	A	N
	Degradation of archeological heritage	2		x	A	N
	Paleontological heritage degradation	1		x	A	N
	Discomfort to the population			x	A	N
	Deterioration of water quality	8	11	x	F	N
	Increased sound pressure levels and vibration	2	1	x	F	N
	Deterioration of air quality	3	1	x	F	N
	Degradation of the natural landscape	3	1	x	F	N
	Displacement, disturbance, and frightening of terrestrial fauna	3	1	x	B	N
	Induction of erosive processes	8	12	x	F	N
	Sedimentation of water bodies	4	5	x	F	N
Vehicle handling, maintenance and operation	Discomfort to the population			x	A	N
	Pressure on the road system			x	A	N
	Increase in road accidents	1		x	A	N
	Overload on the local basic infrastructure	5	1	x	A	N
	Increased sound pressure levels and vibration	2	1	x	F	N
	Deterioration of air quality	3	1	x	F	N
	Deterioration of water quality	8	11	x	F	N
	Increase in the number of road kills of wild animals	2		x	B	N
	Displacement, disturbance, and frightening of terrestrial fauna	3	1	x	B	N
	Soil compaction and densification	1		x	F	N
	Soil Contamination	2		x	F	N

Activity	Impact	Frequency		Workshop	Environment	Nature
		EIS	Papers			
Vegetation Suppression	Increase in hunting and trafficking of wild animals	2		x	B	N
	Increase in accidents with poisonous animals	3		x	A	N
	Deterioration of water quality	8	11	x	F	N
	Degradation of the natural landscape	4	1	x	F	N
	Loss of flora individuals	4		x	B	N
	Injury and death of fauna individuals	4		x	B	N
	Loss of terrestrial fauna habitat	3		x	B	N
	Loss of ecological processes and flows	1		x	B	N
	Increased pressure on natural resources			x	B/F	N
	Induction of erosive processes	8	12	x	F	N
	Sedimentation of water bodies	4	5	x	F	N
Mobilization and permanence of labor	Increasing the wage bill	4		x	A	P
	Increase in the market for goods and services	2		x	A	P
	Spread of Infectious and Endemic Diseases	3	3	x	A	N
	Increase in drug use and prostitution		4	x	A	N
	Modification of social and cultural relations	4		x	A	N
	Increase in violence and criminality		4	x	A	N
	Increase in disorderly land occupation	4	1	x	A	N
	Overload on the local basic infrastructure	5	1	x	A	N
	Increased municipal tax collection	4		x	A	P
	Increased pressure on natural resources			x	B/F	N
Acquisition of service goods and inputs	Rising prices of goods and services		2	x	A	N
	Increased municipal tax collection	4		x	A	P
	Increase in the market for goods and services	2		x	A	P
	Increasing the wage bill	4		x	A	P
Construction of buildings and support units	Overload on the local basic infrastructure	5	1	x	A	N
	Deterioration of water quality	8	11	x	F	N
	Soil Contamination	2		x	F	N
Construction of the cofferdams	Loss of fishing sites			x	A	N
	Increased fish mortality	8	4	x	A	N
	Interruption of the movement of aquatic fauna	6	8	x	A	N
	Deterioration of water quality	8	11	x	F	N

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Activity	*Impact*	*Frequency*		*Workshop*	*Environment*	*Nature*
		EIS	*Papers*			
Exploitation of borrow areas	Building damage			x	A	N
	Discomfort to the population			x	A	N
	Paleontological heritage degradation	1		x	A	N
	Degradation of the speleological heritage	1		x	A	N
	Degradation of archeological heritage	2		x	A	N
	Deterioration of air quality	3	1	x	F	N
	Increases in sound pressure levels and vibration	2	1	x	F	N
	Deterioration of water quality	8	11	x	F	N
	Degradation of the natural landscape	4	1	x	F	N
	Displacement, disturbance, and frightening of terrestrial fauna	3	1	x	B	N
	Induction of erosive processes	8	12	x	F	N
	Sedimentation of water bodies	4	5	x	F	N
Construction of the dam structures	Paleontological heritage degradation	1		x	A	N
	Degradation of the speleological heritage	1		x	A	N
	Degradation of archeological heritage	2		x	A	N
	Deterioration of water quality	8	11	x	F	N
	Increased sound pressure levels and vibration	2	1	x	F	N
	Degradation of the natural landscape	3	1	x	F	N
	Deterioration of air quality	3	1	x	F	N
	Displacement, disturbance, and frightening of terrestrial fauna	3	1	x	B	N
	Sedimentation of water bodies	4	5	x	F	N
	Induction of erosive processes	8	12	x	F	N
Electromechanical assembly	Increased municipal tax collection	4		x	A	P
	Increase in the market for goods and services	2		x	A	P
	Increasing the wage bill	4		x	A	P
	Discomfort to the population			x	A	N
	Increased sound pressure levels and vibration	2	1	x	F	N
	Displacement, disturbance, and frightening of terrestrial fauna	3	1	x	B	N

Activity	Impact	Frequency		Workshop	Environment	Nature
		EIS	Papers			
Demobilization of the workforce	Retraction of the real estate market			x	A	N
	Increase in social conflicts			x	A	N
	Increased competition for jobs			x	A	N
	Decrease in the wage bill			x	A	N
	Loss of life quality	8		x	A	N
	Closing of businesses and services			x	A	N
	Increase in disorderly land occupation	4	1	x	A	N
	Increase in violence and criminality		1	x	A	N
	Decrease in government revenue			x	A	N
	Shrinkage of the market for goods and services			x	A	N
	Increased idleness of social infrastructure and equipment			x	A	N

Legend: Environment: A (Anthropic); B (Biotic); F (Physical)

Nature: N (Negative); P (Positive)

Source: Elaborated by the authors.

The workshop participants added 12 EIs that occur during the installation phase. Most of them are related to labor demobilisation, such as "Rupture of social relations", "Increased idleness of infrastructure and social equipment", "Increased competition for job vacancies", and "Retraction of the real estate market". According to the specialists, these EIs are very significant when it comes to the implementation of large hydroelectric plants. Therefore, there is a weakness in the EIAs. Most of them do not consider the EI associated with decommissioning.

Reading the articles made it possible to include four EIs in the installation phase. The EIs "Increased drug use and prostitution" and "Increased violence and crime" are cited in the papers by Castro-Diaz, Lopez, and Moran (2018), Santos, Cunha, and Cunha (2017) and Tallman et al. (2020). The EI "Loss of social capital of indigenous communities", on the other hand, was mentioned by Hanna et al. (2016). It is noteworthy that all four of these studies explore the socioeconomic impacts in the Amazon region due to the implementation of the Belo Monte hydroelectric dam, which has become world-renowned for being the target of various social conflicts. Another EI is the "Rise in prices of goods and services" that also occurs in the planning stage.

The operation phase is known as the moment when the reservoir is filled. Later the commercial operation of the plant starts with the generation of energy by the turbines. As shown in Table 3, 40 EIs were identified and occurred in the operation phase. Of them, 14 EIs are associated with the anthropic environment, 13 EIS with the biotic environment, and 13 EI with the physical environment. Despite the higher number of EIs associated with the anthropic environment, it was observed based on the citation frequency that articles are more directed towards the identification and assessment of EIs in the physical and biotic environment (ELORANTA et al., 2018; SANTOS et al., 2020; SHEN et al., 2019).

Most of the EIs that occur during the operational phase are related to the environmental aspect "Alteration of the river hydrodynamics", which refers to the change from the lentic to the lotic regime, and which promotes changes in the physical, chemical, and biological characteristics of the aquatic environment. Much of the research aimed to understand the influence of reservoirs on the species composition and diversity of aquatic fauna (ÁLVAREZ-TRONCOSO et al., 2015; NORMANDO et al., 2014; WANG et al., 2013). As shown in Table 3, the EIs that were mentioned the most in the operational phase were the same as those identified in the implementation phase, although the inducing processes are different.

Table 3 | Environmental impacts expected during the implementation phase.

Activity	*Impact*	*Frequency*		*Workshop*	*Environment*	*Nature*
		EIS	*Papers*			
Reservoir Filling	Loss of the local fishing culture	4		x	A	N
	Increased incidence of diseases caused by vectors	3	1	x	A	N
	Interference with catchment and supply systems	3		x	A	N
	Interference in mining activities	4	1	x	A	N
	Loss of areas for leisure and tourism activities	3	1	x	A	N
	Loss of fishing sites			x	A	N
	Improvement of navigability conditions upstream of the dam			x	A	N
	Loss of historical and cultural heritage	3	2	x	A	N
	Loss of productive areas	3	6	x	A	N
	Degradation of archeological heritage	2		x	A	N
	Degradation of the speleological heritage	1		x	A	N
	Paleontological heritage degradation	1		x	A	N
	Pressure on the local fishing economy	4	9	x	A	N
	Deterioration of water quality	8	11	x	F	N
	Modification of the local microclimate	2		x	F	N
	Degradation of the natural landscape	4	1	x	F	N
	Loss of terrestrial fauna habitats	3		x	B	N
	Modification of the diversity and composition of aquatic fauna	4	23	x	B	N
	Modification in the composition and diversity of planktonic communities	2	7	x	B	N
	Increased biomass of potentially toxic cyanobacteria	2		x	B	N
	Increased fish mortality	8	4	x	B	N
	Increased proliferation of insects			x	B	P
	Contamination of the food chain by mercury		2	x	B	N
	Degradation of Estuarine Ecosystems		1	x	B	N
	Interruption of the movement of aquatic fauna	6	8	x	B	N
	Loss of coastal biodiversity		1	x	B	N
	Proliferation of aquatic macrophytes	2		x	B	N
	Change in hydrological regime		9	x	F	N
	Rising water table in the vicinity of the reservoir	3	4	x	F	N
	Greenhouse gas emissions	1	2	x	F	N
	Induction of erosive processes	8	12	x	F	N
	Modification of river channel morphology			x	F	N
	Variation of the hydraulic regime of the river	6	16	x	F	N
	Occurrence of induced earthquakes	4		x	F	N
	Reducing the sediment load downstream of the dam	7	16	x	F	N

Activity	*Impact*	*Frequency*		*Workshop*	*Environment*	*Nature*
		EIS	*Papers*			
Formation of the reduced flow section	Loss of seaworthiness			x	A	N
	Loss of fishing sites			x	A	N
	Pressure on the local fishing economy	4	9	x	A	N
	Loss of the local fishing culture	4		x	A	N
	Interference with the catchment and supply systems	3		x	A	N
	Compromising the use of water for irrigation			x	A	N
	Deterioration of water quality	8	11	x	F	N
	Degradation of the natural landscape	4	1	x	F	N
	Modification of the diversity and composition of aquatic fauna	4	23	x	B	N
	Loss of aquatic fauna habitats	4		x	B	N
	Increased fish mortality	8	4	x	B	N
	Induction of erosive processes	8	12	x	F	N
	Variation of the hydraulic regime of the river	6	16	x	F	N
	Change in hydrological regime		9	x	F	N
	Lowering of the water table in the low-flow section			x	F	N
Commercial operation of the plant	Improvement of navigability conditions upstream of the dam			x	A	N
	Pressure on the local fishing economy	4	9	x	A	N
	Loss of the local fishing culture	4		x	A	N
	Increased municipal tax collection	4		x	A	N
	Increase the reliability of the National Interconnected System	3		x	A	N
	Increased supply of electrical energy	3	1	x	A	N
	Creation of negative expectations, insecurity and apprehension	5		x	A	N
	Increased incidence of diseases caused by vectors	3	1	x	A	N
	Loss of areas for leisure and tourism activities	3	1	x	A	N
	Deterioration of water quality	8	11	x	F	N
	Degradation of the natural landscape	4	1	x	F	N
	Modification of the local microclimate	2		x	F	N
	Loss of coastal biodiversity	2		x	B	N
	Modification of the diversity and composition of aquatic fauna	4	23	x	B	N
	Modification of the composition and diversity of planktonic communities	2	7	x	B	N
	Increased biomass of potentially toxic cyanobacteria	2		x	B	N
	Increased fish mortality	8	4	x	B	N
	Degradation of Estuarine Ecosystems		1	x	B	P
	Loss of coastal biodiversity		1	x	B	P
	Increased proliferation of insects			x	B	P
	Interruption of the movement of aquatic fauna	6	8	x	B	P

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Activity	Impact	Frequency		Workshop	Environment	Nature
		EIS	Papers			
Commercial operation of the plant	Induction of erosive processes	8	12	x	F	N
	Variation of the hydraulic regime of the river	6	16	x	F	N
	Modification of river channel morphology			x	F	N
	Change in hydrological regime do rio	0	9	x	F	N
	Reducing the sediment load downstream of the dam	7	16	x	F	N
	Occurrence of induced earthquakes	4		x	F	N
	Rising water table in the vicinity of the reservoir	3	4	x	F	N

Legend: Environment: A (Anthropic); B (Biotic); F (Physical)

Nature: N (Negative); P (Positive)

Source: Elaborated by the authors.

A total of the 90 different EIs is indicated in the guide. Of them, 80 are negative and 10 positive, 12 from the planning phase, 54 from implementation phase, and 40 from operational phase. It is worth pointing out that the same EI can be caused in more than one phase (and therefore the sum of the different impacts is less than 106). Regarding the environment of incidence, 19 EIs are directly associated with the physical environment, 18 with the biotic environment, and 53 with the anthropic environment. It is to be noted that the highest number of EIs is related to the anthropic environment, and most of them are of a negative nature (32 EIs) and are related to the decrease in the quality of life of the local population. These results coincide with earlier analysis (SANTOS; CUNHA, A. C.; CUNHA, H. F. A., 2017), which found that the burden of building new power plants is greater than their benefits to local communities.

Finally, the guide proposed in this paper aims to contribute to the improvement of the process of preliminary identification of EIs and the identification and consideration of potentially significant EIs during the Environmental Licensing of hydroelectric projects. However, it is worth pointing out that the objective of this guide is not to standardise or exhaust all possible EIs caused by this typology, since each enterprise has its own peculiarities and new EIs may appear depending on the characteristics of the context of the affected environment.

4 CONCLUSION

The guide presented in this paper indicates 90 different impacts, expected in the planning, installation and operational phases of hydroelectric enterprises. Besides the impacts, the environment of their direct action (anthropic, biotic or physical), the nature (positive or negative) and the frequency in which they were cited in the EISs and papers are also indicated.

According to the results obtained through the four stages of this work, it can be observed that the greatest number of impacts occur during the implementation phase, followed by the operational phase, with a good part of these impacts being of a negative nature, affecting the anthropic, physical, and biotic environments. The EISs analysed placed greater emphasis on identifying impacts that occur during the implementation phase. Papers, on the other hand, focus on the impacts that occur during the operational phase, analysing mainly the alterations on aquatic fauna resulting from the formation of the reservoir.

It is expected that this study will contribute to the improvement of the process of preliminary identification of environmental impacts of hydroelectric projects, thus contributing to the improvement of the EIA process of these projects.

As a limitation of this study, it is highlighted that the guide of impacts is limited to being a reference for the identification of the probable EIs of this typology. Thus, the identification of the likely occurrence of an impact (or not) will depend on the specific characteristics of the project and the context in which it will be implemented. In this sense, the experience of the professionals involved in the analysis and the interdisciplinary discussion of the applicability of each impact to a particular project and its context are essential for the proper identification of a project's impacts and cannot be substituted by this guide.

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