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SUMARIO / SUMMARY / RESUMO

EDITORIAL

It is with great excitement that we present this new issue of Environmental Sciences & Practices. In a context of ecological and climatic urgency, the scientific community is faced with the imperative of going beyond mere description of the problems to offer clear and substantiated courses of action. This volume, in its geographic and thematic diversity, integrates precisely this spirit of transition towards a transformative science. The five articles that compose it, in an organic and unpremeditated manner, trace a powerful narrative arc: They begin with a diagnosis of environmental awareness at different scales, progress to the proposal of educational and institutional strategies, and culminate with the presentation of a concrete technical solution. This natural progression from understanding to application is at the heart of relevant and effective environmental practice.

The journey begins with a comprehensive assessment in Discovering the Sea: analysis of Ocean and Polar Literacy levels in a sample of university students. By means of a pilot questionnaire, this study assesses the knowledge and perception of marine and polar ecosystems in a Spanish-speaking university population. A crucial and little-anticipated finding reveals that living near the sea does not guarantee greater ocean literacy, sidestepping common assumptions and redirecting the focus to the quality of formal education. This work is fundamental for educators and curriculum designers, as it highlights specific knowledge gaps and underscores the need to firmly integrate marine sciences into education, laying the groundwork for an informed citizenry capable of protecting these critical ecosystems.

Complementing this global vision, the study Percepção dos impactos ambientais industriais em alunos da 8ª classe do Colégio BG 0007 Comandante Dangereux Catumbela, Angola, applies a focused diagnosis. Through a quantitative methodology, it evaluates the environmental awareness of young students regarding industrial impacts in their local community. The result is revealing and alarming: students do not have a satisfactory level of perception. This finding is a direct wake-up call for educational and environmental managers, as it highlights a dangerous disconnect between industrial reality and citizen training. Its reading is essential to understand the urgency of contextualizing environmental education, linking it to the real socioeconomic pressures that shape the immediate environment.

In response to these diagnosed shortcomings, the review Environmental education, responsible consumption and three R's: review to promote sustainable waste management practices. This article provides the necessary theoretical and strategic framework, synthesizing the state of the art of environmental education, responsible consumption and the Three Rs strategy as pillars for sustainable waste management. Its relevance is cross-cutting: it provides educators with a solid documentary basis for program design and offers policy makers a robust argument for prioritizing the circular economy. It constitutes an indispensable bridge between the identification of a problem and the formulation of a systemic educational response.

The response must also be scaled to broader institutional levels. The qualitative analysis Contribution of the Colombian National Army to environmental crime control and ecosystem restoration examines the role of a key institutional actor in environmental security. It documents operations against crimes such as deforestation and wildlife trafficking, while identifying critical challenges in technical capacity and specialized doctrine. This article is a must-read for governance and security analysts, as it expands the concept of protection to ecological integrity and raises a debate

the project has been designed to provide urgent assistance in strengthening state capacities for conservation in contexts of conflict or high pressure on natural resources.

Finally, this conceptual and strategic path finds its materialization in the Project of a photovoltaic solar energy plant for public lighting, in the center of the Amélia beach in Moçâmedes, Angola". This applied engineering work, through rigorous technical and economic dimensioning, demonstrates the concrete feasibility of a clean energy solution. It presents a replicable model with a positive return on investment and a quantified reduction in emissions. It motivates your reading by showing, with accurate data, how the energy transition is implemented at the local level, reminding engineering, urban planning and planning professionals that sustainability is built with tangible projects that improve community life and protect the climate.

Taken together, these five articles form an eloquent testimony to the necessary evolution in environmental science: from assessment to strategy, and from strategy to implementation. This issue is not a random collection, but a mosaic that, piece by piece, illustrates the full cycle of informed environmental action. We therefore issue a call to action to our global research community. We need to deepen this line of work: replicate diagnostics in new regions, evaluate the effectiveness of the proposed educational strategies in the field and document the long-term performance of technical solutions such as the one presented here. Transdisciplinary collaboration between scientists and researchers in education, social sciences, engineering and public management should be the norm, not the exception. We invite you to read this issue of the magazine as a roadmap and a starting point. May these studies not only inform, but inspire new questions, new collaborations and, above all, new concrete actions that close the gap between knowledge and practice that defines our times.

Editores Jefe / Editors-in-Chief / Editores-Chefes

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DISCOVERING THE SEA: AN ANALYSIS OF OCEAN AND POLAR LITERACY
Descubriendo el mar: análisis de los niveles de alfabetización oceánica y polar en una muestra de estudiantes universitarios

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ABSTRACT

Keywords:
Ocean and Polar literacy, SDG, Environmental Education, Socio-environmental Perception Spanish-speaking Population.

Ocean and Polar Literacy is the level of knowledge, awareness, and perception an individual has of these ecosystems. A high level of ocean and polar literacy allows for the transversal modification of behaviours across present and future generations through the development of critical thinking, promoting sustainable decision-making by. Ocean and polar literacy is therefore a fundamental tool for addressing the current environmental crisis. Nevertheless, there is limited existing evidence to diagnose the degree of ocean and polar literacy within communities, particularly in Spanish-speaking regions.

With the objective of assessing the degree of Ocean and Polar Literacy (knowledge, awareness, and socio-environmental perception), a pilot questionnaire was designed, consisting of 45 questions organized into five blocks. The instrument was constructed based on the adaptation and translation of validated questions from previous studies, complemented with newly developed questions. This tool was applied to a sample of university students in Spain and Latin America (n=273).

We observed that students pursuing studies related to geology have a better Ocean Literacy, highlighting the need to reinforce geology in the mandatory education curriculum. Better polar literacy was observed among respondents from Spain compared to those from Latin America. Contrary to expectations, no significant differences in ocean and polar literacy were found between those who have lived in coastal cities and those who have not. Despite these shortcomings, an encouraging finding is the great interest the surveyed population showed toward marine and polar ecosystems.

RESUMEN

Palabras clave:
Cultura Oceánica y Polar, ODS, Educación ambiental, Percepción Socioambiental, Población Hispanohablante.

La Alfabetización Oceánica y Polar (*Ocean* and *Polar literacy*) es el nivel de conocimiento, sensibilización y percepción que tiene una persona frente estos ecosistemas. Una buena alfabetización oceánica y polar permite modificar transversalmente las conductas de generaciones presentes y futuras, a través del desarrollo de un pensamiento crítico, promoviendo la toma de decisiones sostenibles por parte de los ciudadanos. La alfabetización oceánica y polar, es por tanto una herramienta fundamental para lidiar con la crisis ambiental actual. No obstante, son pocas las evidencias que existen para diagnosticar el grado de alfabetización oceánica y polar de las comunidades, en particular de aquellas de habla hispana.

Con el objetivo de evaluar el grado de alfabetización oceánica y polar (conocimiento, sensibilización y percepción socioambiental), se diseñó un cuestionario piloto que consta de 45 preguntas organizadas en cinco bloques. El instrumento se construyó a partir de la adaptación y traducción de preguntas validadas en estudios previos, complementado con preguntas de elaboración propia. Esta herramienta fue aplicada a una muestra de estudiantes universitarios de España y Latinoamérica (n=273).

Observamos que las personas que cursan estudios relacionados con la geología tienen una mejor alfabetización oceánica, destacando la necesidad de reforzar la geología en el currículo de educación obligatoria. Se observó una mejor alfabetización polar en los encuestados procedentes de España respecto a los de Latinoamérica. Contrario a lo esperado, no se encontraron diferencias significativas en el nivel de alfabetización oceánica y polar entre los que han vivido en zonas costeras y quienes no. A pesar de estas carencias, un hallazgo alentador es el gran interés que la población encuestada mostró hacia los ecosistemas marinos y polares.

Introduction

The Earth is the only planet in the solar system whose pressure and temperature conditions allow the existence of up to 70% liquid water on the surface. Of this water, 97% is found in the oceans, which gives them a determining role in the regulation of the earth's climate, storing large amounts of excess solar radiation in the form of latent heat and acting as the largest long-term CO^2 sink (Sabine et al., 2004). Thanks to the action of the ocean biosphere, the ocean contributes to the regulation of the chemical composition of the atmosphere, releasing approximately 50% of the oxygen we breathe, and sequestering 40% of atmospheric CO^2 emitted by human activity (Field et al., 1998; Falkowski, 2012; Sabine et al., 2004).

In economic terms, the ocean is a crucial resource for the development of activities such as fishing, tourism, trade, energy generation, and international transportation. Fifteen percent of the protein we consume comes from ocean fisheries and is the most traded natural product in the world (FAO, 2020). Additionally, more than 40% of the world's population lives in areas within 200 km of ocean and 12 out of 15 megacities are coastal (Visbeck, 2018). The global ocean economy is estimated to move about €1.38 trillion and is expected to increase to €2.7 trillion by 2030 (Sumalia et al., 2021). Unfortunately, rapid human population growth and industrial development are putting increasing pressure on marine ecosystems, degrading their productivity and biodiversity.

Polar regions are regions with permanent ice, which are fundamental in the earth's energy balance due to their high albedo index, which reduces the net energy input that reaches the earth's surface through solar radiation. In addition, they are ecologically stable areas that have developed high biodiversity and complex food webs (Gili et al., 2000). The ice caps have changed throughout the Earth's history as a function of the variation of the Earth's orbit and the amount of solar radiation received. Currently, the North Pole experiences very strong seasonal variations, which increase the ice surface of the ice floe by up to 6 times during the boreal winter compared to the summer. In contrast, seasonal changes at the South Pole are not as drastic, so Antarctica is always covered with snow, and only the surrounding ice floe varies seasonally in extent. Consequently, at present, seasonal variations at the north pole have a greater influence on the climate system (Ruddiman, 2001).

Despite their importance, both the oceans and the polar regions are suffering strong alterations as a result of intense human activity, including processes such as acidification of waters following high CO_2 emissions, loss of marine biodiversity due to overfishing of resources, eutrophication of coastal margins due to inadequate management of organic waste, or pollution due to increased microplastics (Pörtner et al., 2019). The case of the poles is particularly worrisome, because despite representing remote places for most of the population, the expansion of tourism, hydrocarbon extraction, and increased fishing have increased the environmental impact on these regions. Likewise, their natural wealth has led to increasing geopolitical tension over these regions in recent years (Seethi, 2023).

UNESCO defines *Ocean Literacy* as a person's understanding of the impact the ocean has on his or her life and the impact he or she has on the ocean. In addition, the *Polar Literacy Initiative* defines *Polar Literacy* as an understanding of the fundamental concepts of the Arctic and Antarctic, their essential role in regulating the global climate system, and the connection of their ecosystems to the rest of the world, which empowers the individual to make informed decisions about these critical environments. So far, these concepts have been treated independently in the literature and their integration into a joint framework is not yet sufficiently developed. This paper proposes the notion of “oceanic and polar literacy” as a conceptual approach that allows for an integrated analysis of the understanding of marine and polar ecosystems. Therefore, Ocean and Polar Literacy would be defined as a person's level of knowledge and perception of these ecosystems and understanding of the influence of the ocean

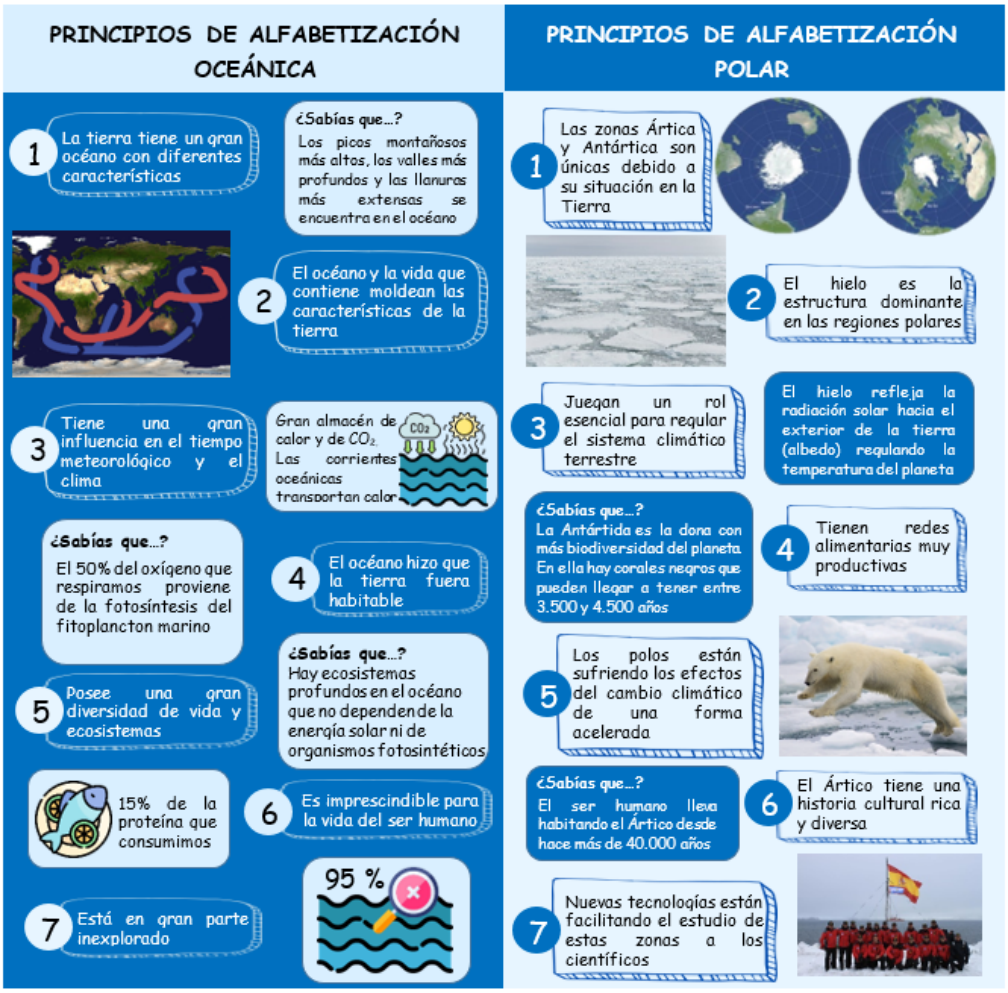
and polar regions on society and vice versa (McKinley et al., 2025; Borja et al., 2020; Schoedinger et al., 2006; Kelly et al., 2021). Adequate literacy implies awareness, sensitization and motivation to make more environmentally sustainable decisions (Cava et al., 2005), making it an essential tool for dealing with the environmental crisis, reducing the impact on oceanic and polar ecosystems.

The term Ocean Literacy was first used in 2002 by educators, researchers and policy makers belonging to the U.S. Ocean Policy Commission, who identified a total lack of public awareness of the relevance of marine and polar ecosystems (Cava et al., 2005). This problem was related, among other causes, to the absence of curricular content that appropriately addressed these issues during secondary education. Therefore, they proposed to develop a theoretical framework for education -Ocean Literacy- in order to help the next generations adopt more responsible and sustainable attitudes towards these environments, thus contributing to reducing the climate crisis.

Similar strategies and efforts to increase ocean and polar literacy have been followed by various countries and organizations (Fauville, 2018). In 2015, UNESCO consolidated the Education 2030 Agenda in which it proposed 17 Sustainable Development Goals (SDGs). In particular, Goal 4 reflects the importance of the educational response not only as a goal, but also as a means to achieve the other SDGs, and Goal 14 calls for the protection of underwater life. In Spain, the National Center for Environmental Education (CENEAM), a reference entity in education for sustainability belonging to the Ministry for Ecological Transition and Demographic Challenge, developed 7 key principles for ocean literacy proposed by Chicote and Pujana (2016) and Santoro et al. (2017), and the community of polar scientists and educators known as Polar-ICE developed 7 principles for polar literacy (polar-ice.org/polar-literacy-initiative/). These principles are summarized in Figure 1.

Figure 1

Summary of the 7 principles of ocean and polar literacy, developed by Chicote and Pujana (2016) and *Santoro et al. (2017), in Spain and the Polar-ICE group, respectively*



People's lack of knowledge about the consequences of their actions on the environment is one of the main factors that have a negative impact on biodiversity and ecosystems. Therefore, it is essential to develop communication, outreach and education initiatives that help the population to (i) know and understand the influence of the ocean and the poles on their lives, (ii) increase awareness of the climatic, economic, political, medical and cultural importance of these environments, (iii) sensitize communities to make more responsible and sustainable decisions regarding the use of these critical ecosystems, (iv) connect different sectors of society to create a common ground that allows a joint understanding and approach to the complexity of achieving a more sustainable society (Santoro et al., 2017; Fauville, 2018). However, in order to develop these communicative, informative and educational strategies, it is first essential to analyze the population's knowledge of these ecosystems and identify which areas of their knowledge about these media require further reinforcement. Most previous studies assessing oceanic and polar literacy have focused primarily on the United States, Canada, and Italy (e.g., Costa and Cadeira, 2018; Realdon et al., 2019; Ashley et al., 2019). Unfortunately, such studies are still scarce in Spanish-speaking countries, which represent 5.91% of the world's population (about 473 million people; The World Bank, 2024).

The study of ocean and polar literacy in the university population is particularly relevant, as most students have recently completed compulsory education. Analyzing their knowledge of oceanic and polar ecosystems allows us to identify possible shortcomings that should have been addressed in previous educational phases. In addition, several studies (e.g., González-Rodríguez, 2024) point out that the university is an ideal context to promote socio-environmental literacy and strengthen students' engagement with global challenges related to

oceans and climate. These learnings are essential for our society, since university students represent a key community in the generation of critical thinking, innovation and social leadership in the face of contemporary environmental challenges. Fostering in them a deep and responsible understanding of the oceanic and polar systems contributes to the development of citizens capable of promoting sustainable actions and actively participating in decision making aimed at protecting the planet. In response to these needs, the present work has three main objectives. To develop a pilot questionnaire for the measurement of oceanic and polar literacy in a sample of Spanish-speaking university population, through the collection, translation and adaptation of questions validated in the scientific literature, complementing the instrument with self-developed items. Second, to analyze oceanic and polar literacy levels in relation to educational and sociodemographic variables such as area of study, academic level, region of origin, age and time spent living in coastal areas. Finally, identify the thematic areas with lower levels of knowledge and awareness in order to guide reinforcement strategies in secondary education and foster greater understanding and awareness of these ecosystems.

Method

An anonymous pilot survey was conducted using the Qualtrics platform (https://www.qualtrics.com/) to assess the level of ocean and polar literacy of a sample of undergraduate, master's and doctoral students from Spain and several Latin American countries, mainly Argentina, Peru and Colombia. The designed pilot survey was available online from April 10 to April 30, 2024.

The questionnaire was developed from a combination of sources: questions taken and translated from previous studies that have proven useful for assessing ocean or polar literacy, modified questions, and self-developed material. Specifically, for ocean literacy, most of the content was adapted and translated from Guest et al. (2015) and, to a lesser extent, from Koulouri et al. (2022). For polar literacy, most of the questions are self-developed due to the scarcity of available evaluation studies. However, to measure awareness and socio-environmental perception of the polar ecosystem, questions were adapted from Hamilton et al. (2008). Tables 3, 4 and 5 specify, next to each item, the article from which it was taken or modified; the questions without reference are self-referenced.

Structure of the Survey

The survey consisted of 45 questions distributed in five thematic blocks (see Annex I), designed to collect information in a progressive and coherent manner with the objectives of the study:

- Block 0. Introduction and consent

This first block presented a brief explanation of the purpose and operation of the survey. In addition, it requested the informed consent of the participant to ensure their voluntary participation and verified that they were at least 18 years old, the legal age of majority in Spain.

- Block 1. Sociodemographic profile and self-perception

Consisting of 14 questions, the purpose of this block was to anonymously define the profile of the participants. Questions related to age, city of origin and residence, years lived in coastal areas, educational level and studies completed were included. Respondents were also asked to rate, on a scale of 0 to 5, how much they thought they knew about various topics: international

politics, economics, science and technology, climate change, oceans, and polar regions (north and south).

- Block 2. Ocean Literacy (Ocean Knowledge)

This block consisted of 12 questions aimed at assessing the level of knowledge about ocean ecosystems. Each correct answer was valued with 1 point, so that the total score of each participant could range from 0 to 12 points.

- Block 3. Polar Literacy (Polar Knowledge)

Composed of 6 questions, this block had the purpose of measuring the degree of knowledge about polar ecosystems. As in the previous block, each correct answer was equivalent to 1 point, with a possible final score between 0 and 6 points.

- Block 4. Awareness and socio-environmental perception

Finally, this block included 8 questions aimed at ascertaining the level of awareness and socio-environmental perception of respondents with respect to oceanic and polar ecosystems, as well as their attitudes towards global environmental challenges

Statistical Treatment of Data

From the answers to the questions in Blocks 2 and 3, a score of *Ocean knowledge* and *Polar Knowledge*was obtained for each respondent, respectively. For each question, the existence or not of a normal distribution was determined using the Shapiro test, and the presence of significant differences between the means of different population groups was evaluated using the Spearman or Krustall-Wallis test, depending on the type of question. The analyses were performed in the R program (R Core Team, 2024) and the results were plotted with SPSS software.

Sampling Method

The sampling method used was by convenience, and the selection could not be completely random due to the impossibility of exhaustively accessing all the universities. A dissemination and open invitation to participate was made, mainly to universities in Spain, Argentina, Peru and Colombia. Responses were therefore voluntary among those who chose to participate. To mitigate the limitations of this sampling, respondents were separated into groups according to key variables such as the type of studies they have completed, whether they have lived more than 50% of their life in a coastal city and their place of origin (Spain or Latin America), thus allowing an analysis of the relationships between these variables and knowledge.

A total of 460 survey responses were received, but responses from those who did not sign the initial consent form or did not complete the survey were discarded. Likewise, the responses of those who did not fall into the category of university student, those who did not specify the area of study (subject of the bachelor's, master's or doctoral program), and those who did not indicate their country of origin were discarded. After applying these exclusion criteria, the initial sample of 460 people was reduced to 273. The target population of the study, Spanish-speaking university students, is estimated at 12.7 million enrolled in 2024 (Instituto Cervantes, 2024). Therefore, for a sample of this population to be statistically representative, a sample size of 385 people is required for a confidence level of 95% with a margin of error of ±5% (Hernández Sampieri et al., 2014). Since the number of useful responses did not reach this threshold, the sample of this study cannot be considered statistically representative. Therefore,

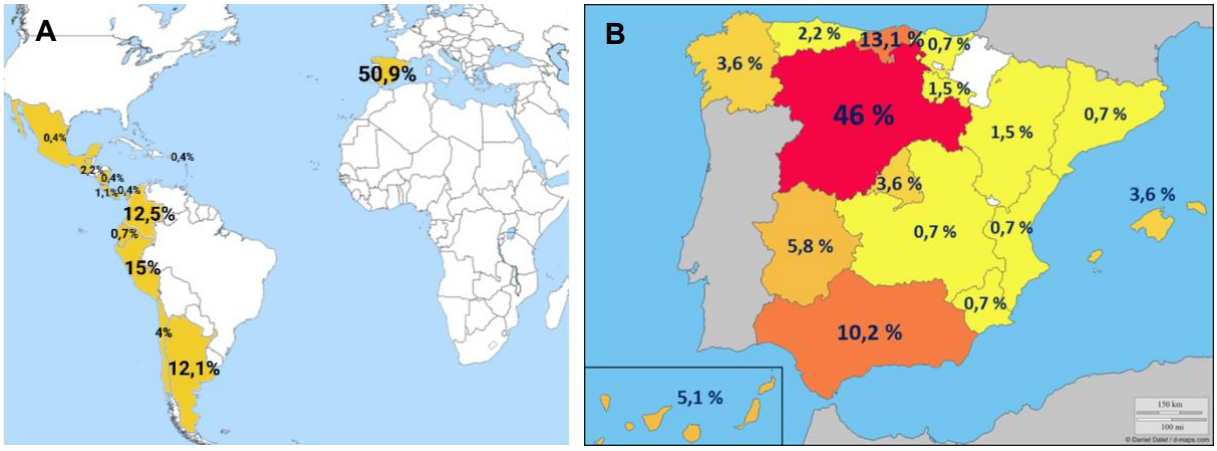
the results obtained cannot be extrapolated to the total Spanish-speaking university population. Nevertheless, this work constitutes a valuable first approach to extrapolate perceptions and knowledge levels in this population, serving as a pilot study to lay the groundwork for future research with a larger sampling effort.

Sample

Respondents came from 12 different Spanish-speaking countries (Figure 2), including Spain (50.9% of respondents), Peru (15%), Colombia (12.5%), Argentina (12.1%), Chile (4%), Guatemala (2.2%), Costa Rica (1.1%), Ecuador (0.7%), Mexico (0.4%), Nicaragua (0.4%), Panama (0.4%) and Puerto Rico (0.4%). Of the Spanish respondents to the survey, the majority (46%) were from Castilla y León. The majority of respondents are between 18 and 25 years old (60.1% of respondents), 28.9% are between 36 and 40 years old and 11% are between 40 and 100 years old.

Figure 2

A) Composition of the sample population studied according to their country of origin. B) Composition of the Spanish sample according to the autonomous community of origin.



Note. The color code refers to the percentage of respondents corresponding to each autonomous community (yellow < 2.5%; orange 2.5-10%; dark yellow 10-20%; red > 20%).

Although an effort was made to obtain relatively similar sample sizes among all Spanish-speaking countries, the sampling achieved is not uniform across countries. However, all of the subgroups discussed below (other than the country of origin) are sampled uniformly.

As shown in Table 1, the sample is mostly composed of Biology students (63.8%), coming from non-coastal regions (53.1%). In terms of geographical origin, the representation between Spain (50.9%) and Latin America (49.1%) is balanced, allowing a comparative analysis between the two contexts. Table 2 shows that the majority of participants are in the 18-25 age range (60.1 %), reflecting a young university population, followed by the 36-40 age group (28.9 %).

Table 1

Composition of the different established population groups

Sample composition										
Studies	**N**	**%**	**Bio vs Geo**			**Proximity to the coast**	**N**	**%**	**Region**	**N**	**%**
BioGeo	152	55,6	Biology	97 N	63,8 %	Coastal	128	46,9	Spain	139	50,9
			Geology	55 N	36,2 %						
Others	121	44,3				Non-coastal	145	53,1	Latin America	134	49,1

Table 2
Age of participants

Sample age		
Age range	**N**	**%**
18-25	164	60,1
36-40	79	28,9
40-100	30	11

Results

The results presented below provide a detailed view of the oceanic and polar literacy level of the surveyed university population. To ensure clarity and rigor in the analysis, the data are organized according to the thematic areas of the questions and under the heading of "ocean and polar literacy: Strengths and Weaknesses in Knowledge" shows the oceanic and polar literacy assessment of the sample.

Thematic Areas

The questions in the questionnaire were classified into different thematic areas according to their relationship with biological (marked in green in Table 3), geological (in red) and geographical (in purple) concepts. This classification makes it possible to identify with greater precision the areas of knowledge in which the surveyed university population presents greater strengths or weaknesses. As shown in Table 3, the results show that students are more familiar with the contents related to ocean biodiversity, reaching an average of 93.23% correct answers. On the other hand, items related to biochemical, physical and chemical processes, such as oxygen and carbon dioxide balance, the hydrological cycle or the chemical composition of seawater, show considerably lower percentages of correct answers (42.49%). Similarly, the geological questions, which deal with aspects such as the origin of the rocks that form the mountains or the basic characteristics of the polar regions, obtain low scores (42.71%), showing a lower mastery of these contents.

Oceanic and Polar Literacy: Strengths and Weaknesses in Knowledge

Table 3 shows the questions from the Guest questionnaire that assess ocean and polar literacy, as well as the percentage of respondents who answered each question correctly.

Table 3

Questions used to assess ocean and polar literacy.

QUESTIONS	% correct answers	
Ocean literacy		**Associated principle**
1. The oceans occupy 70 % of the planet's surface (Guest et al., 2015)	95,97%	1
2. Oceans absorb more CO_2 from the atmosphere than inland terrestrial plants (Modified from Guest et al., 2015)	71,06%	3
3. Marine microorganisms contribute more oxygen to the atmosphere than terrestrial plants	13,92%	4
4. More and more tsunamis will occur due to climate change	33,33%	
5. The majority of living beings that live in the oceans are fish	84,62%	5
6. In the deepest part of the ocean there is no life because no light reaches it (Modified from Koulouri et al., 2022)	93,77%	5
7. How deep is the deepest area on the planet? (Guest et al., 2015)	66,67%	1
8. Most of the rainwater that falls on the continent comes from: (Koulouri et al., 2022)	33,70%	3
9. The salt in the oceans comes from: (Guest et al., 2015)	27,47%	1
10. A whale is: (Guest et al., 2015)	97,44%	5
11. What is plankton? (Modified from Guest et al., 2015)	97,07%	5
12. If you find marine fossils in the rocks of a mountain, it means (Modified from Koulouri et al., 2022)	52,38%	2
Polar literacy		**Associated principle**
1. The North Pole is an ice sheet floating in the Arctic Ocean	61,9%	2
2. The melting of the North Pole will not affect Spain's climate because it is quite far away	91,21%	3
3. In the Arctic there are indigenous populations living	61,90%	6
4. Antarctica is an ice sheet floating in the ocean	64,84%	1
5. At the South Pole it is always night	78,02%	1
6. There is almost no aquatic life in the Arctic and Antarctic oceans due to extreme temperatures	83,52%	4

Note. The colors refer to the subject area of each question. The green ones evaluate biological concepts, the red ones geological and the purple ones geographical. Each question has been associated with an oceanic and polar literacy principle.

Ocean Literacy: In relation to the results presented in Table 3, and specifically with the items related to ocean literacy, it can be seen that the vast majority of respondents demonstrate adequate knowledge of basic biological aspects of the marine environment: 97.4% correctly identify that a whale is a mammal, and 97.07% understand the meaning of the term plankton. The students demonstrated a good level of knowledge regarding principle number 1 ("The earth has a large ocean with different characteristics") as 95.97% are aware of the large dimensions that the oceans occupy on our planet. Similar results were observed in other studies (Camargo, 2023). However, only 13.92% know that the oxygen that marine organisms contribute to the atmosphere is similar to that of terrestrial plants. It is also worth noting that only 27.47% know where the salt in the oceans comes from and only 33.7% know where the continent's rainwater comes from. Analysis of the results reveals that the university students surveyed have a greater knowledge of marine biodiversity than of the physical, chemical and

geological processes of the ocean. In a study conducted by Camargo (2023) in Colombia, they used a survey in which they included similar questions and students had the lowest values in the question about where most of the oxygen in the atmosphere originally came from (only 16 points out of 123) and in the question about the origin of salt in the ocean (22 points out of 123). This suggests that the data from this study are consistent with previous findings regarding knowledge deficiencies in these specific areas in Spanish-speaking countries.

71.06% of respondents are aware of the ocean's important role as a CO_2 sink. However, only 66.67% are aware of how deep the ocean can be. It is worth noting that only 52.38% are aware that part of the rocks that form continental mountains originate in the oceans, and that later, due to tectonics, after millions of years, they can be found in the mountains, sometimes finding marine fossils inside them.

As for the question referring to a tsunami, it is noteworthy that only 33.33% of the respondents answered correctly. A tsunami is mostly caused by an earthquake that takes place under the sea, without any causal relationship with the weather. It is interesting to find that there is a growing tendency in the general population to think that catastrophic events such as volcanic eruptions and earthquakes will increase due to climate change and they are unaware that considering these are not conditioned by the climate, but by the processes occurring in the interior of the Earth. This lack of knowledge is evidence of a generalized lack of training in geology throughout the secondary education process.

Polar literacy: In general, respondents scored better than for ocean literacy, although they seem to have a geographical lack of knowledge of the polar areas. 38.1% consider that all the ice at the North Pole is continental and 35.16% are not aware that the ice at the South Pole is mostly continental and their conception of Antarctica is that of an ice floe floating on the Antarctic Ocean. 91.21% are aware that the melting of the poles will have consequences throughout the world, even in the areas farthest from them, 83.52% know that Antarctica, despite being one of the places with the most extreme climate, harbors life in its waters. Finally, 78.02% recognize how seasonality works at the poles.

Study Area

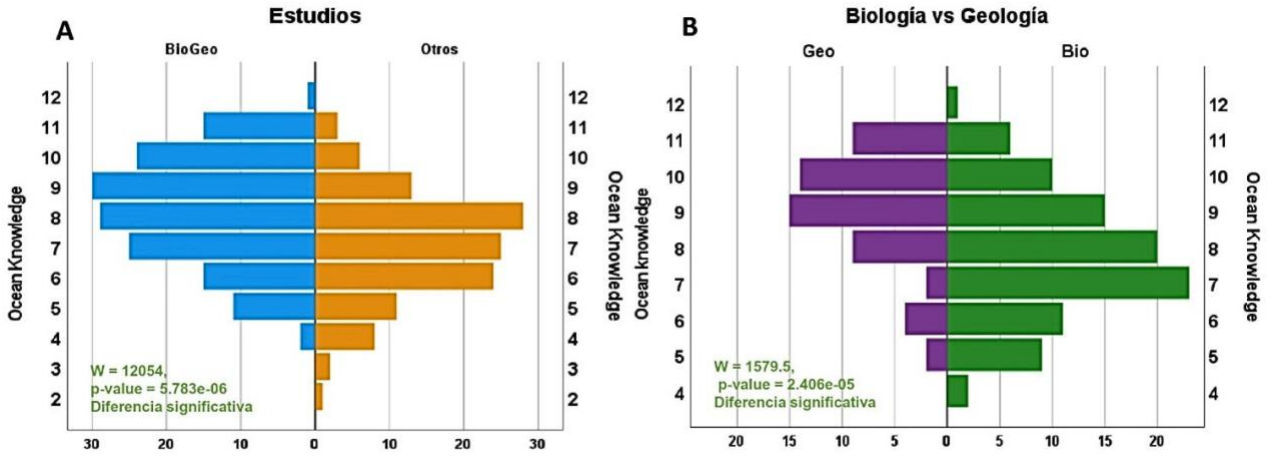
Respondents were divided into the "BioGeo" group, consisting of those studying disciplines related to biology and geology (bachelor's or master's degree in geology, biology, biochemistry, biotechnology and environmental sciences); and the "Other" group, which includes students from other disciplines. A total of 55.6% of the respondents belonged to the "BioGeo" group and 44.3% to the "Others" group (Table 1). This separation was made considering that biology and geology students should have more knowledge about the oceans and poles as these are topics specific to these disciplines. The "BioGeo" group was subdivided into those studying biology (and related subjects) and those studying geology (and related subjects). The "Biology" group constitutes 63.8% of the "BioGeo" group and the "Geology" group 36.2%.

Analysis of the results revealed a clear correlation between the area of study and the *Ocean knowledge* of the respondents. As expected, students in the "BioGeo" group showed higher *Ocean Knowledge* than those in the "Others" group (Figures 3A and 3B). However, the examination of the "Geology" subgroup with respect to the "Biology" subgroup shows a result of great relevance: the "Geology" students exhibited superior *Ocean Knowledge* . In addition, in the overall percentages of correct scores, regardless of the area of study, there are significant deficiencies in basic geological concepts. This problem seems to occur in both Spanish and Latin American schools, because geology is often overshadowed by biology, which receives much

more attention in the didactic programs. The observed results support the notion that there is a significant shortage of attractive and accessible educational resources for teaching geology, and that teachers themselves lack solid training in this subject (García-Yelo et al., 2022). This situation suggests a promising avenue for enhancing ocean literacy in the general population.

Figure 3

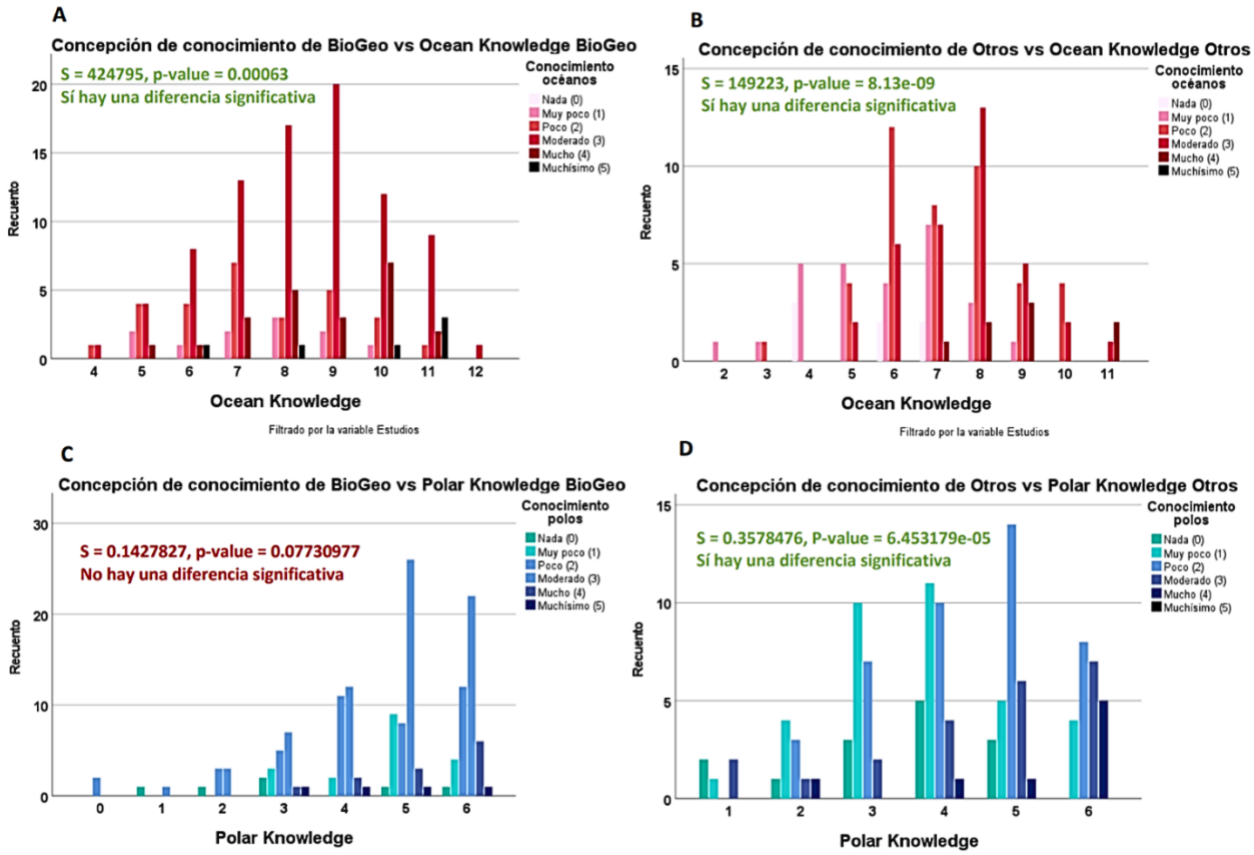
A) Ocean Knowledge score from 0 to 12 of people belonging to the "BioGeo" group (blue color) with respect to the members of the "Others" group (orange). B) Ocean Knowledge of respondents who are pursuing university studies in geology (purple color) compared to those studying biology (green color).



Differences in self-perceived knowledge about the oceans between the "BioGeo" and "Other" groups were evaluated, which allows us to know if each group's self-perceived knowledge about oceans and poles is consistent with the level of knowledge they have demonstrated in the survey. In general, members of the "BioGeo" group tend to report a higher level of prior knowledge about ocean issues compared to the "Other" group, suggesting a relationship between their academic or professional background and their confidence in this area. Figures 4A and 4B show the *Ocean Knowledge* of respondents belonging to the "BioGeo" and "Other" groups, respectively, and the color scale indicates the knowledge they previously believed they had about the oceans. Similarly, Figures 4C and 4D show the self-perceived knowledge for the *Polar Knowledge* of "BioGeo" and "Others" respectively. Similar trend is observed, with the "BioGeo" group showing a higher self-perception of knowledge compared to the "Others" group. This difference could be associated with the degree of previous exposure or familiarity with content related to polar regions. However, this is not the case for the "Others" group. This group has a lower perception of their knowledge of these ecosystems than they have demonstrated, i.e., they believe they know less than they actually do. Overall, the data indicate that the educational profile of the respondents influences their perception of their own level of knowledge of oceanographic and polar issues.

Figure 4

A) Ocean Knowledge of the "BioGeo" group regarding their conception of their knowledge about the oceans; B) Ocean Knowledge of the "Others" group regarding their conception of their knowledge about the oceans; C) Polar Knowledge of the "BioGeo" group regarding their conception of their knowledge about the poles; D) Polar Knowledge of the "Others" group regarding their conception of their knowledge about the poles.



Age Range (in Covariance by Branch of Study)

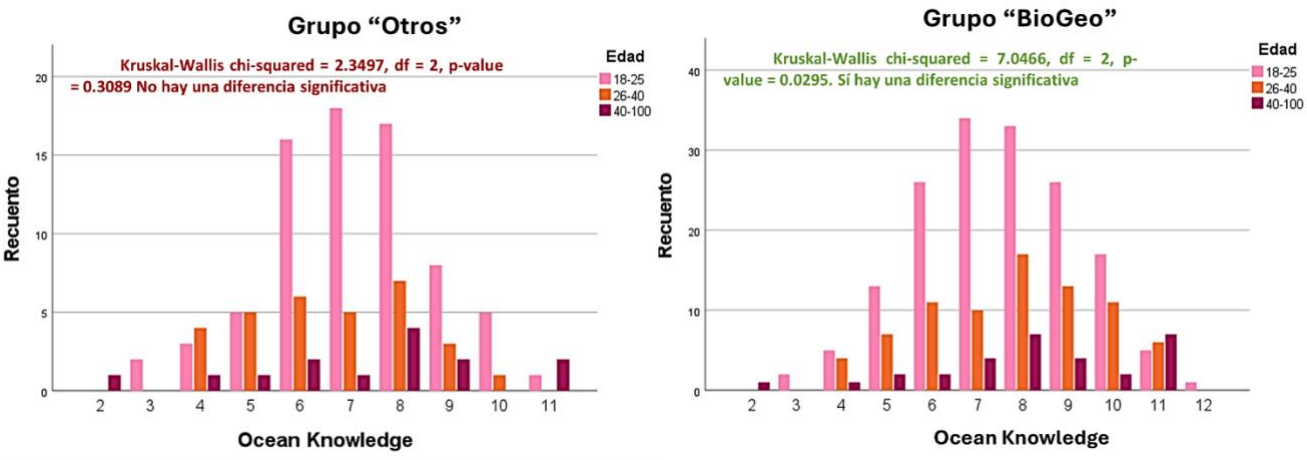
The objective of this subgroup is to assess whether there are differences in the knowledge and perception of the ocean and the poles as a function of the age of the participants. For this purpose, respondents were divided into three age ranges (Fig. 4): 18 to 25 years old (60.1% of the sample), 36 to 40 years old (28.9%) and 41 to 100 years old (11%).

Comparing the scores obtained as a function of age, no direct relationship was observed between age and Ocean or *Polar Knowledge*. However, analyzing the responses according to the age group of the respondents, it can be seen how for the "BioGeo" group both Ocean (Figure 5B) and *Polar Knowledge* have a direct relationship with age according to the Kruskal-Wallis analysis performed. As respondents have been studying these disciplines for longer, they become more ocean and polar literate. However, for the "Others" group, no relationship with age was observed (Figure 5A). Within this group, the respondents with the highest scores are those between the ages of 18 and 25. Specifically, it refers to the population group that has most recently completed compulsory secondary education. However, the score for the rest of the age groups is much lower. This highlights that in the general population there is only an age window during the secondary education stage in which the population acquires knowledge about the

ocean, poles and climate change and this knowledge does not increase with age. The same phenomenon was also observed for *Polar Knowledge*.

Figure 5

Respondents classified by age group. Those between 18 and 25 years of age are shown in pink; those between 26 and 40 years of age are shown in orange; those over 41 years of age are shown in red.



Living Time in a Coastal City

This classification is made considering whether the respondent has lived more than 50% of his or her life in a coastal city. This subgroup sought to assess whether there really is a greater knowledge and/or awareness of the ocean in the populations of coastal regions. However, after evaluating the means by group, no significant differences were found, indicating the apparent irrelevance of this variable.

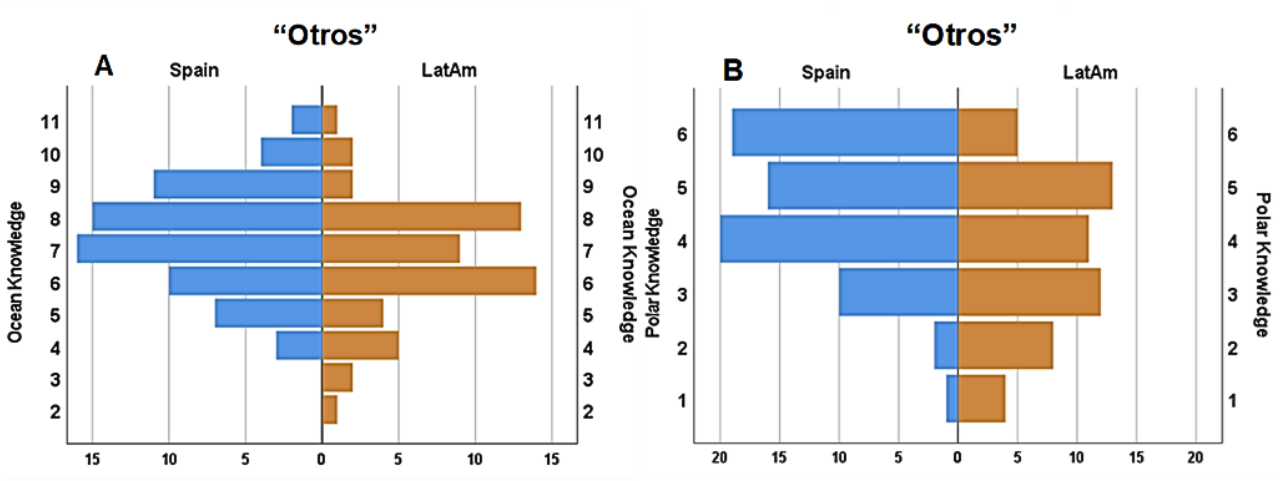
Origin (Spain or Latin America)

The survey was disseminated to different universities in Spain and Latin America. After analyzing whether there is any difference between the *Ocean* and *Polar Knowledge* of the Spanish respondents ("Spain" group) with respect to the group of people from Latin America ("LatAm" group), no significant differences were observed between groups. However, when evaluating the covariance between place of origin and the area of study of the respondent, it is observed that for the respondents of the "BioGeo" group, there is no significant difference in their *Ocean* and *Polar Knowledge* depending on whether they belong to the "Spain" or "LatAm" group. This implies that *Ocean* and *Polar Knowledge* is superior regardless of the place of origin. On the contrary, in the "Others" group, there is a significant difference between the *Ocean* and *Polar Knowledge* of students from Spain with respect to those from Latin America (Figure 6A and 6B). The former scored higher in both *Ocean Knowledge* and *Polar Knowledge*. This seems to reflect that the general university population in Latin America has lower oceanic and polar literacy than their peers in Spain. In the context of Latin America, despite countries such as Colombia that have a large coastal extension in the Sea, the progress of ocean literacy has not

been as expected since compulsory education curricula have excluded ocean topics (Mogias et al., 2019).

Figure 6

A) Ocean Knowledge score from 0 to 12 of university students belonging to the "Others" study group surveyed in Spain (blue) compared to those in Latin America (brown). B) Score from 0 to 6 of the Polar Knowledge of both groups.



Awareness and Socio-Environmental Perception

The assessment of ocean and polar literacy of a population sample is not only to assess knowledge about these ecosystems (i.e., *Ocean* and *Polar Knowledge*), but also to consider and assess the attitude, behavior and awareness of the respondents with respect to these ecosystems.

In this sense, the questions in Block 4 (Tables 4 and 5) focused on evaluating these aspects. Overall, it seems that most respondents are aware that the ocean plays an important role in their lives (63.97%) and 51.1% would be interested in knowing much more about it. Most of them seem to be aware of climate change since 85.66% responded that they did not consider that the climate crisis was being exaggerated. As for the factors on which humans depend mainly on the oceans, the most voted were "Food" with 28.49%, "Climate Regulation" with 26.34% and "Source of Oxygen" with 21.68%. These values suggest that the surveyed university population is aware of the large role the ocean plays in our lives.

The questions "In what year is the extinction of polar bears expected?" and "The ice at the North Pole will be completely thawed" are intended to assess the level of alarmism of the surveyed population regarding these two phenomena closely related to climate change (i.e., loss of biodiversity and sea level changes). For the bear response, 54.41% answered "I don't know", and for the statement on the melting of the North Pole, the responses were almost 50% affirmative and negative. Although there is a slight predominance of affirmative responses, it can be concluded that there is no alarmism. However, it is noteworthy that when the results are considered with respect to the "studies" variable, people in the "BioGeo" group (58.28%) show a somewhat more alarmist view of the melting of the North Pole than those in the "Others" group (48.33%). This increased alarmism and awareness could be linked to the greater oceanic and polar knowledge (*Ocean* and *Polar Knowledge*) demonstrated by this group in the survey.

Finally, the question "Would you support Antarctica being reserved for:" is intended to show respondents' awareness of this place. Considering that greater awareness implies responding that they would support reserving Antarctica for "none of these purposes" and/or for "scientific purposes only", when analyzing the responses according to the "studies" variable, we find that both the "BioGeo" and "Other" groups are sensitized to this place. A 77.5% of the "Others" group said that they would reserve it only for scientific purposes compared to 80.13% of the "BioGeo" group, while 2.65% of the "BioGeo" group answered that they would reserve it for none of the proposed purposes, compared to 6.67% of the "Others" group. It is worth noting that when both responses are combined, awareness is higher for the "Others" group. Likewise, the answer "for scientific, tourism and economic purposes" had 10% of responses in the "Others" group versus 13.91% in the "BioGeo" group. These results show, therefore, that the "Others" group has a more restrictive attitude towards site exploration, which could be related to the underestimation of the value of the scientific knowledge provided by the study of these areas. This perspective suggests a lack of familiarity with the fact that research in these environments need not result in environmental degradation, as long as appropriate conservation measures and sustainability protocols are implemented. As for the rest of the thematic areas, no significant relationship was found between attitude and behavior as a function of place of origin or age.

Table 4

Questions asked to assess attitude, behavior and awareness of the oceans and poles.

QUESTIONS					
Awareness and socio-environmental perception					
How important is the ocean to you? (Guest et al., 2015)					
Don't know (0)	Very little (1)	Little (2)	Moderate (3)	A lot (4)	Very much (5)
0 %	0,37 %	0 %	9,19 %	25,74 %	63,97 %
To what extent would you be interested in learning more about the ocean? (Guest et al., 2015)					
Don't know (0)	Very little (1)	Little (2)	Moderate (3)	A lot (4)	Very much (5)
0 %	0 %	2,57 %	14,34 %	31,62 %	51,10 %
Do you think the climate crisis is being exaggerated?					
Yes		No	I do not know		
8,82 %		85,66 %	5,15 %		
Point out the three ways in which you believe humans benefit most from the ocean (Guest et al., 2015)					
Food		Medicines	Climate regulation		Boat transportation
28,49 %		1,43 %	26,34 %		9,68 %
Power generation		Mineral extraction	Oxygen source		Recreation
6,99 %		2,15 %	21,68 %		3,23 %
To what extent is the ocean explored?					
Don't know (0)	Very little (1)	Little (2)	Moderate (3)	A lot (4)	Very much (5)
0 %	34,8 %	47,62 %	11 %	4,4 %	1,47 %
To what extent does the ocean influence the climate of the continents?					
Don't know (0)	Very little (1)	Little (2)	Moderate (3)	A lot (4)	Very much (5)
0 %	0,37 %	0,37 %	4,76 %	31,14 %	62,64 %
What year is the estimated extinction of polar bears? (modified from Hamilton 2008)					
I do not know	2030	2040	2050	2100	

54,41 %	8,82 %	10,66 %	17,28 %	9,19 %

Table 5
Questions asked to evaluate the attitude, behavior and awareness of the poles.

Studies	**The North Pole ice will be completely thawed** (Hamilton, 2008)			
	TRUE		FALSE	
All	53,87%		46,13%	
BioGeo	58,28%		41,72%	
Others	48,33%		51,67%	
Studies	**I would support Antarctica being reserved for:** (Modified from Hamilton, 2008)			
	I do not know	for scientific purposes only	for scientific, tourism and economic purposes	for any of these purposes
All	4,41%	78,68%	12,13%	4,41%
BioGeo	3,31%	80,13%	13,91%	2,65%
Others	5,83%	77,50%	10,00%	6,67%

Discussion and Conclusions

The results of this study highlight the need to improve oceanic and polar literacy in the Spanish-speaking population. As anticipated, students majoring in biology and geology expressed a higher level of ocean and polar literacy than the rest of the surveyed population (McKinley et al., 2025; Guest et al., 2015).

A particularly relevant and noteworthy finding is that, within this specialized group, geology students demonstrated superior oceanic knowledge. This underscores the critical importance of geology as a fundamental discipline for understanding the physical, chemical and geological processes that regulate these ecosystems. Given that geology is often invisible or marginalized in the compulsory education curriculum (García-Yelo et al., 2022), reinforcing its teaching in these early stages represents a transversal and effective strategy. This would not only directly improve ocean and polar literacy, but also the overall understanding of the current climate crisis (Metzger, 2024). In other studies, a relationship has been documented in which students with a higher level of ocean literacy tend to manifest a stronger and more positive appreciation of the marine environment (Guest et al., 2015).

In the specific context of polar literacy, a significant difference linked to geographical origin was identified: students from Latin America who did not study disciplines related to biology or geology showed a lower level of *Polar Knowledge* than those from Spain. This finding suggests that strategies to foster ocean and polar literacy should be adapted to the particularities of each region, with special emphasis on the general community that is less involved with topics in areas related to the natural and Earth sciences (UNESCO, 1977).

Contrary to what might be expected, no statistically significant differences in the level of oceanic and polar literacy were detected between those who have resided in coastal cities and

those who have not. This result is consistent with previous studies and suggests that geographic proximity, by itself, is not a determining factor in generating in-depth knowledge or effective awareness of these ecosystems (Fauville et al., 2019). However, in a study conducted in Nova Scotia, students had in their day-to-day lives greater interaction with the ocean, demonstrated higher levels of knowledge (Guest et al., 2015).

Generally, teachers identify that the main obstacles that hinder the process of teaching ocean culture are funding, the interest of educational institutions in including marine environmental education activities, and the support of other institutions (Camargo, 2023). Contrary to what might be expected, access to information technology (computer and internet) has been ruled out as an obstacle to teaching ocean literacy. Furthermore, it has been observed that such access does not significantly influence the level of knowledge possessed by students (Camargo, 2023).

Finally, despite the identified gaps, in several aspects of ocean and polar literacy, the surveyed population has shown interest and curiosity towards ocean and polar ecosystems. This result is highly encouraging as it evidences a solid motivational base upon which effective educational programs can be developed and implemented, fostering a comprehensive and critical understanding of the complex relationship between the oceans, the poles and contemporary global challenges.

Limitations and Future Prospects

It is important to note that the survey has certain limitations in relation to the size of the sample, so it cannot be considered representative of the Spanish-speaking university population. Additionally, we identified self-selection bias as an inherent limitation of sampling. This may imply that those participants who choose to respond to the survey have a greater interest in or knowledge of the topics covered, which could influence the results. That is, people who choose to respond to the survey may have different characteristics and literacy levels than those who choose not to respond.

This study shows that there are significant challenges and challenges to assessing and implementing effective ocean and polar literacy. Fully developing - and therefore truthfully estimating - the dimensions and components of literacy is complex, since it is not only based on knowledge about these media, but also on attitudes, beliefs and behaviors towards the sea and the poles, achieving attitudinal responses that are informed and respectful of them. Studying the relationship between a person's level of knowledge about these topics and his or her attitude towards them becomes a great challenge, since the two dimensions of literacy are not necessarily correlated.

Developing a single survey that works equally across linguistic and cultural differences in such a diverse population is complex. However, it is important to note that the results of this experience will serve as a basis for the development of a new version of the survey. To this end, some content will be (i) reviewed for clarity and alignment with the content, (ii) additional items will be added to the perception questions, (iii) questions to identify the respondent's profile will be improved, and (iv) linguistic expressions will be reviewed to avoid cultural bias.

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Perception of industrial environmental impacts among 8th-grade students at College BG 0007 Commander Dangereux, Catumbela, Angola

Percepção dos impactos ambientais industriais em alunos da 8ª classe do Colégio BG 0007 Comandante Dangereux Catumbela, Angola

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Perception, Environmental Impact, Industry, Students, Catumbela

ABSTRACT

This research addresses the perception of industrial environmental impacts among 8th-grade students at College 0007 BG Commander Dangereux in Catumbela, Angola. Industry is a significant factor in environmental degradation. In this context, understanding how students perceive and interpret local industrial environmental challenges and impacts is crucial, as this perception can influence their future actions to preserve the environment. The research aims to analyze the level of environmental awareness of the environmental effects among 8th-grade students at the aforementioned school. The methodology adopted in this research was descriptive, with a quantitative, cross-sectional, and non-experimental approach. Therefore, data collection used a 15-item questionnaire on an ordinal qualitative Likert scale, consisting of three dimensions: general knowledge of environmental impacts, perception of environmental risks, and actions and solutions to minimize industrial environmental impacts. The questionnaire was administered to 113 students. To test the hypothesis that students had a significant perception of industrial environmental impacts, the Wilcoxon test was applied to one sample. The results showed a statistically significant difference between the median observed in the responses and the reference value of the Likert scale ($p < 0.001$), thus refuting the hypothesis that students have a relevant environmental perception on the topic. Therefore, it can be concluded that most students do not have a satisfactory level of environmental perception regarding industrial environmental impacts, as indicated by the median being lower than the reference value.

Palabras clave:
Percepção, Impacto ambiental, Indústria, Alunos, Catumbela

RESUMEN

A pesquisa aborda a percepção dos impactos ambientais industriais em alunos da 8ª classe do Colégio 0007 BG Comandante Dangereux Catumbela, Angola. A indústria representa um fator importante na degradação do meio ambiente. Nesse contexto, compreender como os alunos percebem e interpretam os desafios e os impactos ambientais industriais locais é fundamental, uma vez que essa percepção pode influenciar suas ações futuras em favor da preservação do meio ambiente. A pesquisa visa analisar o nível de percepção ambiental sobre os impactos ambientais em alunos da 8ª classe do Colégio em referência.

A metodologia adotada nesta pesquisa foi descritiva, com enfoque quantitativo, de corte transversal e não experimental. Portanto, utilizou-se, na coleta de dados, um questionário com 15 itens em escala de Likert qualitativa ordinal, constituído por três dimensões: conhecimentos gerais sobre impactos ambientais, percepção dos riscos ambientais e ações e soluções para minimizar os impactos ambientais industriais. O questionário foi aplicado a 113 alunos. Com o intuito de testar a hipótese de que alunos apresentavam uma percepção significativa sobre impactos ambientais industriais, foi aplicado o teste de Wilcoxon para uma amostra. Os resultados mostraram diferença estatisticamente significativa entre a mediana observada nas respostas e o valor de referência da escala de Likert ($p < 0,001$), refutando, assim, a hipótese de que os alunos possuem percepção ambiental relevante sobre o tema. Conclui-se, portanto, que a maioria dos alunos não apresenta um nível de percepção ambiental satisfatório acerca dos impactos ambientais industriais, conforme indicado pela mediana inferior ao valor de referência.

Introduction

In recent years, industrial activities have caused environmental degradation as a result of the irrational use of natural resources, putting the normal functioning of the earth's spheres (atmosphere, hydrosphere, biosphere and geosphere) at risk. Against this backdrop, the deterioration of planet Earth began to take on alarming proportions. For example, with the "advent of the industrial boom, large industrial complexes were established near densely populated areas, where chemicals dangerous to both humans and the environment began to be processed and stored"(Kulman, 2021, p. 20). Similarly, Shah et al. (2021) state that accelerated economic growth in recent decades has contributed significantly to the increase in environmental pollution. The authors point out that the industrial and manufacturing sectors are considered fundamental to a country's economy, as they are responsible for approximately half of the pollution levels recorded.

Furthermore, according to Villegas et al., (2023)the planet's habitat has been profoundly impacted by factors such as technological advances, population growth, environmental pollution and global megatrends. Faced with these increasingly complex challenges, it is essential for institutions, governments and communities to establish a horizontal and authentic dialog aimed at solving social problems with an ecological approach. Industrial activity is therefore a factor in a society's economic growth, but its disorderly growth is a threat to the environment. Climate change, soil and air pollution and the degradation of ecosystems are some of the consequences of industrial activity that affect the environment and human health.

Environmental perception is a fundamental concept for understanding how individuals interact with and respond to their environment. Given this reality, environmental education is a process that enables individuals to investigate environmental problems, actively participate in the search for solutions and adopt actions that promote environmental improvement. This process contributes to the development of an in-depth understanding of environmental issues and fosters the formation of skills needed to make conscious and responsible decisions (Busi et al., 2023). In this context, environmental education is an instrument that plays an essential role in raising the awareness and commitment of future generations to adopt sustainable practices. Thus, understanding students' perceptions of industrial environmental impacts is essential for evaluating the efficiency of educational activities in the Angolan context and suggesting improvements in teaching strategies.

In the municipality of Catumbela, the industries installed in the Catumbela Industrial Development Pole (PDIC) have caused significant impacts on the local environment, which is a major social concern. Considering this scenario, this research aims to understand how students perceive the environmental impacts of industries. The way they perceive these impacts can directly influence their environmental awareness, as well as their pro-environmental attitudes and behaviors in favor of sustainability. In addition, various studies indicate that the transmission of environmental education for sustainable development has been explored mainly from the perspectives of sustainable consumption and pollution management.

The municipality of Catumbela, located in the province of Benguela (Angola), is considered the most industrialized in the region, mainly due to the presence of the PDIC, installed along the Catumbela River Delta. According to Huvi (2019) the delta has edaphic and hydrogeological characteristics favorable to the development of agriculture, as well as being the main source of drinking water for the coastal cities of Benguela province. In this context, the PDIC has driven significant industrial growth in recent decades, which has contributed significantly to its economic growth.

However, this progress has been accompanied by severe impacts, such as contamination of the air, water and soil, as well as loss of biodiversity. Furthermore, the communities living near these industries are among the most affected by these negative externalities. These include students, who, as members of these communities, are also exposed and subject to these environmental impacts.

Despite their relevance, students' perception of the environmental impacts caused by industrial activities is still limited. This lack of knowledge can significantly compromise the role these students will play as future managers and agents of transformation in building a sustainable society. Against this backdrop, the following research problem is proposed: What is the level of perception of 8th grade students at Colégio BG 0007 Comandante Dangereux Catumbela (Angola) about environmental impacts resulting from industrial activities?

The choice of topic was motivated by the need to understand how students perceive and interpret environmental challenges in their local context, given that this perception can directly influence their future actions in favor of environmental preservation and, consequently, contribute to sustainable development. The research is particularly relevant as it is set in a geographical context where there is a significant concentration of industries, located in an area of high agricultural potential and with the presence of important groundwater reservoirs. This scenario poses considerable challenges to sustainability and the balance between economic development and the preservation of natural resources. In addition, the 8th grade Geography course includes a unit on industrial activity and its relationship with economic development. This thematic unit, throughout its sub-themes, does not propose a critical analysis of the harmful effects generated by industrial activity on the environment. Therefore, the coincidence between the syllabus and the local context represents an educational opportunity to promote environmental education in the school environment, contributing to the formation of a critical awareness of local environmental problems.

From a theoretical point of view, this research is justified by the growing concern about environmental degradation and the depletion of natural resources, phenomena that have challenged humanity today. In this context, companies in the productive sector, especially industries, are among the main agents causing negative environmental impacts, due to the intense exploitation of natural resources. In this way, the theoretical references that underpin this research seek to contribute to expanding the literature on environmental education, especially in terms of its ability to foster and improve students' perception of environmental challenges, both on a local and global scale. According to Collado et al. (2020) environmental education has proven to be a significant and relevant pedagogical tool for transforming attitudes and behaviors, promoting the development of pro-environmental attitudes and thus helping to build a society guided by the principles of sustainability.

From a practical point of view, environmental education in schools is an important tool for building a critical perception of environmental problems, helping to raise students' awareness and finding solutions to understand and tackle the environmental challenges caused by industrial activities. This aspect becomes especially relevant in regions with a high level of industrialization, such as the municipality of Catumbela in Angola. Furthermore, as Araújo argues (2021) the inclusion of environmental education in the school environment is an effective strategy for transforming students' perceptions, broadening their understanding of the industrial environmental impacts caused by industrial activity. In this sense, this research has the potential to support the development of more effective educational projects, with environmental education as an essential tool in mitigating the negative effects of industrialization (Bibeiro et al., 2021).

From a methodological point of view, the purpose of this research is to provide support for the development of teaching strategies in environmental education, centered on the students' perception of the environmental impacts resulting from industries. In this sense, the

use of participatory methodologies in the teaching-learning process, such as problem-based learning, case studies and environmental studies, or visits to areas impacted by industries or school projects aimed at building sustainable alternatives, contributes significantly to building more reflective environmental thinking that is committed to sustainability. These methodological approaches, as highlighted by Souza & Santos, (2021) promote the active involvement of students in the educational process, fostering the development of a critical perception of environmental problems, while encouraging the proposal of contextualized solutions.

Therefore, this analysis aims not only to enrich the academic debate on environmental perception in schools, but also to contribute to the development of public policies aimed at sustainability, with a focus on education as an instrument of social transformation. The general objective of this research is to analyze the level of perception of industrial environmental impacts among 8th grade students at Colégio BG 0007 Comandante Dangereux Catumbela, Angola.

Method

This research was carried out using a quantitative methodological approach. The level of research adopted is descriptive, as it aims to describe the characteristics of a specific phenomenon or situation. The design of this research is non-experimental, because the study variable was not manipulated. According to Hinojosa Mamani et al. (2024) cross-sectional research designs collect data at a single point in time, with the main aim of describing and analyzing the current state of the variables of interest in a population. This research was carried out at Colégio BG 0007 Comandante Dangereux, located in the municipality of Catumbela, a suburban town with the same name, in the province of Benguela, Angola, with a sample made up of 113 8th graders, randomly selected from a population of 160 students, with a 95% confidence level and a maximum admissible error of 5%.

To collect the data, a political questionnaire consisting of 15 items was used, divided into three dimensions. The instrument was structured on a five-point Likert scale (1 - Strongly disagree, 2 - Disagree, 3 - Neither disagree nor agree, 4 - Agree, 5 - Strongly agree) in order to measure students' attitudes and opinions.

In this research, data processing followed a descriptive statistical approach, in accordance with Espinoza Casco et al. (2023) “Descriptive statistics consists of the graphical and numerical methods used to summarize and process data and transform them into information” (p. 104). Thus, descriptive statistics is a statistical procedure that aims to represent and describe the data of a problem and represent it graphically.

Microsoft Office Excel was used to organize the data. For statistical analysis, two software packages were used: the statistical analysis software Program for Statistical Processing (PSPP) version 1.4.1-g79ad47 for Windows, used for descriptive statistics (frequencies, mode and median), the results of which were presented in table form, and Jeffreys's Amazing Statistics Program (JASP) software version 0.19.3 for Windows, used to apply the Wilcoxon test to a sample in order to check for significant differences in relation to the neutral point of the Likert scale.

As far as descriptive analysis is concerned, the answers on the Likert scale were grouped into three categories in order to facilitate the interpretation of the data and identify the general trends in the participants' opinions: The options “1 - Strongly disagree” and “2 - Disagree” were grouped together in the (Disagree) category, the option “3- Neither disagree nor agree” was kept alone, under the designation (Neutral) and the options “4 - Agree” and “5 - Strongly agree” were grouped together in the (Agree) category.

In addition, the reliability of the Likert scale used in the research was assessed using the Cronbach's alpha coefficient, which was 0.83, indicating a good internal consistency of the instrument. Second Tarakçı Eren & Düzenli (2021) this result represents a reliable level for assessing students' environmental perception. To Popa (2020) also highlights values of around 0.83, whose instruments contain 15 items and a sample of 113 participants, which are considered very good, especially in educational and social surveys.

Results

Table 1
General knowledge of industrial environmental impacts

Items	f (1)	f (2)	f (3)	f (4)	f (5)	% (1)	% (2)	% (3)	% (4)	% (5)	Median	Fashion
Item 1. Industrial activities are one of the main causes of environmental pollution.	19	58	8	15	13	16,8	51,3	7,1	13,3	11,5	2	2
Item 2. Industrial gas emissions contribute to global warming and climate change.	10	36	16	32	19	8,8	31,9	14,2	28,3	16,8	2	2
Item 3. Industries are responsible for much of the contamination of water resources.	17	42	14	24	16	15,0	37,2	12,4	21,2	14,2	2	2
Item 4. Industrial activities contribute significantly to air pollution.	20	28	4	28	33	17,7	24,8	3,5	24,8	29,2	2	5
Item 5. Soil contamination caused by industries is detrimental to the practice of agriculture.	32	36	9	31	5	28,3	31,9	8,0	27,4	4,4	2	2

Note. *5-point Likert scale: 1 = Strongly disagree; 5 = Strongly agree. The data reflects the distribution of the participants' responses (N=113). The absolute frequencies (f) represent the number of responses for each category. Mode and median refer to the central tendency of the answers for each item. The values have been rounded to one decimal place.*

According to the data presented in Table 1, the majority of participants, 52.8%, disagreed with the statement, selecting “Strongly disagree and Disagree”. Only 38.2% of the participants expressed some degree of agreement, indicating “I totally agree” and “I agree”, and 9.0% remained neutral. The median was 2 (Disagree), showing a central tendency towards disagreement among the participants. The results showed that, in general, there was a strong tendency to disagree among the participants, suggesting a negative perception of the statement evaluated. In the context of this research, we tested the hypothesis that students have a general knowledge of industrial environmental impacts. To do this, the Wilcoxon one-sample test was applied to check whether the median of the answers differed from the neutral value of the Likert scale (reference value = 3), which indicates an average level of knowledge.

An alternative directional hypothesis was considered, according to which the answers would tend towards values greater than 3 ($\mu > 3$), which would indicate that the students demonstrate general knowledge about industrial environmental impacts. However, this

hypothesis was refuted, since the test revealed a median equal to 2 in the five items evaluated, with values (V = 64441.000 and p < 0.001) indicating a statistically significant difference below the reference value. In this way, the results suggest that, in general, students showed a lower-than-expected level of knowledge about the environmental impacts caused by industrial activities.

Table 2

Perception of the environmental risks generated by industrial activities

Items	f (1)	f (2)	f (3)	f (4)	f (5)	% (1)	% (2)	% (3)	% (4)	% (5)	Median	Fashion
Item 6. Industrial activities pose a great risk to human health due to pollution.	33	41	9	17	13	29,2	36,3	8,0	15,0	11,5	2	2
Item 7. Pollution caused by industries negatively affects biodiversity and ecosystems.	14	38	17	29	15	12,4	33,6	15,0	25,7	13,3	2	2
Item 8. Pollution caused by industries directly affects global climatic conditions.	29	51	11	9	13	25,7	45,1	9,7	8,0	11,5	2	2
Item 9. Poorly managed industrial waste can cause serious public health problems.	12	38	2	24	37	10,6	33,6	1,8	21,2	32,8	2	2
Item 10. Industrial activities cause environmental problems, even in regions far from urban centers.	28	43	9	19	14	24,8	38,0	8,0	16,8	12,4	2	2

Note. *5-point Likert scale: 1 = Strongly disagree; 5 = Strongly agree. The data reflects the distribution of the participants' answers (N=113). The absolute frequencies (f) represent the number of answers for each category. Mode and median refer to the central tendency of the answers for each item. The values have been rounded to one decimal place.*

According to the data presented in Table 2, the majority of participants agreed with the statement, with 57.9% of participants selecting “Strongly disagree” and “Disagree”. On the other hand, 33.6% of participants indicated “I agree” and “I totally agree”. Only 8.5% remained neutral. The median was 2 (Disagree), indicating a tendency to disagree among the participants. The results revealed that there was a strong inclination to disagree among the participants, suggesting a negative perception of the statement evaluated.

In the context of this research, we tested the hypothesis that students perceive the environmental risks generated by industrial activities. To do this, the Wilcoxon test was applied to a sample in order to check whether the median of the answers differed from the neutral value of the Likert scale (reference value = 3), which represents an average level of perception. An alternative directional hypothesis was considered, according to which the answers would tend towards values greater than 3 ($\mu > 3$), indicating that the students perceive environmental risks generated by industrial activities at a higher level than the reference value. However, this hypothesis was refuted, since the test revealed a median equal to 2 in the five items evaluated, with values (V = 64441.000 and p < 0.001) indicating a statistically significant difference below the reference value. Thus, the results showed that the participants tended to have a lower-than-

expected level of knowledge regarding the perception of environmental risks resulting from industrial activities.

Table 3

Actions and solutions to minimize industrial impacts

Items	f (1)	f (2)	f (3)	f (4)	f (5)	% (1)	% (2)	% (3)	% (4)	% (5)	Median	Fashion
Item 11. Companies in the industrial sector have a social responsibility to mitigate the environmental impacts they cause.	19	58	8	15	13	16,8	51,3	7,1	13,3	11,5	2	2
Item 12. The development of green industries is the solution to minimizing environmental impacts.	10	36	16	32	19	8,8	31,9	14,2	28,3	16,8	2	2
Item 13. Individual actions can help minimize the negative effects of industries on the environment.	17	42	14	24	16	15,0	37,2	12,4	21,2	14,2	2	2
Item 14. Consumers have the power to put pressure on industries to be more sustainable.	20	31	3	25	34	17,7	27,4	2,7	22,1	30,1	2	5
Item 15. Industries must invest more in sustainable practices and technologies to reduce pollution.	33	32	9	32	7	29,2	28,3	8,0	28,3	6,2	2	1

Note. *5-point Likert scale: 1 = Strongly disagree; 5 = Strongly agree. The data reflects the distribution of the participants' responses (N=113). The absolute frequencies (f) represent the number of responses for each category. Mode and median refer to the central tendency of the answers for each item. The values have been rounded to one decimal place.*

According to the data presented in Table 3, the majority of participants, 52.7%, disagreed with the statement evaluated, indicating “Disagree” and “Strongly disagree”. On the other hand, 38.4 of the participants showed some level of agreement, selecting “I agree” and “I totally agree”. While 8.9% remained neutral. The median was 2 (Disagree), suggesting a central tendency towards disagreement among the participants. These data show a strong trend of disagreement among the participants, suggesting a negative perception of the statement evaluated.

In the context of this research, we tested the hypothesis that the majority of students believe that the adoption of certain actions and solutions by industries can minimize the environmental impacts generated by industrial activities. To do this, the Wilcoxon one-sample test was applied to check whether the median of the answers differed from the neutral value of the Likert scale (reference value = 3), which represents the average level of knowledge or agreement. An alternative directional hypothesis was considered, according to which the answers would tend towards values higher than 3 ($\mu > 3$), indicating that the students would believe that the adoption of certain actions and solutions by industries can minimize the environmental impacts generated by industrial activities. However, this hypothesis was refuted, since the test revealed a median equal to 2 in the five items evaluated, with values (V =

64441.000 and $p < 0.001$) indicating a statistically significant difference below the reference value. Thus, the results showed that the participants tended to have a lower level of knowledge than expected in relation to actions and solutions to minimize industrial environmental impacts.

Discussion and Conclusions

With regard to the students' perception of the main environmental impacts generated by industrial activities, the results reveal a very worrying environmental perception. Most of the students disagreed that industrial activities are responsible for environmental impacts such as environmental pollution, global warming and climate change, loss of biodiversity, air pollution, water and soil contamination. Only a minority of students showed any degree of agreement with these statements recognized by science. The hypothesis that the students have a general knowledge of industrial environmental impacts that is higher than the reference median was refuted. These findings are in line with the results of Dopelt & Radon (2020) who identified limited knowledge among students about the environmental impacts of industry. However, they observed that their pro-environmental attitudes and behaviors are significantly influenced by their level of environmental knowledge. Similarly, Maurer & Bogner (2019) found that individuals with a higher level of education tend to have more contact with ecological ideas than those with less schooling. Thus, a possible explanation for the lower level of knowledge may be related to the lack of environmental education content in the curricula. Thus, the integration of environmental education into curricula with a view to maximizing students' perception of the current environmental problems facing humanity, in order to form critical citizens who are prepared to face current challenges.

Previous studies suggest that environmental education plays a key role in promoting sustainable development. According to Taboada-González & Aguilar-Virgen (2024)it is capable of fostering a mindset towards sustainability, empowering individuals to become agents of change. It also helps to raise awareness of the importance of environmental preservation. On the other hand, there was a worrying tendency to be unaware of or undervalue the impacts caused by industrial activities, which contrasts with various findings in the literature. (Bose, 2024) points out that industries are among the main emitters of greenhouse gases, especially carbon dioxide, which is a crucial factor in aggravating global warming and climate change. Along the same lines, Zhang et al. (2020) point out that industrial activities are responsible for significant forms of environmental pollution, affecting water resources, soil and biodiversity, especially in regions with a strong industrial presence. Shah et al. (2021) reinforce this perspective by stating that industrial pollution represents a significant threat to the environment, causing the degradation of ecosystems and generating high social costs, including for human health and safety.

Thus, the results suggest that this dissatisfaction may be influenced by various factors, such as the absence or poor presence of content on industrial environmental impacts in curricula, low exposure to themes on industrial environmental problems. The level of disagreement shown by the students in relation to their general knowledge of industrial environmental impacts means that they have a limited perception of the environmental impacts produced by industries. Environmental knowledge is therefore a key factor in identifying and assessing environmental risks and, consequently, in taking pro-environmental measures in favor of the environment.

Regarding the perception of environmental risks generated by industrial activities. The results showed that the majority of students disagreed with the statements directly associating industrial activities with environmental risks. Only a minority indicated some level of

agreement with the statements evaluated, such as: industrial activities directly affect climatic conditions and public health. The level of disagreement presented by the students in relation to the environmental risks resulting from industrial activity demonstrates an existing gap in terms of perception in the general knowledge of the environmental impacts produced by industries. The hypothesis that students perceive the environmental risks generated by industrial activities to be higher than the reference median was refuted. These results reveal a lack of awareness of the negative effects caused by industries, which can be attributed to the low level of environmental knowledge observed in the items assessed. Similar findings were identified by Dopelt & Radon (2020)whose research shows that students with higher levels of environmental knowledge have significantly more pro-environmental attitudes and behaviors. Along the same lines, Janmaimool & Khajohnmanee (2019) observed that students who took part in a course on environmental issues had more positive environmental attitudes than those who did not. This suggests that the higher the level of environmental knowledge, the greater the ability to understand environmental risks, which favors sustainable behavioral changes.

On the other hand, these results contrast with the scientific literature that shows the risks and impacts of industrial activities on the environment and human health. According to Ramadani et al. (2025)industrial activities are responsible for significant emissions of pollutants, contributing to the contamination of soil and water, with serious implications for ecological balance and public health. Ruba et al. (2021) also point out that industrial growth, when dissociated from sustainable principles, causes degradation of natural resources, generating air, water and soil contamination, as well as affecting entire ecosystems. Corroborating these findings, Pabón Guerrero et al. (2020), argue that industrial activities represent the main source of heavy metals released into the environment, negatively affecting human health, animals, plants, water sources and soils, thus compromising the entire food chain. According to Ogwu et al. (2024)the causes of these problems are diverse, including the excessive use of agrochemicals, inadequate disposal of industrial waste and poor solid waste management. In addition, industrial activities contribute significantly to global climate change, especially due to the emission of greenhouse gases. According to Mikhaylov et al. (2020) these emissions have led to a gradual increase in the planet's average annual temperature, exacerbating the effects of climate change.

Therefore, the results show that the majority of students had a negative level of perception. Thus, these findings suggest the need to integrate thematic units on environmental risks into curricula in order to raise students' level of environmental awareness. However, understanding how students assess these risks represents an opportunity to understand how students are aware of the damage produced by industries, and from there to adopt environmental practices and actions that contribute to the preservation of the environment.

Regarding the perception of actions and solutions to minimize the environmental impacts generated by industrial activities. In general, the results indicated that the majority of students showed a strong degree of disagreement with the statements evaluated. Although a small number of students agreed with the statement that consumers have the power to put pressure on industries to be more sustainable, this reveals a perception in line with scientific literature that recognizes these factors as the main environmental management tools for controlling and minimizing industrial environmental impacts. The hypothesis that students believe that the adoption of certain actions and solutions by industries can minimize the environmental impacts resulting from industrial activities, which was higher than the reference median, was refuted. These results are in line with the findings of Chakraborty et al. (2024), which show that although students are becoming increasingly aware of sustainable practices and environmental impacts, their perceptions of solutions to mitigate the effects of industrial activity are still heterogeneous. While some show engagement and understanding, others

remain critical or indifferent, which highlights the importance of a more practical and engaging educational approach to sustainability.

These results showed that, despite the majority of students having no general knowledge of industrial environmental impacts and a poor perception of industrial environmental risks, some students believe that adopting certain actions and solutions can help mitigate the negative effects of industries on the environment. According to Montefalcone et al. (2025) emphasize that the search for sustainable solutions in the industrial sector must consider the balance between economic growth, social justice and environmental preservation, since genuine sustainability depends on the harmonious interaction of these three elements.

The environment represents capital that supports industrial activities, and the goods and services produced are used by man for his survival. It is therefore imperative to adopt actions aimed at mitigating the impacts caused by the extraction and production of natural resources. As highlighted by Gabriela de Oliveira et al. (2021) the implementation of sustainable practices is an essential condition for the continuity of organizations. This need can arise both from the pressure exerted by stakeholders and from the search for strategies that improve organizational performance, promote competitive advantage, protect the environment, meet social demands and ensure compliance with the standards established by environmental policy instruments.

Therefore, the results show that the majority of students had a limited level of perception in relation to the statements assessed. Thus, these findings suggest the importance of reinforcing the presence of thematic units in curricula; in order to consolidate students' perception of the actions and solutions that industries must adopt to guarantee the sustainability of resources. Thus, the degree of disagreement shown by the students represents an opportunity to design educational policies aimed at contributing to the preservation of the environment, towards sustainable development.

In conclusion, with regard to the perception of general knowledge about the environmental impacts resulting from industrial activities, the statistical results indicated that the alternative hypothesis proposing a level of knowledge higher than the midpoint of the scale (reference value = 3) was refuted. The median observed was equal to 2 in all five items evaluated, with statistical significance ($V=64441.000$; $p < 0.001$), showing that the students demonstrate a low level of knowledge than expected. This finding points to an important gap in students' environmental education, especially when it comes to understanding the negative effects of industrial activities on the environment, such as environmental pollution, warming and climate change, contamination of water resources and soil contamination.

With regard to the perception of environmental risks associated with industrial activities, the results followed a similar trend. The alternative hypothesis, that students would perceive such risks at a higher level than the neutral point on the scale, was also refuted. Again, the median was 2. With statistical significance ($V = 64441.000$; $p < 0.001$), showing that students have a limited perception of the risks to human health and the ecological balance caused by these activities. This result reveals a weakness in students' environmental awareness, indicating that the impacts on health and well-being resulting from pollutant emissions and environmental degradation are still poorly understood in the educational context analyzed.

Finally, with regard to the hypothesis that students believe in the effectiveness of actions and solutions to minimize the environmental impacts generated by industrial activities, the alternative hypothesis was also rejected. The analysis again revealed a median of 2 in the five items evaluated ($V = 64441.000$; $p < 0.001$), showing a negative or underdeveloped perception of statements such as the use of sustainable technology and practices, corporate social responsibility, adoption of green industries and individual actions to minimize environmental impacts. These results suggest that students are not only unaware of the environmental

problems caused by industrial activities, but also show disbelief or ignorance of the viable means of mitigation.

It can therefore be concluded that, in the context of the sample investigated, students show a low level of environmental knowledge and awareness in relation to the impacts, risks and possible solutions associated with industrial activities. These conclusions reinforce the need to rethink the pedagogical and curricular practices adopted by educational institutions, with a view to the systematic and critical inclusion of environmental education, in a transversal, participatory and contextualized way. In addition, the data obtained reinforces the urgency of educational actions that favor the development of environmental literacy as a fundamental tool for building ecologically and socially responsible citizenship towards sustainable development.

One of the limitations is related to the scope of the sample, which was restricted to students from a single educational institution. This factor limits the generalization of the results to other educational, social and geographical realities. The lack of a qualitative assessment to further explore the reasons behind the answers is also a major limitation, as it prevented subjective aspects of the students' perceptions from being better understood. In addition, the research focused solely on environmental impacts related to industrial activities, disregarding the interrelationship with other pollutants, such as different types of transportation, agricultural activity, etc. This thematic delimitation, although necessary for the study, limits the general and systemic view of the environmental problem.

Finally, given the limitations mentioned above, future research should expand the sample to include students from different levels of education (secondary and higher education), urban and rural areas and varied social contexts. Comparative studies between regions or between public and private schools can also provide relevant information on the effectiveness of environmental education policies.

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ENVIRONMENTAL EDUCATION, RESPONSIBLE CONSUMPTION AND THE THREE RS: A REVIEW TO PROMOTE SUSTAINABLE URBAN WASTE MANAGEMENT PRACTICES

Educación ambiental, consumo responsable y tres R: revisión para fomentar prácticas sostenibles del manejo de residuos urbanos

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ABSTRACT

Climate change is a priority issue today, not only because of its constant presence on political and economic agendas, but also because of the impacts it generates on life on the planet. What is at stake is the sustainability of human life, making it urgent to adopt measures to mitigate its effects. Among these, the proper management of municipal solid waste is of particular importance, as it contributes to approximately 5% of greenhouse gas emissions.

This article presents a review of the state of the art of the following relevant aspects for the promotion of sustainable urban waste management practices: environmental education, responsible consumption and the three R's strategy (reduce, reuse and recycle). This research is developed under a qualitative approach and a documentary methodology, prioritizing official sources such as international organizations, environmental authorities, universities and educational institutions, in order to offer a broad and reliable vision of the subject.

An overview of the generation of urban solid waste and its repercussions is presented, as well as the evolution of environmental education as a tool for transformation. Responsible consumption is discussed as an ethical basis for sustainable decision-making, while the three Rs are presented as a concrete, accessible and effective strategy. The current challenge is to strengthen the dissemination and practice of these actions, promoting an aware and committed citizenship with the care of our common home: the Earth.

Palabras clave:
Educación ambiental, consumo responsable, tres R.

RESUMEN

El cambio climático es un tema prioritario en la actualidad, no solo por su presencia constante en las agendas políticas y económicas, sino por los impactos que genera sobre la vida en el planeta. Lo que está en juego es la sostenibilidad de la vida humana, por lo que se hace urgente adoptar medidas que permitan mitigar sus efectos. Entre ellas, la gestión adecuada de los residuos sólidos urbanos cobra especial importancia, ya que estos contribuyen aproximadamente al 5 % de las emisiones de gases de efecto invernadero.

Este artículo presenta la revisión del estado del arte de los siguientes aspectos relevantes para el fomento de prácticas sostenibles del manejo

de residuos urbanos: la educación ambiental, el consumo responsable y la estrategia de las tres R (reducir, reutilizar y reciclar). La presente investigación se desarrolla bajo un enfoque cualitativo y una metodología documental, priorizando fuentes oficiales como organismos internacionales, autoridades ambientales, universidades e instituciones educativas, con el fin de ofrecer una visión amplia y confiable del tema.
Se presenta una visión general sobre la generación de residuos sólidos urbanos y sus repercusiones, así como la evolución de la educación ambiental como herramienta de transformación. El consumo responsable se analiza como base ética para la toma de decisiones sostenibles, mientras que las tres R se presentan como una estrategia concreta, accesible y efectiva. El reto actual es fortalecer la divulgación y práctica de estas acciones, promoviendo una ciudadanía consciente y comprometida con el cuidado de la casa común: la Tierra.

Introduction

We cannot remain indifferent to the current environmental crisis, marked by the consequences of climate change, a phenomenon accelerated by a model of civilizational development centered on excessive consumerism. The dominant economic system is based on anthropocentrism, linear production and accelerated consumption that continues to consider natural resources as unlimited. This logic promotes the continuous production of goods and services whose usefulness is ephemeral, but whose environmental impact is long-lasting.

The principle of "the more you sell, the more you earn" has guided economic growth, without considering with equal rigor the waste generated: both those derived from the production process and those arising from discarding, disuse or planned obsolescence. This problem transcends the economic sphere; it is also an ethical issue that directly calls into question the responsibility of human beings towards the environment they inhabit.

The excessive generation of municipal solid waste represents one of today's most pressing challenges. Tons of materials are discarded daily in homes, businesses, stores and educational institutions, which if properly managed could represent an opportunity to reduce the consumption of resources, promote circular economies and contribute to a truly sustainable development. To this end, it is necessary to promote conscious decisions that integrate ethical values, technical knowledge and individual and collective commitments.

In response to this problem, many efforts have been made to find practical solutions that allow citizens to actively contribute to the mitigation of environmental impact. Within this framework, environmental education, responsible consumption and the application of the so-called three Rs (reduce, reuse, recycle) are key pillars for promoting a cultural transformation towards sustainability. As stated by UNESCO (2021), environmental education should be promoted as an essential driver to achieve sustainability, highlighting the importance of practices such as responsible consumption and proper waste management, including the three Rs.

This context raises the need for a review of the state of the art that gathers and systematizes relevant information on these issues, offering teachers, researchers and community leaders conceptual and methodological tools for the design of pedagogical strategies. The main objective of this review is to provide an updated overview of the problems associated with the increase in urban solid waste, to analyze the role of environmental education in the formation of committed citizens, to explore responsible consumption as a starting point for change, and to highlight the transformative potential of R's in everyday life. Finally, significant experiences are presented that integrate these elements and that can guide new proposals to reduce environmental impact from the local to the global level.

Method

The methodology used for the elaboration of this article is framed within the framework of documentary research with a qualitative approach, in correspondence with the proposed objective. According to Arias (2012), documentary research with a qualitative approach makes it possible to analyze, interpret and understand phenomena based on the systematic study of bibliographic and documentary sources, which is especially useful when seeking to build solid theoretical or conceptual frameworks. For this purpose, searches and reviews were conducted and organized around the main related subtopics: solid waste production and its environmental impact; current solid waste management in developed and developing countries; environmental education; responsible consumption; the three R's (reduce, reuse, recycle); and the strategies that integrate these elements in terms of solid waste reduction.

The documents selected come mainly from official sources, such as international environmental agencies, sector ministries, universities and educational institutions. The selection of sources responded to their thematic relevance, institutional reliability and timeliness, in order to guarantee the validity of the inputs analyzed. The purpose of this review is to build a solid frame of reference to support pedagogical proposals aimed at promoting environmental responsibility from a critical and transforming perspective.

Results

Solid Waste Production and Its Impact on the Environment.

It is necessary to begin this section with the definition of solid waste. Solid waste is defined as materials or products that are discarded in solid, semi-solid, liquid or gaseous state, contained in containers or deposits, and can be classified according to their characteristics and origins into three different groups: municipal solid waste (MSW), special management waste (SMW) and hazardous waste (HW) [Secretaría de Medio Ambiente y Recursos Naturales. (2019)]. Solid urban waste will be taken into account for this review.

The final disposal of solid waste continues to be a major problem today. According to Franklin, O. [Franklin, O. (2025)] "5% of all greenhouse gas emissions are attributed to solid waste and another 8%, to food waste. Together, they account for more than shipping and air transport combined."

For the UN Environment Program (2024), the overview of solid waste production will be as follows:

> Municipal solid waste generation is expected to increase from 2.1 billion tons in 2023 to 3.8 billion tons in 2050. In 2020, the global direct cost of waste management was estimated at $252 billion. When the hidden costs of pollution, ill health and climate change from poor waste disposal practices are taken into account, the cost rises to $361 billion. If urgent action is not taken on waste management, by 2050 this annual global cost could almost double to a staggering $640.3 billion.

It is not only the production of large volumes of municipal solid waste, but also the management of such waste and the effects it has on the integrity of the planet (something is missing here). For the World Bank (2019, March 6), the solid waste issue also includes:

> Floods, diseases, polluted oceans, which are some of the many consequences of not treating what we waste. Garbage not only ends up in large, foul-smelling landfills but also has a devastating impact on the planet and could be even worse in the future.
>
> According to the study, the world generates 2.01 billion tons of municipal solid waste per year, and at least 33% of this waste is not treated. Rapid urbanization, population growth and economic development are projected to increase the amount of waste globally by 70% in the next 30 years if urgent action is not taken. A future where living with garbage could be the new normal.
>
> But it is not only the large North American, European or Asian cities that could be affected by this development. Latin American cities are not exempt from this problem: each of their inhabitants generates almost one kilogram of garbage per day, but only 4.5% of waste is recycled at the regional level.

In his interview to Climática (n.d.), journalist Oliver Franklin-Wallis, writer of the book "Wasteland" states:

> That we don't think about the future until it's too late. Take a plastic soft drink bottle: it could take up to 450 years to degrade in the environment. In the process, it will release microplastics and nanoplastics that could have serious effects on the health of humans and the rest of life on this planet. We produce about 500 billion plastic bottles a year,

and that's just one type of waste! Litter is the physical equivalent of global warming: it is something we all see and touch every day.

From another perspective, as López (n.d.) says, when "garbage is put in its place", a series of processes originate that involve diverse and complex problems that are difficult to solve, ranging from the forms of governmental organization to provide this service, to corruption in its management at different levels, to the exploitation and manipulation of a group of the community dedicated to these tasks, to the environmental problems caused by the accumulation of this waste.

In addition to the real waste aspect of abandoning materials that could be reused, which results in a greater and more irrational exploitation of natural resources, both renewable and non-renewable.

Solid Waste Management in Developed and Developing Countries

The European Parliament (2024, March 25) states that

> each European generated an average of 5 tons of waste in 2022, amounting to a total of more than 2.2 billion tons. In Europe, the aim is to recover waste or, in other words, to use it in different ways. The residues can be recycled, used as backfill (e.g., to replace soil for slope reclamation or for safety purposes in geotechnical applications? or landscaping engineering) or can be incinerated and the energy produced from this process can be used. In less than two decades, from 2004 to 2022, the amount of waste recovered increased by 40.6%, from 870 to 1,223 million tons. Recovered waste accounted for more than half of total waste (61.4%) in 2022. The remaining waste was landfilled (30.2%), incinerated without energy recovery (0.4%) or disposed of in some other way (8.0%). Solid waste going to landfills is partially exported from the EU to other countries.
>
> In 2022, waste exports to non-EU countries reached 32.1 million tons, a slight decrease of 3% compared to 2021. Most of the waste exported out of the EU (55%) consists of ferrous metal waste (iron and steel), which mainly goes to Turkey. The EU also exported a large amount of waste paper (15%), with India being the main destination. In 2022, 39% of EU waste went to Turkey (12.4 million tons), followed by India (3.5 million tons), the United Kingdom (2.0 million tons), Switzerland (1.6 million tons) and Norway (1.6 million tons).
>
> Municipal waste is waste generated by households, businesses, offices and public institutions. They represent only about 10% of the total waste and are managed by municipal authorities. In 2022, the volume of municipal waste generated varied greatly among EU countries, from 301 kg per capita in Romania to 803 kg per capita in Austria. The percentage of municipal waste recycled increased from 19% in 1995 to 48% in 2022, while in the same period the percentage of waste deposited in landfills decreased from 61% to 23%.

In Latin America, the production of solid waste has been increasing due to industrial development, the growth of population centers and consumption [Instituto de Estudios Urbanos. (2021)]. According to the Inter-American Development Bank (IDB). (2023),

> it is estimated that the average annual generation of municipal solid waste (MSW) in Latin America and the Caribbean for 2018 was 224 million tons (a figure equivalent to 1.02 kg/inhabitant per day). In 2020 the COVID-19 pandemic caused an estimated 6% reduction in MSW generation (211 million tons), linked to a drop in gross domestic product (GDP) per capita. By 2030, it is estimated that MSW generation will reach 259 million tons, which will bring an associated increase in the demand for services, infrastructure and business and institutional capacity. Argentina, Brazil, Colombia and Mexico account for about 74% of total solid waste generation in the region.

The management of the final disposal of MSW is done as shown in figure one, within which it is highlighted that of the total MSW generated in 2018 in the region, 4%, on average,

was subjected to valorization process, 57% was deposited in landfills and 39% was taken to inadequate disposal sites (12.5% of the inadequate disposal sites correspond to controlled landfills and 26.5% to open dumps)

Figure 1

Destination of collected waste.

Source. Adapted from Inter-American Development Bank. (2023).

Environmental Education

Environmental education was first mentioned in an international context at the Stockholm Conference on the Human Environment in 1972, where the Declaration on the Human Environment was adopted. The following is a quote from the UN (2023) in the Environmental Education Toolkit for Latin America and the Caribbean,

> environmental education, aimed at both the younger generations and adults, and paying due attention to the less privileged sector of the population, is essential in order to lay the foundations for a well-informed public opinion and for individuals, companies and communities to act responsibly in protecting and improving the environment in all its human dimensions. It is also essential that the mass media avoid contributing to the deterioration of the human environment and disseminate educational information on the need to protect and improve it, so that people can develop in all aspects. (p. 6)

It is essential to promote environmental education, aimed at both young people and adults, paying special attention to underprivileged sectors. This will strengthen well-informed public opinion and encourage responsible behavior on the part of individuals, companies and communities, aimed at protecting and improving the environment in all its human aspects.

> Another relevant international document, adopted in 1975, is the so-called Belgrade Charter, which is considered a general framework for environmental education. The goal of environmental education is established there: "To reach a world population that is environmentally aware and interested in the environment and its related problems, and that has the knowledge, skills, attitudes, motivation and desire to work individually and collectively to find solutions to current problems and to prevent those that may arise in the future."
>
> Later, at the Intergovernmental Conference on Environmental Education organized by UNESCO and UNEP and held in Tbilisi in 1977, several aspects were clarified and defined, which constituted the theoretical foundation of environmental education. This is based on an understanding of the environment as a totality that encompasses both natural aspects and those derived from human activities. (p. 7)

These three historical moments shared a vision of the environment as an interconnected system, influenced by human activities. However, concrete strategies for delivering environmental education or integrating it into school curricula have not yet been developed.

Starting in the 1980s, international texts on the environment began to incorporate concepts related to school scenarios, as well as the impacts of human actions on the environment. These impacts not only affect present generations, but also compromise future generations.

The Colombian environmental policy (2012) includes an international vision on environmental education, which highlights the following:

> At the Moscow meeting (1987), UNEP and UNESCO proposed some curricular strategies based on interdisciplinarity and integration to promote environmental education in the world. There, a consensus was reached regarding the concept of environmental education as a process in which individuals and communities become aware of their environment, based on knowledge, values, competencies, experiences and will, so that they can act individually and collectively to solve present and future environmental problems.
>
> The discussion and evaluation of these curricular strategies, their development and achievements in some regions of the world were the subject of the International Training Seminar for the Incorporation of Environmental Education in the Primary School Curriculum (Malta) and the Seminar for the Incorporation of Environmental Education in the Secondary School Curriculum (Cairo), both held in 1991. These seminars resulted in recommendations such as the participation of teachers in the design of a curriculum that incorporates the environmental dimension in all school plans and processes, and research into evaluation methods for these processes. (p. 11)

In the 1990s, environmental education acquired a more political connotation, seeking to influence academic, business and social spaces in order to reach the entire world population. This perspective allowed for greater awareness of environmental impact and the need for its mitigation, as mentioned in Colombia's Environmental Education Policy (2012, p. 11):

> In 1992, the European Economic Community, through its Policy and Action Program for the Environment and Sustainable Development, Action 21, proposed that, without prejudice to the prerogatives of the Member States, all those aspects related to the environment, included in both natural science and human and social science courses, that prepare for practical life, should be incorporated into all school curricula at different levels. The Action 21 proposal was unanimously accepted at the Rio Conference in 1992. Specifically, this program focuses on the development of environmental awareness, training and education. Later, in October of the same year, an environmental education meeting was held in Toronto, Canada, which underscored the aforementioned approach, confirming the need to promote intersectoral and inter-institutional work strategies to strengthen environmental education.

Responsible Consumption

At the beginning of the 21st century, the international community is concerned about the serious impact of pollution on the environment and the negative consequences it generates, and in response to this situation, the Sustainable Development Goals (SDGs) were adopted at the international level, where environmental education was specifically linked to Goal 4: Quality Education. In particular, target 4.7 states that:

> To ensure that all students acquire the knowledge and skills necessary to promote sustainable development, including through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and

non-violence, global citizenship and appreciation of cultural diversity and the contribution of culture to sustainable development. (UN, 2015).

Along the same lines is sustainable development goal number twelve, known as responsible production and consumption. This objective has its origin in the concern for the depletion of the planet's resources, in a context of constant population growth. If by 2050 the population is 9800 million, it would take almost three planets to provide the natural resources needed to maintain current lifestyles. (UN, 2015). In view of this, there is an urgent need to take action. The UN indicates that there may be two paths: 1. Reduce waste generated and 2. Think carefully about what you buy and choose a sustainable option whenever possible. Two actions within the reach of any person, hence the importance of education in responsible consumption.

For its part, the Earth Charter published in 2000, promoted by the United Nations World Commission on Environment and Development since 1987 and jointly drafted by thousands of people around the world, has become a benchmark for sustainable development issues. Based on sixteen principles, in which common values are recognized. Principle four reads "To ensure that the fruits and beauty of the Earth are preserved for present and future generations." As well as in principle fifteen "Eradicate poverty as an ethical, social and environmental imperative." This principle is based on the idea of "Enabling all human beings with the education and resources required to achieve a sustainable way of life. In addition, provide the social security and support networks required for those who are unable to support themselves." These are examples of shared responsibility and its relation to education.

For Mejía, M. (2022), responsible consumption "can be defined as that decision made by a consumer who is concerned about the consequences generated by a purchase and its subsequent effect on the environment and society, as well as the waste generated in this process" When consumers become aware that their purchasing decisions can reduce the impact on the environment and adopt practices to materialize this ethic of care for the environment, they become responsible consumers.

In the words of CONPES 3874 of 2016, which refers to the Colombian Comprehensive Policy for Integrated Solid Waste Management, the premise is that companies extract materials, apply energy to them to manufacture a product and sell that product to the end consumer, who then discards it when it no longer serves the user's purpose.

The logic of discarding has generated problems on different fronts, such as pressure on resources, pollution associated with production, and the effects on final disposal, which includes inefficient recovery, reuse and reduction processes. In addition, there is little economic interest in integrated waste management, as it implies investments that often do not generate the desired profitability. It must be remembered that, in the capitalist system, economic utility is the main purpose and hence the economistic convenience or not of any productive effort is evaluated. As stated by the Ellen MacArthur Foundation (2013) the linear production model incurs resource losses in several ways:

Waste in the production chain. In the production of goods, significant quantities of materials are normally lost between extraction and final manufacture.

Waste along the value chain in food markets. Material losses are recorded at different steps in food production: harvesting, transportation, storage and consumption. Across the entire food supply chain, these global losses are estimated at one-third of the food produced for human consumption each year.

Waste at the end of its life cycle. For most materials, utilization rates are quite low compared to primary manufacturing rates.

The Three R's (reduce, reuse, recycle)

Moving from the theory of responsible consumption to daily practice is possible through the application of the three R's. We speak in the plural, as there are several visions of these R's:

- During the G8 Summit in June 2004, Japan's Prime Minister Koizumi Junichiro Junichiro presented the three Rs initiative: reduce, recycle, reuse. This initiative seeks to build a recycling-oriented society. According to this strategy, it can be an excellent guiding thread for environmental education in any community in which it is intended to influence environmental culture.
- Suarez (2013) describes the three Rs (reduce, reuse, recycle) as: an old philosophy that began as an environmentalist thought and became for many a way of life. It is based on the reduction of consumption in general, the reuse of the elements that can from the use of the same and recycling, which has to do with the rescue of elements discarded in different scenarios of everyday life of man, to process them and make them new elements or part of them. Recycling consists of choosing a material that after one or more processes can be converted into raw material or part of a new product. In recent years, recycling has gained importance as one of the most practical ways of renewing domestic and industrial waste, etc., materials that people throw away every day without taking advantage of them (p. 5).
- In their review of 114 definitions of circular economy Kirchherr et al. (2017), evidenced that there are at least nine concepts involved in the practical exercise of circular economy, employing the R's:

Figure 2

Codification of actions within the framework of the circular economy.

Source. Adapted from The 9R Framework Source, Kirchherr et al. (2017).

- Mejía, M. (2022) proposes seven R's: recycle (separate at source), reduce, reuse, reject, reclaim, redistribute and reflect.
-

Environmental Education, Responsible Consumption and the R's, Progress in Implementation

In times of climate change, a comprehensive understanding of the processes that generate the planet's environmental imbalances is urgently needed. In addition to the great influence of greenhouse gases on global warming of the atmosphere, it is important to value, within the polluting contributions, the irresponsible use of natural resources to satisfy fatuous consumption needs, far beyond the essential needs of human beings.

Reversing the current state of threat to the biosphere requires an urgent and profound transformation of the global energy model and of the voracious patterns of consumption of resources and environmental services.

Education for sustainability emerges as a relevant approach for the transformation of the mental models of the population based on values, awareness, social and generational responsibility and, above all, on the survival of homo sapiens on earth. Arias, B. (2016)

On the front line (of greenhouse effect reduction, or global warming? Here something is missing) are the states, understood as nations, departments, municipalities, provinces, states, or any other form of political-administrative organization. In addition to this transformation, there is the commitment derived from international agreements, especially the Sustainable Development Goals. The following are some of the exercises that have been undertaken in relation to the combination of environmental education, responsible consumption and the three Rs.

Alberto Sileoni, Minister of Education of the Republic of Argentina in 2007, indicated in the presentation of the guide for primary school teachers on environmental education, "this process involves and makes society, but especially the State, responsible. Who has the legitimacy to promote and demand the care of the environment. Likewise, to generate conditions, through public education, to establish a new relationship: community life, development and environment." The same text states that environmental education

> is characterized by its heterogeneity of practices, i.e., there are many different educational practices that are identified as EA (environmental education), as explained in the section on experiences. However, if we investigate and look for a common component or characteristic, we will see that they all promote some type of change, beyond the approach and the didactic strategy used, whose common characteristic is that of action, that is, it is an education for action. Prioritizing changes at the individual level (changes in attitudes) or, at the other extreme of possibilities, oriented towards changes in the social order and, why not, in civilization. (p.18)

For Simancas, R. et al (2019), environmental education is strengthened through responsible consumption and the application of practices such as the R's, which translates into education for sustainable development:

> It is therefore essential that educational institutions begin to develop within their academic and extracurricular programs, educational courses that critically and analytically provide students with a point of view of the real situation of the planet and the immediate and long-term solutions to these environmental problems. In this way, having trained the students environmentally, the educational community will begin to transform itself into a more sustainable environment, more environmentally friendly, and certainly much more responsible; thus achieving that in the future these people will have a positive impact on the society outside the educational entity and in this way, the longed-for environmental education will be multiplied.

As stated by Nay-Valero, M., & Febres Cordero-Briceño, M. E. (2019). Environmental education adapts to the conditions of each context in which it is conceived,

> The diversity and progression of international documents together with the contributions of various researchers show that American educational processes are under reflection and transformation in order to adapt and respond to the demands of society. In the case at hand, environmental issues in their social, economic,

> environmental, political, cultural and natural dimensions have been considered in curricular reforms at the country level. Four central paradigms can be identified in the international guidelines that have been developed over (the last?) four decades: the environmentalist paradigm, characterized by knowledge of ecosystems in their natural conditions, as a provider of resources and opportunities for exploitation, with an anthropocentric vision; the globalization paradigm characterized by incorporating the New World Economic Order; the paradigm of globalization, characterized by understanding and assuming the integration of complexity based on the multidimensionality of environmental problems; and the paradigm for sustainability, characterized by a biocentric vision of complex and systemic interrelationships, determined by the interwoven network of interrelationships between political, economic, social, cultural, environmental, technological and ethical dimensions.

For Martínez, R. (2012), reaching people in particular has to be the objective of environmental education, therein lies the transformation influencing the apprehension of new consumption habits, a new civilization,

> Learning strategies should generate epistemic curiosity, task control, confidence and challenge, generating healthy lifestyles towards the care of the environment and oneself. Questioning, for example, the forms of energy generation, consumption and transportation habits, identifying the distribution of differentiated responsibilities in the problem of air pollution and environmental polycrisis.
>
> Participation, in its deepest and most complete sense, can be conceived as a process in which an individual or group investigates and analyzes a specific situation, seeks alternatives and possible positive contributions to help solve the problem; prepares a plan of action and evaluates its possible effects; takes action, putting into practice what has been agreed upon and evaluates the results obtained as a group.
>
> Solid waste management is conceived as a process of actions ranging from awareness to waste treatment and disposal, including the values and norms that determine product consumption. These are integral and participatory actions and those that take place between society and its natural environment. Such as the need to recycle because of its implications on the environment and your health.

Progress in the implementation of the R's with respect to solid waste reduction.

Cruz et al. (2024) conducted a literature review of practical applications of the three R's technique in educational institutions, especially in secondary schools at the national level in Peru and internationally. The study aimed to promote the development of values of responsibility towards the environment in secondary schools, in addition to identifying knowledge gaps that need to be explored in new studies in the context of secondary education.

> After analyzing the thematic content, three categories of representative issues for the 3Rs strategies (Reduce, Reuse, Recycle) in the environmental attitude towards solid waste in high school students were evidenced: the use of pedagogical strategies for the proper management of solid waste with the application of the 3R's technique, the management of solid waste from educational institutions; and the ethical-environmental teaching from the value of responsibility in the proper management of solid waste with the application of the 3R's technique.

Table 1

Categories of representation of the 3 R's strategies in the secondary educational context

Category 1. The use of educational strategies for the proper management of solid waste with the application of the 3R's technique.

Pedagogical strategies for the adequate management of solid waste with the application of the 3R's technique, importance of relating education with environmental pedagogy, adequate management of solid waste.

Category 2. Solid waste management in educational institutions
Solid waste; classification; solid waste management in the educational institution.
Category 3. Ethical-environmental education based on the value of responsibility for the proper management of solid waste with the application of the 3R's technique
Environmental pedagogical strategies; conceptual and attitudinal change in high school students as part of the ethical-environmental teaching from the value of responsibility

Source. adapted from Cruz, Williams & Arroyo-Ñahui, Madeleyne & Condor-Salvatierra, Edwin. (2024).

In the discussion, the authors of the same study obtained the following results for the three aforementioned categories:

In the first category, it is discussed from demonstrating that through a pedagogical strategy it was possible to obtain a change in the perception that students have regarding recycling, solid waste management and the protection that should be had with the environment, for this reason it is necessary to continue implementing strategies to be reminding students of the mission that everyone has to safeguard nature.

In the second category, solid waste can be classified into usable and non-usable. Respondents did not identify this clearly and therefore it is necessary to start with a precise explanation of these terms. Similarly, according to the regulations and the solid waste control procedure, solid waste can be classified into domestic and industrial waste, the former including usable waste (paper, cardboard, glass, tin, plastic). If this standard is taken into account and compared with the students' responses, it can be affirmed that the respondents lack the knowledge base that would allow them to argue how to classify solid waste.

The findings refer to the precept of preservation and conservation based on a culture or ecological conduct with the practice of the value of responsibility and norms that seek to appreciate the interrelationships between the student and the environment, his culture, his habits, his conduct and his biophysical environment, generating a real conscience for the maintenance of the different ecosystems in which living beings interact, promoting their sustainable development.

Discussion and Conclusions

Facing climate change requires not only adaptation measures, but also an active participation in the reduction of solid waste from an individual and daily basis. The growing generation of waste, widely documented as one of the main causes of environmental pollution, represents a priority challenge in all social contexts. This challenge must be addressed not only by public policies, but also from educational spaces, homes and communities.

In this sense, environmental education, responsible consumption and especially the three R's are consolidated as practical, accessible and meaningful tools. These practices allow people of different ages, socioeconomic levels and cultural backgrounds to effectively contribute to the reduction of environmental impact and more efficient use of resources.

Since its origins, environmental education has promoted an ethical vision that recognizes nature as a living being that deserves care, respect and protection. This approach has given rise to reflections on responsibility, freedom, peace and solidarity in relation to

modes of production and consumption. Indeed, progress has been made towards an ethic of environmental care that must be strengthened and deepened.

Currently, environmental education is projected in multiple areas of human life: in companies, through corporate social responsibility; in communities, through public policies; and in educational institutions, through pedagogical projects and strategies. These actions are aligned with the Sustainable Development Goals (SDGs). However, there is still a need to translate environmental values into real, daily and sustained practices.

Techniques such as the three R's provide a concrete basis for responsible decision making, enabling people to understand the impact of their consumption habits and generate new opportunities for more sustainable forms of economy. The circular economy, based on the reuse of materials and respect for resources, is one of the most promising alternatives on this path.

We are, therefore, facing a scenario of opportunity that demands greater research production aimed at developing methodologies, strategies, technologies and processes capable of reducing the environmental impact of urban solid waste. This challenge requires a renewed ethic, useful and applicable knowledge, and a closer approach to the realities of citizenship in order to build sustainable solutions with local and global impact.

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Contribution of Colombian Army in control environmental crimes and ecosystem restoration

Contribución del Ejército Nacional de Colombia en el control de delitos ambientales y la restauración de ecosistemas

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ABSTRACT

The prominent role of the Colombian National Army in ecological degradation and biodiversity loss has not been covered in depth, even less so in the context of climate and environmental security. The objective of the study was to analyze the Army's efforts to contribute to the control of deforestation, illegal wildlife trade, and other environmental crimes, as well as its support activities in ecosystem restoration. The qualitative methodology consisted of a non-experimental cross-sectional design, with a descriptive level and case studies. A semi-structured interview was conducted on a convenience sample of 30 individuals already belonging to strategic civilian and military sectors with influence in decision-making on environmental issues. The main finding was that the Army faces ongoing and crucial challenges with regard to the development of regulatory norms and doctrine for environmental protection. Likewise, limitations in technical capacity, planning, execution, sustainability, and monitoring were revealed in military exercises supporting ecosystem rehabilitation, which requires strengthening the documentation and technical-scientific evaluation of these processes. It was concluded that the Colombian National Army contributes significantly to climate resilience in the territories, further honoring its constitutional mission as guarantor of the security of the population and the sustainable development of the nation, all as a result of its operational and logistical efforts for the protection and conservation of ecosystems and biodiversity.

Palabras clave:
delitos ambientales, restauración de ecosistemas, biodiversidad, protección ambiental, Ejército Nacional de Colombia.

RESUMEN

No ha sido cubierta a profundidad la participación prominente del Ejército Nacional de Colombia en materia de degradación ecológica y la pérdida de biodiversidad, aún menos dentro del contexto de la seguridad climática y ambiental. El objetivo del estudio fue analizar los esfuerzos de contribución del Ejército, en el control de la deforestación, el comercio ilegal de vida silvestre y otros delitos ambientales, así como las actividades de apoyo en la restauración de ecosistemas. La metodología cualitativa consistió en un diseño no experimental transeccional, con nivel descriptivo y de estudio de casos. Se aplicó una entrevista semiestructurada sobre una muestra por conveniencia de 30 individuos,

	ya pertenecientes a sectores civiles y militares estratégicos con injerencia en toma de decisiones sobre temas ambientales. Como principal hallazgo, se identificó que el Ejército posee desafíos vigentes y cruciales, esto respecto al desarrollo de regulaciones normativas y doctrina para la protección ambiental. Asimismo, quedaron develadas las limitaciones de capacidad técnica, planeación, ejecución, sostenimiento y seguimiento; en los ejercicios militares de apoyo para la rehabilitación de ecosistemas, lo cual demanda un fortalecimiento de la documentación y evaluación técnico-científica de los mencionados procesos. Se concluye que el Ejército Nacional de Colombia aporta una significativa generación de resiliencia climática en los territorios, ya haciendo mayor honor a su misión constitucional, como garante de la seguridad de la población y el desarrollo sostenible de la nación, todo esto como resultado de sus esfuerzos operacionales y logísticos para la protección y conservación de los ecosistemas y la biodiversidad.

Introduction

Colombia currently faces enormous challenges to promote the protection and recovery of ecosystems and biodiversity, due to territorial dynamics associated with deforestation and the illegal exploitation of mining deposits, activities that in many cases are controlled by armed groups that generate territorial conflicts and weaken institutional capacity for environmental control (Suárez Perilla, 2021). In this context, pressure is intensifying on strategic ecosystems at the national and regional level, such as the Amazon and the Biogeographic Chocó, where illegal resource extraction dynamics have led to habitat fragmentation, displacement of species and loss of biodiversity (Mayorquín Tovar and Moreno Carvajal, 2022).

The protection of the natural base in the country has a robust regulatory framework, based on the ratification of the Convention on Biological Diversity (CBD) through Law 165 of 1994, which establishes a commitment to the conservation of biodiversity, its sustainable use and the fair and equitable participation in the benefits derived from its use (Congress of Colombia, 1994). In compliance with these commitments, the National Biodiversity Policy was formulated in 1995 and updated in 2012 as the National Policy for the Integrated Management of Biodiversity and its Ecosystem Services (PNGIBSE), integrating the considerations of the 2011-2020 action plan of the CBD and the Aichi Targets (Ministry of Environment and Sustainable Development [MADS], 2012). Other relevant public policies are the document CONPES 4050 of 2021 "Policy for the Consolidation of the National System of Protected Areas - SINAP" (National Planning Department [DNP], 2021), and the document CONPES 4021 of 2020 that defines the "National Policy for the Control of Deforestation and Sustainable Forest Management" (DNP, 2020). These policies are aimed at reducing biodiversity loss through sectoral and cross-sectoral strategies to promote the sustainable use of the natural heritage in areas where socio-environmental conflicts have predominated, such as High Deforestation Areas (HEC).

Under this scenario, deforestation in Colombia is one of the main threats to conservation, highlighting that between 2001 and 2021, about 3.2 million hectares of forests were deforested, of which 89% was produced by illegal activities, threatening about 24% of natural ecosystems (World Bank Group, 2023).

Another critical aspect to take into account is related to the affectation of environmental conservation zones such as protected areas and forest reserve zones established by Law 2 of 1959, identifying that by 2022, 10% of deforestation in the country (12,449 ha) was generated in protected areas and 27.2% (33,602 ha) in Forest Reserve Zones (Instituto de Hidrología, Instituto de Hidrología). Meteorology and Environmental Studies [IDEAM] and MADS, 2023).

The drivers of land use change due to deforestation are mainly associated with ~~land~~ grabbing and extensive cattle ranching, expansion of transportation infrastructure without proper planning, expansion of the agricultural frontier, illicit crops, illicit mineral extraction, and illegal ~~logging~~ (IDEAM and MADS, 2023). Likewise, land use conflicts are highlighted in 50% of the country's territory, due to the expansion of cattle ranching in soils with agricultural vocation, or the development of agriculture in conservation areas, which promotes the loss of biodiversity, ecosystem services, the increase of desertification processes and soil detriment in 16.5% of the territory (MADS, 2017).

Another factor that dynamize~~s~~ these negative processes for ecosystems is the lack of State presence in areas that are difficult to access or remote from major cities, allowing the presence of armed groups in the territory and the development of illegal activities, becoming situations that generate serious socio-environmental conflicts (Lozano, 2015), evidencing that the weak State presence in rural areas facilitates the expansion of illegal economies, generating significant environmental impacts, perpetuating dynamics of violence (Morales Muñoz et al., 2025; Ayala and Pérez, 2025). Other problems can be identified, such as wildlife trafficking, in

whose dynamics local communities, financed by criminal agents, interact. However, in Colombia this phenomenon has not been prioritized for attention, because efforts are concentrated on combating criminal activities such as illicit crops and illegal mining, despite the fact that the country is part of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (InSight Crime & IGARAPÉ Institute, 2021).

On the other hand, the environmental consequences of the Peace Agreement in Colombia stand out, such as increased deforestation, illegal dynamics associated with illicit crops, illegal exploitation of mining deposits, extensive cattle ranching, land grabbing, among others, ~~the~~ areas that were liberated by the extinct Revolutionary Armed Forces of Colombia (FARC) have a low capacity for state regulation and weak environmental governance, being occupied by new illegal actors, which intensify pre-existing socio-environmental conflicts (Garzón et al., 2020). Likewise, the illegal exploitation of minerals has affected indigenous populations, in National Natural Parks and forest reserves, generating serious damage on public health due to the use and dumping of harmful inputs such as mercury (Guio Rodríguez, 2018).

Following this context, the National Development Plan 2022-2026 "Colombia Potencia de la Vida", indicates that it is necessary to implement strategies to reduce deforestation and promote the restoration of degraded ecosystems, in order to minimize the impacts on protected areas, promoting solutions based on nature and the resilience of the territories in the face of the climate crisis, pointing out the low results to curb the loss of biodiversity due to deforestation and the development of regeneration processes (DNP, 2023).

Due to obstacles related to low political will, insufficient legislation and public policies, lack of financing, weaknesses in technical capacity and limited investment in research and monitoring (Solano and Torres, 2022), it is identified that the restoration processes developed at the national level do not contribute efficiently to national biodiversity conservation objectives.

In this sense, the National Army of Colombia, has positioned itself as an important actor to contribute to the preservation and defense of the environment and natural resources, in accordance with the provisions of Article 103 of Law 99 of 1993, which states that the Armed Forces shall ensure the protection and defense of the environment and natural resources, as a primary element of national sovereignty (Ministry of National Defense, 2017).

The Army also promotes its role of supporting the control and surveillance activities established in Articles 64 and 65 of Law 99 of 1993, in relation to the mobilization, processing, use, exploitation and commercialization of renewable natural resources, which are developed by the territorial entities and the territorial environmental authorities. On the other hand, the Ministry of National Defense, established environmental protection through support to environmental authorities, territorial entities and the community, as a mission area of contribution of the defense sector (Ministry of National Defense, 2017). The triangulation of these actors has allowed the joint alignment of their respective action strategies, in order to confront environmental crimes and cooperate, permanently, in the management of climate change within the framework of "Guarantees for Life and Peace 2022-2026".

It should also be noted that the doctrinal development of the National Army has included the response to threats or anthropic events as part of its land power capabilities. This action is framed within the Defense Support to Civil Authority (ADAC) operations, which correspond to non-lethal missions and other support activities, in response to the requirements of civil authorities, within the framework of the law, through the use of available capabilities and means (National Army, 2017).

Similarly, the National Army issues Environmental Management guidelines and directives to mitigate the impacts on the environment due to the development of the Force's

mission, through the Department of Military Engineers, which is part of the Chief of Staff of Plans and Policies (National Army, 2023a). It also coordinates the implementation of environmental guidelines through the Engineers Command with the Environmental Management Section, with environmental advisors and managers in the divisions, brigades and battalions (National Army, 2023b). Cooperatively, the National Army supports the protection and defense of the environment, through the planning and conduct of military operations, to combat environmental crimes, through the Brigade against the illegal exploitation of mining deposits, a unit that operates throughout the national territory, in a joint, coordinated and interagency manner (Ministry of National Defense, 2017).

In the above context, it should be noted that the nation has an Army that contributes to peace building, not only from the territorial security approach, but also from the perspective of its contributions to sustainable development. However, this participation has not been analyzed in depth, in terms of its strategic importance for achieving national climate resilience and biodiversity conservation objectives.

In view of the above, the purpose of this article is to analyze the contribution efforts made by the Colombian National Army in the control of environmental crimes such as deforestation and the illegal exploitation of mining deposits, as well as the activities to support the restoration of degraded ecosystems, as partial results of an investigation carried out in 2024. The study highlights the support functions of the National Army, in accordance with its mission and capabilities, within a context of environmental conflicts due to climate change, biodiversity loss and armed conflict.

Method

Design

According to the degree of structuring of the data, the research presents a qualitative type, with a non-experimental field design, descriptive scope and cross-sectional (Hernández Sampieri et al., 2014). With the purpose of describing in depth the observed phenomenon, a qualitative method based on case studies was applied, from different areas and sectors of the Colombian armed institution linked to the environment, in an attempt to explore complex dimensions in their real context of realization (Atlas.ti, 2025). In the approach to the object of study, a combination of several techniques was applied for the collection of information, specifically, self-developed semi-structured interviews, direct observation and documentary analysis, seeking an appropriate fit with the aforementioned approach of case studies (Jiménez Chaves and Comet Weiler, 2016).

Categories

The categories that guided the collection of secondary and empirical information, as well as the categories of codification and analysis correspond, in the first instance, to the contribution of the development of control and surveillance operations and actions, in which the perceptions and opinions of the population sample are analyzed, on the effectiveness of operations oriented to the control of environmental crimes and the collaboration with other entities. Secondly, the environmental restoration support activities are presented, analyzing the projects developed by the Force, community participation and their results, as described in Table 1. The categories were analyzed descriptively without interdependent relationships between them, according to the scope of this research.

Table 1

Operationalization table of categories.

Category	Conceptual Definition	Operational Definition	Dimensions	Indicators
Contribution from the development of control and surveillance operations and actions	National Army efforts to control deforestation and other environmental crimes.	Extent to which the Army contributes to the control of environmental crimes.	Development of control and surveillance operations and actions.	Perception of the effectiveness of operations and control and surveillance actions.
			Support to other entities.	Opinions on collaboration with other entities.
Environmental restoration support activities.	Activities carried out by the National Army for the remediation of negatively impacted ecosystems.	Degree of participation in ecosystem restoration projects.	Restoration Projects.	Perception of the effectiveness of reforestation and restoration projects.
			Results and Project Evaluation.	Feedback on the results and evaluation of restoration projects.

Participants

The population sample, made up of 30 individuals, 53% (16) of whom were women and 47% men (14), was derived from a non-probabilistic sampling among the sectors of national planning, defense, environment, cooperants and/or international allies (Table 2). Most of the participants belong to the 30 to 40 years age group, representing 53% of the sample (16), followed by the over 50 years age group with 23% (7), the 40 to 50 years age group with 13% (4) and finally the 20 to 30 years age group with 10% (3). The individuals were selected according to their relationship and influence in decision-making regarding the planning and/or execution of environmental protection guidelines, biodiversity and the control of environmental crimes. A semi-structured interview was administered to these study units, in which they were asked about their contribution to the control of environmental crimes and the support of ecosystem restoration processes. 19 interviews were conducted virtually and 11 in person, according to each interviewee's availability and location

Other sociodemographic data about the sample are omitted for ethical and confidentiality reasons.

Table 2

Distribution of interviewees by entity

Sector	Institution	Number of interviewees	Role
National Planning	National Planning Department	1	Articulates medium- and long-term planning
Defense	Ministry of National Defense	2	Defines safety policies including environmental protection
	General Command of the Military Forces	3	Strategically directs the Military Forces in environmental protection
	Colombian National Army	12	Supports environmental crime control and environmental protection.
Environment	Ministry of Environment and Sustainable Development	1	Formulates environmental policies and coordinates intersectoral actions.
	National Natural Parks	2	Administers and manages the National Natural Parks System.
	Corporation for the Sustainable Development of the Southern Amazon (Corpoamazonía)	1	Executes environmental policies and plans in the

Sector	Institution	Number of interviewees	Role
	Corporation for the Sustainable Development of the Northern and Eastern Amazon (CDA)	1	territory as the highest authority.
	Amazon Vision Program	2	Articulates deforestation planning and control efforts between government, international cooperation and communities.
International cooperating partners and/or allies	United Nations Office on Drugs and Crime (UNODC)	2	Supports institutional strengthening in the control of environmental crimes
	GiZ - German Cooperation Colombia	1	Provides support for institutional strengthening and capacity building for conservation and environmental control.
	United States Agency for International Development (USAID)	1	It finances and accompanies conservation, environmental governance and crime control projects.
	Center for Management and Operation of the Amazon Protection System (CENSIPAM)	1	Regional cooperation for the control of cross-border crime.

Instrument

Data collection was carried out by means of a semi-structured interview as a flexible instrument which, according to Díaz Bravo et al. (2013), allows adjustments in the application of concepts or questions in order to reduce ambiguities. The interview included questions such as: What actions do you consider important to implement for the adequate management of climate change and the protection of biodiversity, especially in the Colombian Amazon; What weaknesses and strengths do you identify in the contribution activities developed to support the control of deforestation and other environmental crimes, especially in the Colombian Amazon; Do you know of actions or initiatives of the National Army for the restoration of degraded ecosystems; and What weaknesses and strengths do you identify in these restoration practices?

The instrument was validated by expert judgment, yielding a content validity coefficient of 0.96, which corresponds to excellent inter-judge agreement (Hernández-Nieto, 2011).

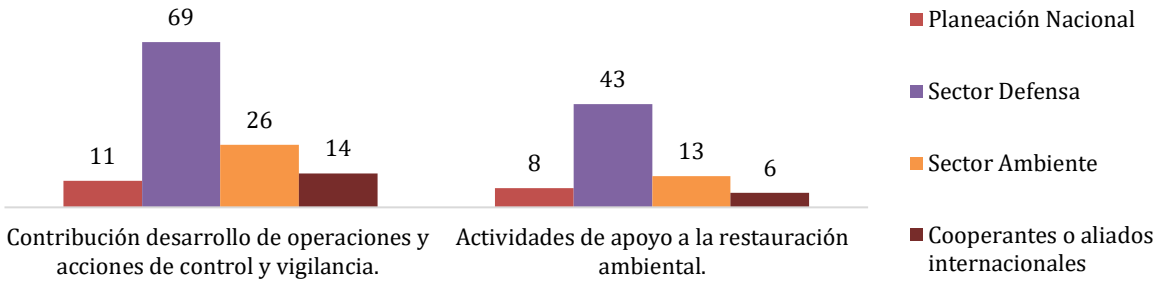
Data Analysis

The qualitative data analysis phase was supported by the *ATLAS.ti* version 25 software, which facilitates the process of storing, processing and interpreting large amounts of qualitative data, through an iterative process of hybrid coding, based on the research categories proposed and the generation of second-level or emerging categories. Similarly, descriptive statistical techniques were used to analyze the frequency of occurrence of quotations related to the categories and the distribution of these categories in the different sectors to which the interviewees belong.

Results

The coding process based on the research categories yielded 120 citations associated with the category of contribution to the development of operations and control and surveillance actions, and 70 citations from the category of support activities for environmental restoration, and Figure 1 shows their distribution in the different sectors of the interviewees. The results also show that quotations were present in 27 of the interviews, which corresponds to 90% of the sample.

Figure 1
Distribution of citations between interviewees' sectors and research categories



In the coding process, emerging or second level categories were identified, related to challenges and opportunities for the National Army in the control of environmental crimes and support for ecosystem restoration, which are presented in Table 3.

Table 3
Emerging or second level categories

Description	Categories
Challenges or threats	Technical and logistical challenges. Institutional Barriers. Conflict and Security. Public policy guidelines and legislation
Opportunities	Technological innovation, logistics and operations. International Collaboration. Training and Capacity Building. Resilience and Adaptation to Climate Change.

The perception and opinions of those interviewed suggest that the National Army's contribution to the control of environmental crimes is framed within the framework of the operations of Support to the Defense of the Civil Authority (ADAC), developing mainly logistical and security support to other state entities whose main mission is the administration and control of the use of natural resources. One of the strengths of these exercises is the use of military intelligence for operational planning and as an input to guide judicial investigation processes. Likewise, the environmental and defense sectors highlight the presence of the Army throughout the national territory, which allows the development of actions in areas where environmental authorities and other entities do not have the capacity to enter, highlighting the air mobility capacity. Additionally, 36 % of the sample highlights the development of the inter-institutional articulation strategy in the Amazon called “Environmental Bubble” as of 2016, as a positive exercise to dynamize the coordination and development of operations and actions, mainly to control the increase in deforestation and attack other crimes such as the illegal exploitation of mining deposits.

In view of the above, emerging strategies of the National Army have been identified, such as the aforementioned Environmental Bubbles, the Artemisa Plan, the Amazonia Plan and the activation of specialized units such as the Brigade against the Illegal Exploitation of Mining Deposits (BRCMI), to confront criminal dynamics associated with organized armed groups, which ~~affect~~ natural resources, promote the invasion of protected areas, impacting the conservation and protection of biodiversity. However, the perception of the interviewees, especially the environmental sector, suggests a weakness in relation to the questioning of the effectiveness of the operations developed for the control of deforestation, due to the fact that

the agents of deforestation have not been impacted, only the lowest links in the criminal chain, which shows weaknesses in the institutional synergy.

Figures 2 and 3 present the challenges and opportunities for the National Army to contribute to the control of deforestation and other environmental crimes, through the development of operations and activities for the control and surveillance of natural resources.

Figure 2

Challenges of the National Army to contribute to the control of environmental crimes.

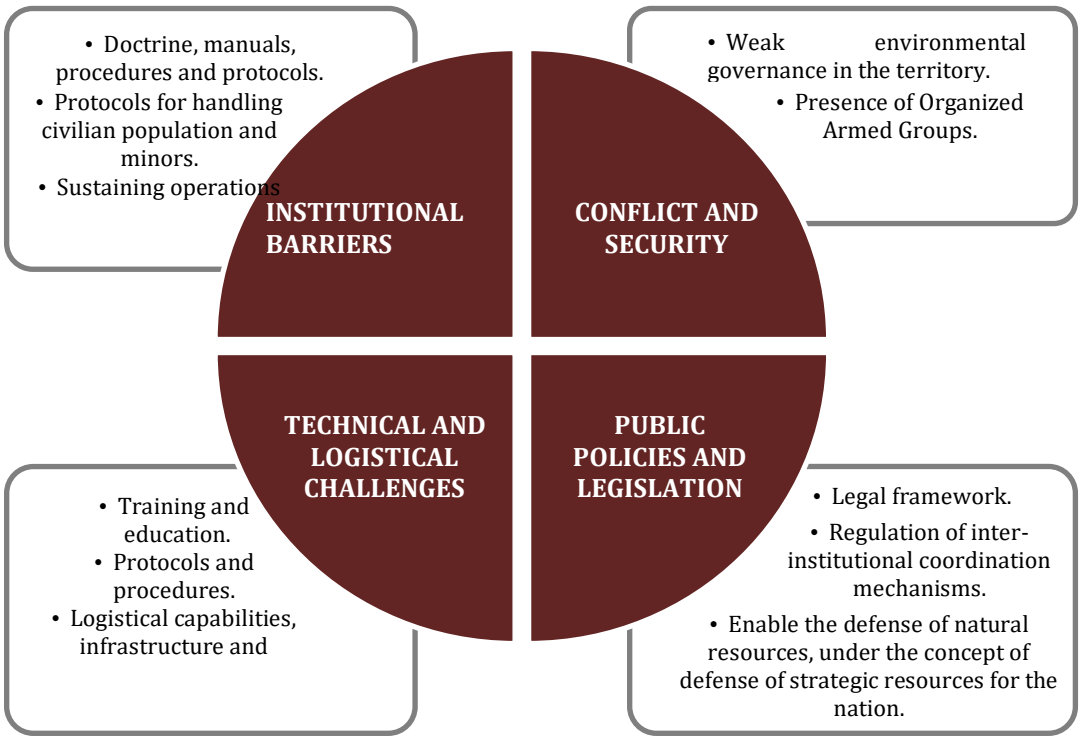
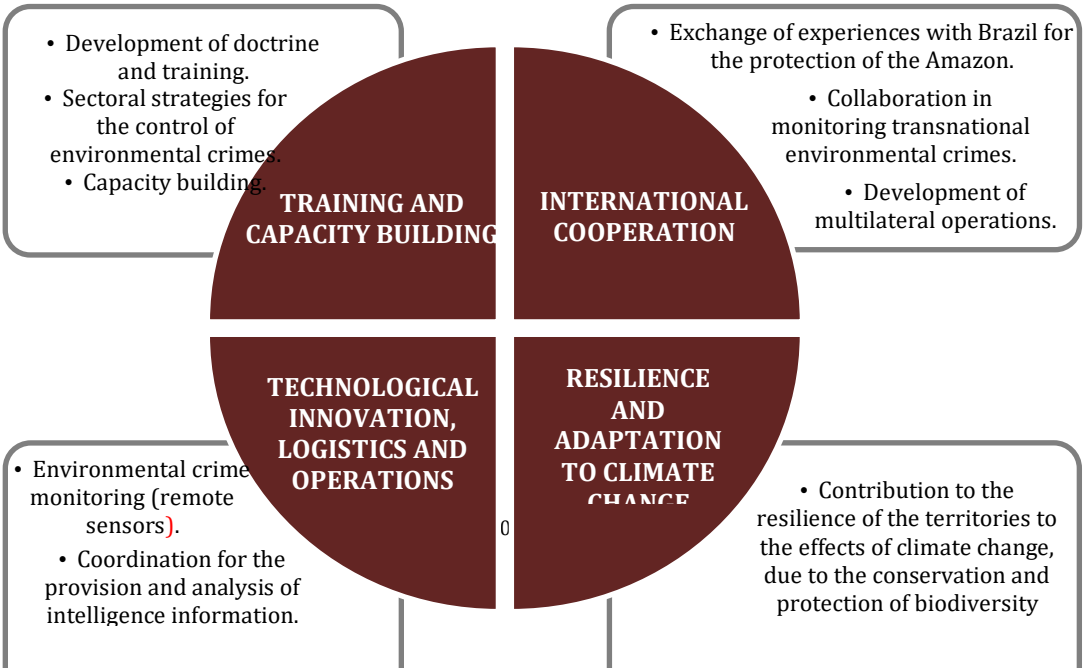


Figure 3

Opportunities for the National Army to contribute to the control of environmental crimes.



With respect to the findings in the category of environmental restoration support activities, the latter are associated with the development of reforestation campaigns inside and outside military units and the production of plant material through the establishment of nurseries, emphasizing the experience of propagating frailejon in units located in high mountain ecosystems. The perception of the sample with respect to these exercises, especially the national planning sector and some environmental authorities, indicates that they have positive effects for the image of the institution, by showing-activities other than coercive actions carried out in the framework of military operations, which can promote a positive approach with the communities.

In contrast to this result, there are other opinions within the defense sector, part of the environmental sector and international cooperants or allies, who question the relevance of developing this type of activities that do not correspond to the mission of the National Army. In this regard, weaknesses in the technical capacity that may limit compliance with regulatory standards in the production of plant material, inadequacies in the planning, monitoring and maintenance of sowings or plantations, as well as a lack of scientific documentation on the military exercises carried out.

Following up on the above, Figures 4 and 5 present the challenges and opportunities for the National Army to continue the development of these initiatives, so that it cooperates more effectively with ecosystem restoration and, consequently, with biodiversity conservation.

Figure 4

Challenges of the Army in the development of environmental restoration support activities

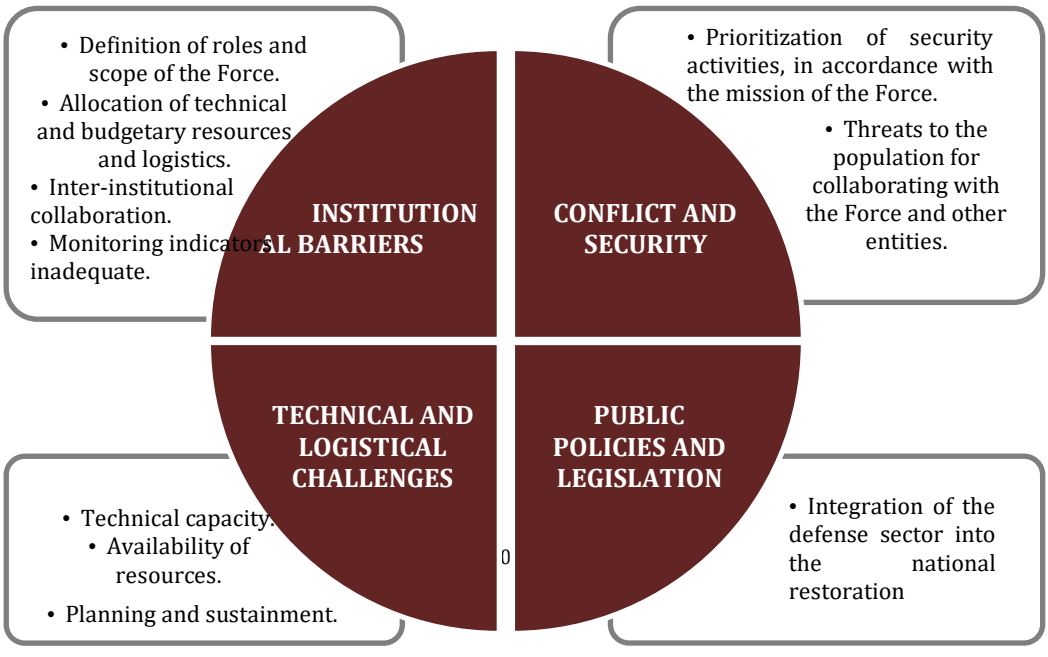
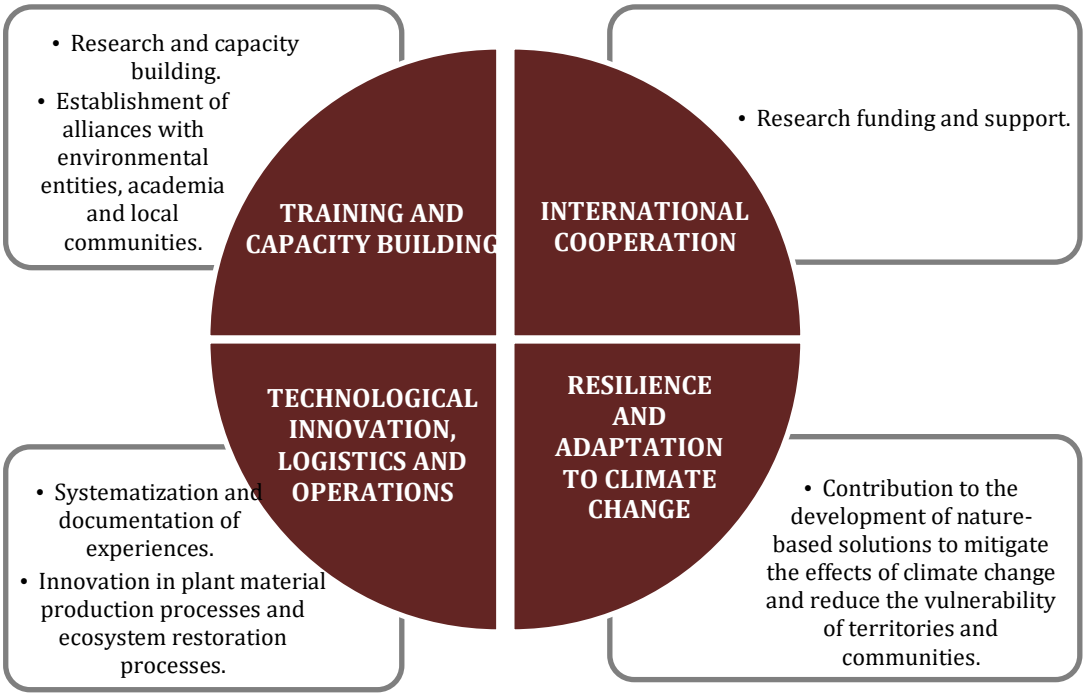


Figure 5

Opportunities for the National Army to develop activities in support of environmental restoration



Discussion and Conclusions

It stands out as an opportunity for the National Army, in accordance with the opinion of the interviewees, to include as a complementary measure of adaptation to climate change, the protection approach to biodiversity protection, in the midst of the Army's contributing role to the undertaking of operations and control and surveillance actions, in accordance with the doctrine related to the Defense Support to Civil Authority (ADAC) operations (National Army, 2017).

According to the results, the National Army's contribution to the control of environmental crimes is based on the use of its operational, intelligence and logistical capabilities to support other authorities in the fulfillment of their mission. In this regard, Garzón et al. (2020) indicates that the experience of the Military Forces in operational planning, intelligence deployment, and their mobility capabilities, constitute the main advantages in environmental protection processes.

Similarly, the Army's differential capabilities, including deployment to strategic areas of the national territory, contribute to the effective control of illegal dynamics associated with organized armed groups that use the exploitation of natural resources for their financing (Ayala Sánchez, 2023).

On the other hand, the experiences of inter-institutional articulation led by the National Army arise as a response to the increase in deforestation and other environmental crimes in the Amazon, articulating state entities responsible for the regulation and surveillance of natural resources and protected areas (Murillo and Ceballos, 2021). Likewise, operations aimed at reducing deforestation have been executed in order to comply with Directive 10 of 2018 corresponding to the orders to comply with judgment 4360-2018 of April 5, 2018, related to the control of deforestation in the Amazon (Piñeros et al., 2020). To improve the efficiency of these actions, it is necessary to activate specialized units such as the BRCMI to carry out environmental protection tasks.

Although the benefits of the participation of the National Army in the control of environmental crimes are evident, there are questions regarding the efficiency of the results in relation to the limitation of resources, use of capacities, excessive use of force and relations with local communities involved in the criminal chain (Garzón et al., 2020). In view of these considerations, the Major Operation Artemisa promoted in the 2019-2022 government period, to combat deforestation, is based on respect for human rights and international humanitarian law (IHL), favoring the formation of Sustainable Forest Nuclei (Ayala Sanchez, 2023).

The National Army's challenges are centered on the lack of doctrine, procedures and protocols for the control of environmental crimes, despite new regulations that empower the National Army to take preventive punitive measures and destroy heavy machinery, in accordance with Law 2387 of 2024. However, there are no specific implementation procedures and protocols. In addition, Giraldo et al. (2024) points to the need to establish a robust legal and conceptual framework that allows for inter-institutional coordination and effective ~~integration of the~~ human rights approach, especially in territories with weak environmental governance and socio-environmental conflicts such as the Amazon.

With respect to the above, the need to regulate the technical and operational coordination of spaces such as the National Council to Combat Deforestation and other associated crimes (CONALDEF) and other spaces of inter-institutional articulation is evident, to promote the effective introduction of capacities against environmental crimes and other illegal activities that degrade natural resources (Garzón et al., 2020), underlining the importance of recognizing natural resources as strategic assets of the nation, which require prioritization in the objectives of national defense protection.

On the other hand, there are shortcomings in the allocation of resources, a situation that translates into a lack of logistical, infrastructure and equipment capabilities to guarantee the sustainability of operations. The scarcity of these resources fosters conditions for the permanence of illegal actors in territories that are difficult to access, highlighting the dynamics in the border rivers and forests of the Amazon, where control mechanisms of the environmental authorities and the National Army are not sufficient to control illegal cross-border activities *(Environmental Investigation Agency* [EIA], 2019).

Despite the challenges exposed, Cabrera and Macías (2020) establish that the Military Forces have a substantial role in front of environmental protection, despite the fact that this type of activities corresponds to non-traditional missions, being necessary to strengthen the actions of the Army against environmental crimes to describe in the doctrine tasks of environmental protection, control and monitoring (Morales, 2017).

On the other hand, innovation in the monitoring of environmental crimes and environmental degradation dynamics, at local and multilateral levels, is noted as a potential opportunity, as described by Miranda (2022) in his study on the potential environmental protection tasks of the Peruvian Armed Forces, which highlights the use of remote sensors, unmanned aircraft and satellite images for these purposes.

Regarding the development of ecosystem restoration support activities, oriented to reforestation processes and production of plant material by military units, these can contribute to the recovery of territories affected by the armed conflict, through the restoration of ecosystem services (Jiménez and Vega, 2020).

Despite the positive experiences, weaknesses are still identified with respect to technical capabilities, sustainability and evaluation of the effectiveness of this type of activities developed by the National Army, so it is necessary to have adequate monitoring mechanisms and specialized experts, given the complexity of the processes and ecosystems (Mola et al., 2022).

On the other hand, the main challenges identified are the lack of a clear definition of the Army's responsibilities in environmental restoration activities, which would enable the allocation of resources, in order to integrate the Force into national restoration strategies. For this reason, implementation will depend to a large extent on inter-institutional collaboration, especially through the signing of agreements with environmental authorities (Gordón, 2022).

In addition, the development of ecological restoration processes in the territory is interrupted due to the persistence of the armed conflict, as it challenges the Army's priority attention in maintaining security and the constraint of illegal armed actors among the communities. This scenario deteriorates the link between state institutions and the communities, who are afraid to participate in the aforementioned restoration of the territory due to the constant threats from these organized armed groups (Garzón et al., 2020).

As opportunities for the processes of support to restoration developed by the Army, the development of research and capabilities, fostering innovation and systematization of experiences, through alliances with academia, environmental authorities and civil society, which also make it possible to attract international cooperation resources, stand out. In this regard, the Scientific Working Group for the United Nations Decade on Ecosystem Restoration (2022), positions the importance of generating long-term inter-institutional alliances, since restoration processes are prolonged, and this is an opportunity for the generation of knowledge and innovation that produces multiple benefits for environmental sustainability.

Based on the discussion, it is concluded that the cooperation efforts of the National Army in the control of environmental crimes are mainly oriented towards the control of illegal activities that affect the environment and serve as a source of financing for illegal armed groups. In this way, the need to strengthen normative and doctrinal regulations is highlighted, evaluating the need to create specialized units. For this reason, it is recommended that comparative studies be carried out with Armed Forces in the region, in order to evaluate experiences and strategies that can be replicated for the protection of natural resources and the control of environmental crimes.

Regarding ecosystem restoration activities, seen as a support or contribution effort, they already show considerable technical limitations, which translate into errors in planning, sustainability and evaluation, despite the fact that they identify potential benefits in terms of improving the institutional image and generating alliances with other institutions. In this regard, it is pertinent to suggest studies that technically and scientifically evaluate the methods used by the Army in reforestation processes and propagation of plant material, in relation to its mission and the effectiveness of these logistical exercises.

The main limitation of the study was the restricted access to key participants, which was mitigated by involving relevant stakeholders from the design of the research, ensuring the anonymity of the results, through the implementation of information management protocols that were communicated in a transparent manner, which allowed the generation of trust and active participation.

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Project for a photovoltaic Solar Power plant for Public Lighting in the Centrality of Praia Amélia in Moçâmedes, Angola

Projecto de uma central de energia solar fotovoltaica para iluminação pública, na centralidade da Praia Amélia em Moçâmedes, Angola

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ABSTRACT

This research presents, in the introduction, a general objective, which is to develop a photovoltaic power plant for public lighting in the Praia Amélia housing project, and specific objectives, which consist of describing and sizing the components of the plant. The methodology is based on a mixed model (qualitative-quantitative). Through bibliographic research, interviews, and direct measurements, theoretical foundations, as well as electrical and technical data of the housing project, were obtained. Thus, using latitude and longitude, monthly direct and global irradiation values and average temperatures were obtained through PVGIS. The results show that Moçâmedes presents suitable conditions for photovoltaic objectives. From the system sizing, with modules tilted at 15°, the critical month yielded a monthly global irradiation of 179 kWh/m^2 and a daily value of 5.78 kWh/m^2. With a demand of 116,250 W, the system uses 664 modules of 400 W, 3 controllers of 200 W, 48 batteries, and an inverter of 145,313 W. The system does not account for losses due to shading or dust but does consider 1.56% losses due to temperature and 7,309 W losses in cabling. Therefore, the system demonstrates economic feasibility by presenting a positive Net Present Value (NPV), with payback expected within 11 years. In the discussion, compared to similar photovoltaic projects in Cape Verde and Mozambique, this project proves to be more ambitious and to have greater socioeconomic and environmental impact, due to its higher load and its potential to reduce power demand on the local 63 MW thermal plants by 0.44%. This contributes positively to the reduction of greenhouse gas emissions (GHG). Thus, the plant shows technical value by accounting for total losses of 11,339 W (equivalent to 28 modules) in a system with a surplus margin of 61 modules.

Palabras clave:
Energias renováveis; Energia solar fotovoltaica; Dimensionamento de sistemas fotovoltaicos; Iluminação pública; Angola.

RESUMEN

Esta investigação apresenta, na introdução, objetivo geral, que consiste em desenvolver uma central fotovoltaica para iluminação pública, na centralidade da Praia Amélia, e específicos, que consistem em descrever e dimensionar componentes da central. A metodologia baseia-se no modelo misto(quali-quantitativo). Por meio da pesquisa bibliográfica, entrevista e medição direta, obtiveram-se fundamentos teóricos, dados elétricos e técnicos da centralidade. Assim, com a latitude e longitude, através do PVGIS, obtiveram-se irradiações mensais direta, globais e

	temperaturas médias. Dos resultados, Moçâmedes apresenta condições adequadas para objetivos fotovoltaicos. Do dimensionamento e com módulos inclinados à 15^0, obteve-se no mês crítico, radiação global mensal de 179 KWh/m^2 e diária de 5,78KWh/m^2. Com demanda de 116250W, o sistema utiliza 664 módulos de 400W, 3 controladores de 200W, 48 baterias e inversor de 145313W. Assim, o sistema não prevê perdas por sombreamento e poeira, porém apresenta perdas de 1,56% devido à temperatura e 7309W no cabeamento. Dessa forma, o sistema demonstra viabilidade econômica ao apresentar um Valor Presente Líquido (VPL) positivo, com amortização prevista para ocorrer em 11 anos. Da discussão, em relação a projetos fotovoltaicos similares de Cabo Verde e Moçambique, este projeto demonstra-se mais ambicioso e com maior impacto socioeconômico e ambiental, por possuir carga maior e, no seu dimensionamento, reduzir a potência nas centrais térmicas de 63MW locais, em 0,44%. Este dado impacta positivamente a redução de emissões de GEE. Portanto, a central apresenta valor técnico, ao acautelar as perdas totais de 11339W (28 módulos), em um sistema com margem superior de 61 módulos.

Introduction

Renewable energies have been around since ancient times. The search for better living conditions and the discovery of new forms of better accommodation have changed the perspective of man's vision, putting clean sources at the bottom of the list to the detriment of emitters. This has led to important changes in nature and impacts that have led governments to redirect their energy sources towards renewable sources (Pinho & Galdinho, 2014).

In fact, this rethinking is due to changes in the levels of greenhouse gas emissions, which, according to the IPCC (2007, cited by Uczai & Tavares, 2012), increased by 70% between 1970 and 2004. Although this increase is not simply the result of fossil fuels, it is considered the main driver. In this context, any prospect of change must be based on policies to promote research, development and implementation of renewable sources.

Angola's energy approach is making substantial progress in adopting the concept of decarbonization in the energy field. According to Losekann and Botelho (2019), the transition to a low-carbon economy is a notion that is best suited to directing energy policies, with the aim of ensuring environmental stability and mitigating climate change. As proof of this, from 2016 to 2021, Angola increased its energy production from renewable energies by around 14% and supplies 61% of the country's entire energy load (IRENA, 2024).

Public lighting is an essential factor for people's well-being. In this way, providing a central station from a clean source can solve various problems that the centrality has faced, such as public insecurity, crime and/or vandalism, inadequate visibility on the streets and impeded access to leisure venues at night (Leite & Alves, 2023, p. 8228-8236). Thus, with the intention of satisfying the community's socio-economic and environmental needs, this project is necessary.

The photovoltaic plant project has a positive impact on the technical and theoretical development of photovoltaic energy, since it is one of the most widely used energies. In this context, a power station is an innovation, as it has various practical, technical, socio-economic and environmental applications, as well as contributing to the applicability of the energy transition that is needed today (Grijó, 2014, p.28-28)

These applications as a whole aim to generate employment, reduce polluting emissions, diversify Angola's energy matrix and, above all, encourage investment in this source, since the municipality of Moçâmedes has high solar potential (ALER, 2022). However, with this project, not only would the problem relate to seasonal night-time lighting be solved, but it would also provide a theoretical apparatus with a basis for more scientific reflections and with a scientific methodology.

The solution to the problem of street lighting through corrective maintenance has not been effective, since Tsshara (2024) points out that the lack of energy brings with it various problems, such as, on the one hand, the bureaucratic issues involved in resolving the problem and, on the other, the embarrassment of a partial power cut during the maintenance period, which has been in hours of productivity.

This research is justified by the need to contribute to the applicability of energy actions for environmental protection, aimed at in the international agreements that Angola has ratified. In fact, this article makes it possible to use photovoltaic energy for public lighting.

It is therefore a practical application project, analyzing and describing the current literature on photovoltaic energy, based on achieving the general objective of developing a photovoltaic solar power plant for public lighting and the specific objectives of describing the main components of photovoltaic power plants and sizing them.

Therefore, the following concepts are presented in abbreviated form throughout the approach:

- IESS- Ideal Solar Studies and Solutions
- IRENA- International Renewable Energy Agency
- IRSEA- Regulatory Institute for Electricity and Water Services
- PRODEL- Public Electricity Production Company
- ALER- Lusophone Renewable Energy Association
- PVGIS- Photovoltaic Geographical Information System

Theoretical Background on Photovoltaic Solar Energy

(i) Photovoltaic Solar Energy and Its Caracterization in Angola

Solar energy is a renewable energy that comes from the light and heat of the sun. Solar modules are used to harness this energy, which, when positioned towards the sun, produces inexhaustible energy (Soares & Santos, 2020). Photovoltaic systems can be isolated (offgrid) or connected to the grid (ongrid).

Angola has an estimated solar potential of 55GW, very close to South Africa and California (ALER, 2022, p. 134). Of this potential, more than 405GWh (2%) will be supplied to the electricity grid from 2022, approximately 10% more than renewable energies. However, the country aims to reach 1GW by 2027 in its 2017 Action Plan (IRENA, 2024).

(ii) Incidence of Solar Radiation on the Earth and Radiation Incident on the Modules

The radiation that the sun emits from its corona, coming from its temperature, is enormous. This flux, when measured near the Earth's atmosphere, is 1367W/m^2, which is the solar constant. This value, in relation to the radius of the earth, can provide a total power of 174,000 TW. Of this amount, around 46% is absorbed or reflected by the atmosphere, and of the remaining 54%, 7% is reflected and 47% is absorbed, giving a total power on the earth's surface of 94,000 TW. Solar radiation can be Radiation due to albedo, Global Radiation and Total Radiation. (Pinho & Galdinho, 2014). Pereira (2022) sees it as Direct Radiation, Diffuse Radiation and Reflected Radiation.

Due to the various power losses of the flow in the earth's atmosphere, resulting from difficulties, albedo radiation, diffuse radiation, direct radiation and atmospheric conditions, the incident radiation on the earth's surface is 1000W/m^2. This radiation becomes the standard value used in the sizing of photovoltaic systems (Ovelha, 2017).

(iii) Main Components of a Photovoltaic Plant

The use of photovoltaic solar energy is growing. Therefore, projects are defined according to the size and characteristics of the photovoltaic plant, which, according to Madeira (2022, p. 44), "are large-scale energy production systems made up of components such as modules, inverters, batteries, controllers, voltage transformers, cables and protection and control devices and control devices.

- **Photovoltaic module:** is a component made up of a set of interconnected solar cells responsible for converting solar energy into electricity... (Mariano & Urbanetz, 2022).

Therefore, to achieve high loads, the cells in the modules must be connected in series to increase the voltage and in parallel to increase the current. Photovoltaic modules are guaranteed for 25 years or more, making them resistant to adverse weather conditions (Wood, 2022).

Photovoltaic modules produce direct current (DC) electricity. Thus, depending on the technology used and the arrangement of the cells, the photovoltaic module has specific electrical and thermal parameters and characteristics (Granja, 2017). These parameters and characteristics can be presented as the short-circuit (Isc) and maximum power (Imp) currents, the open-circuit (Voc) and maximum power (Vmp) voltages and the maximum power point (MPP), (IESS, 2019).

Photovoltaic module technologies can be characterized, according to Granja (2017); (Mariano & Urbanetz, 2022) and Azambuja (2022) as: Monocrystalline Silicon cell technology, with efficiencies of 14%, 17%, 20% or more; Polycrystalline Silicon cell technology, with efficiencies of 13 and 15%; Thin film cells, with 6 to 11% and Multijunction a-Si/μc-Si cells, with 8, 9% or 35% when composed of other elements.

In this context, when choosing a technology, Mariano and Urbanetz (2022) emphasize that project-dependent characteristics and factors must be taken into account. These include efficiency, architectural aspects and the area available.

- **Photovoltaic inverters:** these are devices made up of current control, islanding detection, synchronization and MPPT (Maximum Power Point Tracking) systems. These devices convert the direct current produced by the modules into alternating current, ... (Azambuja, 2022).

Inverters, according to Nogueira (2023, cited by Barreto, 2024), can be central inverters (row) and modular inverters (microinverters). According to Granja (2017), its parameters are efficiency, nominal power and maximum power in direct current (DC), nominal power and maximum power in alternating current (AC), power factor, power on and off, stand-by power and night mode, nominal voltage DC and AC, MPP voltage range (Maximum Power Point), maximum DC voltage, switch-off voltage, nominal and maximum current (DC), harmonic distortion rate, noise level and temperature range.

- **Photovoltaic batteries:** the production of energy in photovoltaic systems is not continuous, so there is a need to store energy in batteries, since the modules only produce energy during the day. This function is of great importance in photovoltaic systems. Its parameters are battery capacity, maximum charge and discharge current, charge and discharge voltage, depth of discharge and useful life (Pinho & Galdinho, 2014, p.163-175).

For certain voltage or current requirements, batteries are connected in series and/or parallel. The batteries to be used must, according to Fadiga (2004), meet shallow cycles every day and deep cycles for several days or weeks, have a high cyclic life for deep discharges; low maintenance; high charging efficiency; the ability to remain discharged; low self-discharge; minimal change in performance when working outside the operating temperature; availability from suppliers and considerable cost and energy density.

- **Load controllers**: are devices that control the flow of power between the generation system and the storage system. These devices protect the battery from overcharging and discharging, prevent it from continuing to charge when it reaches its charging limit and fall below the recommended limit by monitoring the voltage at its terminals (Oliveira, 2023).

Thus, IESS (2019) points out that controllers control voltage values, protect against polarity reversal, short-circuiting.... They are classified as Parallel or Shunt controllers, which prevent reverse currents, and series controllers, which interrupt the supply to extreme loads when the battery reaches the depth of discharge threshold, and MPP controllers, which lower the generator's voltage due to reduced solar incidence, making energy production unfeasible Granja (2017).

In the view of Mariano and Urbanetz (2022) and Oliveira (2023), they classify On/Off controllers as which open and close when the voltage of the battery pack reaches predetermined values; PWM (Pulse Width Modulation) controllers which control the voltage through pulse width modulation control and MPPT controllers which track the point of maximum power of the modules.

- **Protection devices:** photovoltaic systems are subject to damage from the sun. In this context, fuses, circuit breakers, surge protection devices (SPD), earthing systems and lightning protection systems (SPDA) are needed to protect them (Mariano & Urbanetz, 2022).
- **Transformers**: voltage transformers have the role of raising or lowering the voltage supplied by the inverters to values suitable for distribution, working according to load requirements (POOR et al., 2012, cited by Barreto, 2024).
- **Wiring in photovoltaic systems:** the energy produced by the modules is transported by the conductors, which must be considered in conditions that meet the specifications of the photovoltaic installations. The conductors in photovoltaic systems are classified as DC and AC (Pereira, 2021). Therefore, due to extreme solar conditions, high voltages and climatic factors, conductors must have characteristics such as maximum operating voltage, operating temperature, resistance to ultraviolet (UV) radiation and water (Moreno, 2019).

Method

The aim of this research is to develop a photovoltaic power plant in the Praia Amélia Centrality in the municipality of Moçâmedes, Namibe, Angoa. The town has solar insidence that can be used to solve the problem of public lighting.

The electrical characterization shows that it is powered by the Thermal Power Station, which carries a low voltage of around 15,000V to the transformer stations, lowered to voltage levels of around 380V in a three-phase system. The economic characterization shows that it depends on external services, and there is no local economic sustainability in its current operation, but its own spaces tend to enable entrepreneurs to open businesses. The centrality has 465 lampposts distributed along the main roads, verified in the archives and confirmed by the direct count criterion. These poles are 12 meters high, with 250W sodium vapor lamps that provide orange lighting with a radius of 15 meters for 12 hours. The poles are 25 meters apart.

The methodology is based on a mixed model, i.e. qualitative-quantitative, which guides the study towards the questions that aim to achieve the research objective (Morais & Neves, 2007, p. 1-2). In order to gather the theoretical basis, a bibliographical review was carried out of books available on the internet, in the library and in the Renewable Energy laboratory of the Pascoal Luvualu Polytechnic Institute in Moçâmedes.

To obtain the number of lampposts, distances between lampposts, lighting radius, color of lighting, measurement of lamppost heights, participant observation and direct measurement were used.

In order to obtain the technical and electrical data for the centrality, we consulted the physical files available at the local administration and interviewed two (2) local administration technicians for 15 minutes on the first two points in the guide below and two (2) electrical engineers for 10 minutes on the last two points in the guide below.

- Data on the dimension of centrality;
- Data on the total number of homes and their type;
- Data on the source of energy generation for centrality and;
- Data on the local electrification configuration.

The photovoltaic generation system for street lighting was sized using the parameters of latitude -15°11'45" and longitude 012°09'07", with the support of the European Commission's PVGIS (2024) website, which provided specific data on monthly direct irradiation, global irradiation and average temperatures for the site on November 12, 13 and 14, 2024.

Using equations 1 to 11, the components of the photovoltaic system were calculated.

Equation 1

Calculating the number of modules to be installed (Azambuja, 2022, p. 21)

$$N_p = \frac{E_t}{HSP * P_{max}}$$

N_p : Number of modules

HSP : Peak sun time

E_t: Energy demanded

P_{max} : Module power

Equation 2

Calculation of total system power (Sousa & Franco, 2018, p.54)

$$P_t = N_p * P_{max}$$

P_t : Total power to be installed

N_p : No. of module

P_{max} : Module power

Equation 3

Calculating the total energy of the system (Pinho & Galdinho, 2014, p. 328)

$$E_{GS} = P_t * HSP$$

E_{GS} : Total energy generated

P_t : Total power to be installed

HSP : Peak sun time

Equation 4

Calculating the number of batteries in parallel (Pinho & Galdinho, 2014, p. 313).

$$N_{bp} = \frac{C_{ts}}{C_{bat}}$$

N_{bp}: Number of batteries in parallel

C_{ts}: System capacity

C_{bat}: Battery capacity

Equation 5

Calculating the number of batteries in series (Pinho & Galdinho, 2014, p. 313)

$$N_{bs} = \frac{V_s}{V_b}$$

N_{bs}: Serial number

V_s: System voltage

V_b: Battery voltage

Equation 6

Calculation of the installation's total battery quantity (Pinho & Galdinho, 2014, p. 313).

$$N_{Total} = N_{bs} * N_{bp}$$

Equation 7

Calculating the conductor section specification (Wate, 2023, p. 68)

$$s = \frac{0{,}036 * I * L}{V_t * C_t}$$

S: conductor section.

I: the electric current.

L: the length of the conductor.

Vt: System voltage.

Ct: voltage drop, corresponding to 1%.

Photovoltaic systems are subject to losses associated with the orientation and inclination of the modules, shading, dust accumulation, cabling and module losses due to temperature (Silva, et al., 2018**,** p. 14; Tonolo, 2019, p. 36). Losses due to temperature and conductors are determined using equations 8 and 9.

Equation 8

Calculation of power loss in the module due to temperature (Teixeira & Silva, 2021, p.10).

$P_{MPT} = (1-(Tm-25^0C)*\%Pm)$

P_{MPT}: Module power due to temperature loss

Tm: average local temperature

Pm: module power coefficient

25^0C: Standard module test temperature

Equation 9

Calculation of power loss in conductors (Macita, 2022 p. 30)

$$P_M = \frac{2 * N * L * I^2}{S * K}$$

P_M: Power losses in conductors

N: Number of rows

S: Cable section

K: conductivity of the material

L: Length

I: Electric current

The economic evaluation of the project is carried out using equations 10 and 11.

Equation 10

Calculation of Net Present Value (Sousa & Franco, 2018, p.44).

$$VLP = -I_O + \sum_{n=1}^{n=N} \frac{F_{ci}}{(1+i)^n}$$

NPV: net present value.
I_0: investment.
n: period analyzed.
F_{ci}: Cash flow for the period.

Equation 11
Calculation of the investment's amortization time (Sousa & Franco, 2018, p.44).

$$\text{Payback}_{\text{simples}} = \frac{I_0}{F_{ci}}$$

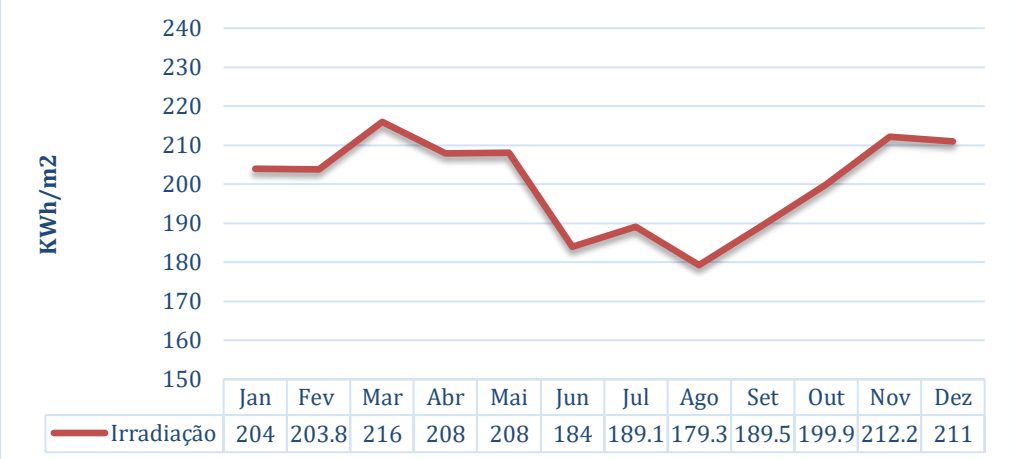
Payback: investment amortization time.

Results

Based on the interview carried out using the points in the guide, it was found that the centrality is located just under 5 km from the city center, occupying an area of approximately 1,827km^2. It has 2,000 housing units, spread over 11 blocks, with 3-bedroom houses and apartments, a hospital, sports fields, leisure facilities, a school complex, a kindergarten and the Faculty of Engineering and Technology.

Information on global monthly irradiation, direct normal irradiation and average temperatures for sizing, obtained from the European Commission PVGIS website (2024), is shown in Figures 1, 2, 3 and 4.

Figure 1
Monthly global irradiation at angle equal to latitude

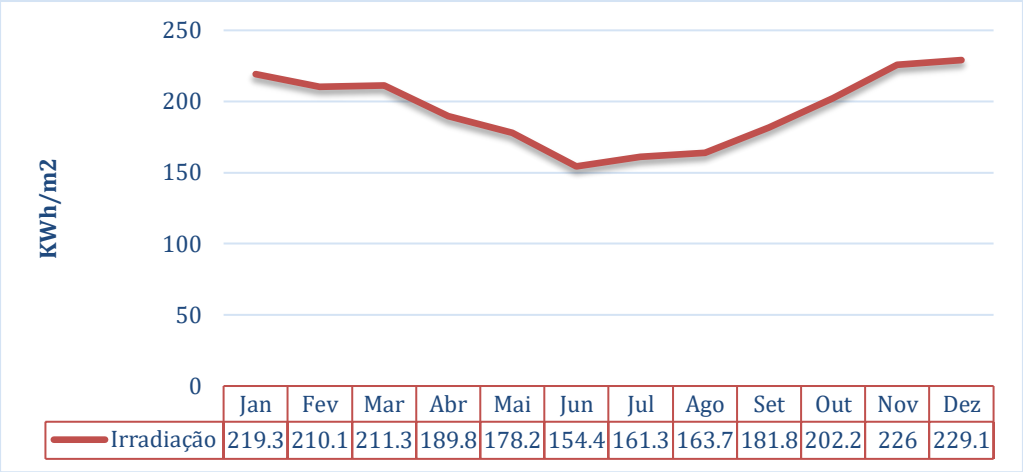


Note. Irradiationmonthly irradiation at angle equal to 15^0, based on data from European Commission PVGIS (2024).

According to figure 1, the monthly global irradiation with modules inclined at 15^0 provides irradiations with a maximum of 2016 kWh/m^2 in March and a minimum of 179 kWh/m^2 in August. This shows a rise from January to March, a fall from April to May, a fall in June, a rise in July and then a fall in August, rising until November, with a slight fall in December. August is therefore the critical month. Dividing its monthly radiation by the days of the month gives a daily average of 5.78 kWh/m^2/day, used for sizing.

Figure 2

Global horizontal irradiation at the optimum angle.

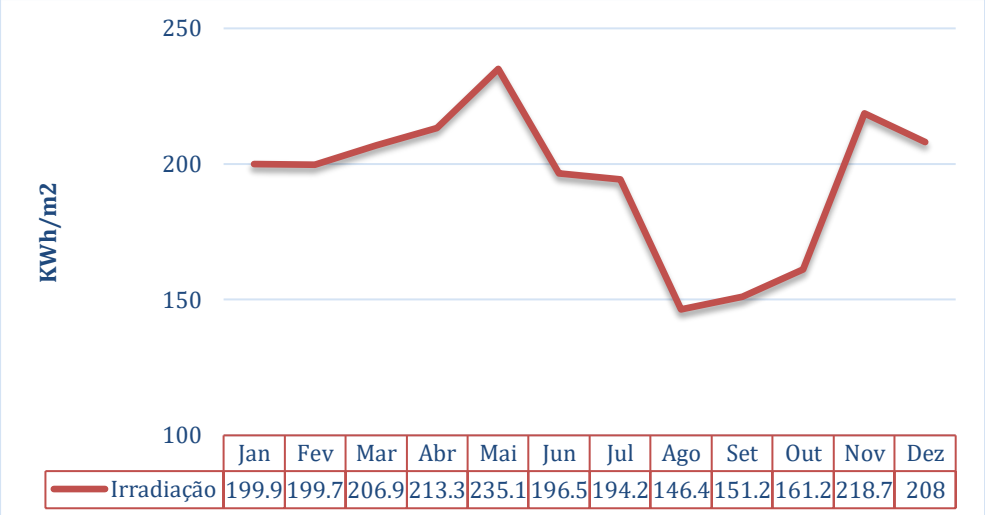


Note. This shows monthly irradiation at optimum angle, drawn up using data from European Commission PVGIS (2024).

Figure 2 shows a maximum of 229 kWh/m^2 in January and a minimum of 154 kWh/m^2 in June. It also shows a general downward irradiation behavior from January to June and an increase from July to December.

Figure 3

Normal direct irradiation

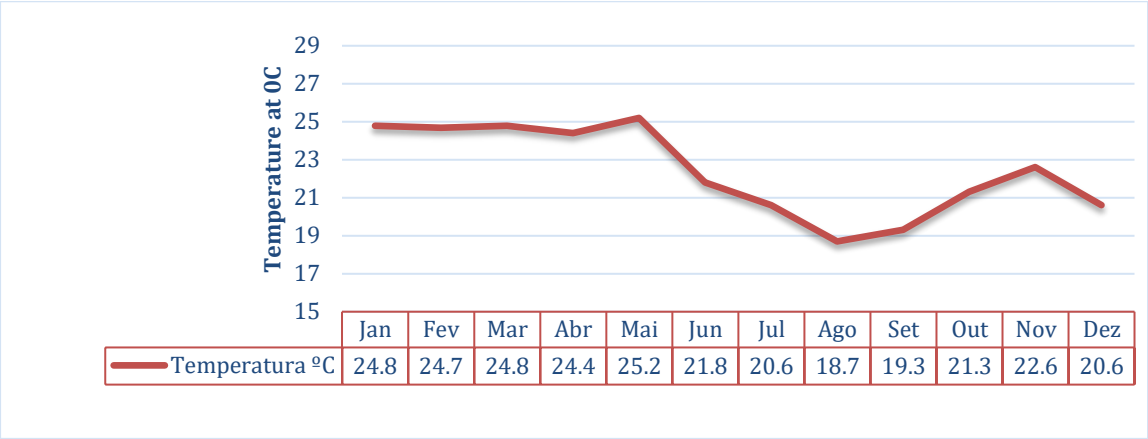


Note. This figure shows the monthly direct irradiation, drawn up using European Commission PVGIS data (2024).

Figure 3 shows a maximum of 235 kWh/m^2 in May and a minimum of 146 kWh/m^2 in August. The general trend is flat from January to February, up from February to May, down from June to August, up from September to November and down in December.

Figure 4

Temperature variation in Moçâmendes



Note. This figure shows the daily temperature drawn up from the European Commission PVGIS (2024).

Figure 4 shows the temperature with a maximum of 25.2^{0}C in May and a minimum of 18.7^{0}C in August. There was growth from January to April, a rise in May, followed by a fall from June to August, a rise in September to November, followed by a fall in December.

From these parameters of incident irradiation and average temperatures at the site, the European Commission PVGIS (2024) website, which provides direct and global irradiation and the average temperature of Moçâmedes for sizing the photovoltaic plant, the following analogies were made of the irradiation and temperatures provided.

As shown in figure 1, global irradiation at an angle of 15^{0}corresponds to a monthly average of 209 kWh/m^2 and an annual average of 2504.75 kWh/m^2.

In figure 2, which shows horizontal global irradiation, the monthly average is estimated at 193.92 kWh/m^2 and the annual average at 2327.04 kWh/m^2.

Figure 3 shows normal direct irradiation, where the monthly average is 193.42 kWh/m^2 and the annual average is 2321.12 kWh/m^2.

Figure 4 shows the average monthly temperatures, which correspond to approximately 22.4^0 C.

Sizing the Photovoltaic Generation System

In order to size the generation system, some data is needed, namely the consumption parameters and the characteristics of the photovoltaic module. These are shown in table 1.

Table 1

Consumption parameters and the module.

Load	No. of poles	Time	Energy per pole	Total energy
250W	465	12 hours	3000 Wh	1.4MWh
Daily incident irradiation of the worst month (August)				5.78KWh
Module power				400W
Power coefficient				-0,6%
Module voltage/ Module current				31.01V/12.90A

Note. Consumption parameters in the centrality of Praia Amélia.

Depending on the specifications in table 1, the number of modules to be installed is determined using equation 1.

$$N_p = \frac{1395000Wh}{5{,}78h*400W}$$

N_p =603,373

In this context, the number of modules will be 603.3. To this value must be added 10%, which is the configuration correction and safety factor due to wiring and temperature losses. Therefore, the number of modules to be installed will be 664. In fact, the system has no shading losses, no orientation losses and no significant dust losses, as the installation site is preferably rocky. It is therefore possible to determine the total photovoltaic generation power and the energy generated using equations 2 and 3.

$P_t = 664 * 400W$

$P_t = 243200\text{W}$

$E_{GS} = 265600W * 5{,}78h$

$E_{GS} = 1535168Wh$

From these values, the installation conditions are given in the following descriptions.

- ❖ System voltage: 600V;
- ❖ System current: 452A;
- ❖ Number of modules in series: 19;
- ❖ Number of rows: 35;
- ❖ Number of modules in parallel (rows): 35.

Sizing the Controller

When sizing the controller, the maximum current that the system will supply must be taken into account, corrected by 25% and in line with the battery specifications. These parameters are checked in the description below.

- System current: 452 A
- Corrected current (15%): 520 A
- Current of each controller: 200A
- Total power of the controllers: 312000W

Sizing the Battery Bank

In order to supply the lighting load demand in the time considered, the battery bank must be sized and chosen with the following characteristics:

1. Demand corrected by 15%: 1604250Wh
2. Battery voltage chosen: 51,2V
3. System voltage: 600V
4. Days of autonomy: 0.5
5. Determined system capacity: 1485.4Ah

Determine the number of batteries in parallel using equation 4.

$N_{bp} = \frac{1485{,}4Ah}{410Ah}$

$N_{bp} = 3{,}6$

For the stability of the system, 4 batteries are used, thus storing a higher margin of charge, increasing the useful life. The number of batteries in series is then calculated using equation 5.

$N_{bs} = \frac{600V}{51{,}2V}$

$N_{bs} = 11{,}718$

This value is rounded up to 12 batteries connected in series. However, the total number is determined by equation 6.

$N_{Total} = 12 * 4$

$N_{Total} = 48$

This result implies that the storage system will have 4 columns in parallel, each containing 12 batteries in series.

Inverter Sizing

The sizing of the load inverter is based on the power demanded by street lighting consumption. From this value, a safety correction factor of 25% of the power demanded is taken into account. So these parameters are:

- Power demanded: 116250W, which is the result of the product of the number of poles, 465, and the lamp wattage, 250 W.
- Power corrected by 25%: 145313W

Cable sizing

The conductors are dimensioned based on the parameters in equation 7. The characteristics of the categories are shown in Table 2:

Table 2

Cabling sizing.

Categories	*Distances (m)*	*Current (A)*	*Voltage (V)*	*Section (mm²)*
Modules	1	12.90	31.01	2.5
Strings	2	155	600	2.5
Strings to regulators	5	155	600	5
Battery regulators	3	465	600	10
Batteries on sale	3	465	600	10
Inverter to main switchboard	3	632	230	30

Note. This table shows the sizing of cabling by category.

System Losses

The losses associated with the plant were taken into account when sizing. For example, the modules are inclined at 15^0, favoring self-cleaning, and oriented to the geographical north, due to the site's southern location. As for dust losses, the region has conditions that favor the absence of significant dust and dirt, corrected by tilting and maintenance whenever possible.

The module's losses due to temperature are calculated using equation 8, considering that the power coefficient of the chosen module is equal to -0.6%/^{0}C (0.006) and the average local temperature is 22.4^{0}C.

P_{MPT}=1- (22,4-25)*(-0,006)

P_{MPT} = 0,9844

P_{MPT} = 98,44%

This result shows that the module will supply 98.44% of its maximum load under the local temperature conditions.

In order to determine the losses in the cables using equation 9, the current, section and length of the cables will be taken into account, considering copper as the material from which they are made.

Losses in the connection between modules:

$$P_M = \frac{2*1*19*12,90^2}{2,5*56}$$

P_M =45W

1- Losses in the connection between rows:

$$P_M = \frac{2*2*12*12,90^2}{2,5*56}$$

P_M=457W

2- Connection losses for controllers:

$$P_M = \frac{2*5*1*155^2}{5*56}$$

P_M=2574W

3- Connection losses to the batteries

$$P_M = \frac{2*3*1*465^2}{10*56}$$

P_M=2317W

$$P_M = \frac{2*5*1*155^2}{5*56}$$

P_M=2317W

Economic Viability

The economic feasibility analysis was based on the material prices in Table 3 and the production parameters in Table 4.

Table 3

Data on the plant's economic viability.

Parameters		**Brand**	**Value (KZ)**	**Quantity**	**Total (kz)**
Module		Shinefar	40.145,00	608	24.408.160
Controller		DM	5.291.804,00	3	15.875.412
Inverter		ATESS	2.965.244,75	1	2.965.244,75
Battery		Dawnice	692.498,70	48	33.239.937,6
Protective devices	Circuit breaker	TOMZN	1.368,57	32	43.794,24
		TOMZN (2p/4p)	5.494,4/22.959,2	5/1	50.431,06
	SPD	EARU	903,26	3	2.709,78
		EARU	5.277,40	2	10.554,8
Cabling and connectors					100.700
Total					76.696.944,2
Project (5%)					3.834.847,21

Installation and maintenance (15%)	11.504.541,6
Investment value	92.036.332,8

Note. This table shows the values for assessing the economic viability of the plant.

Table 4

Production data from the photovoltaic plant.

Parameters	Value	Unit
Daily production	1.405,696	KWh
Annual Production	513.079,04	KWh
Kwh price	15,61	Kz
Annual cash flow (F_{ci})	8.009.163,81	Kz/KWh
Investment value I_O	92.036.332,8	Kz
Discount rate (t)	10	(%)
Design lifetime	30	Years

Note. This table shows the plant's electrical and economic production data.

Based on table 4, the NPV (Net Present Value) is calculated using equation 10, which, when positive, means that the project is economically viable.

$\mathrm{VLP}_{30} = -92036332{,}8\mathrm{kz} + \sum_{t=30}^{t=30} 7281058{,}01Kz$

$\mathrm{VLP}_{30} = -92036332{,}8\mathrm{kz} + 30 * 7281058{,}01Kz$

$\mathrm{VLP}_{30} = 126395407\mathrm{Kz}$

Over the course of 30 years, the project will appreciate in value, as the VLP is positive. The time over which the project will be amortized by equation 11 is:

$Payback_{\mathrm{simples}} = \frac{92036332{,}8\mathrm{kz}}{8009163{,}81\mathrm{kz}} ano$

$Payback_{\mathrm{simples}} = 11{,}49$ anos

Therefore, the investment value will be amortized over a period of approximately 11 years.

Discussion and Conclusions

In this discussion, reference is made to comparing the results of this study in Angola with the projects in Cape Verde and Mozambique, as well as with the similar project in Huambo, also in Angola.

Angola, Cape Verde and Mozambique are heavily dependent on fossil fuels for energy production. Thus, in the fight for environmental stability, significant steps have been taken in the use of renewable solar and wind sources (Varela, 2021; Macita, 2022).

Angola has 2.7% public lighting (IRSEA, 2022), which is considered low when compared to Cape Verde, which has 10% public lighting (Varela, 2021). This low percentage of electrical development in lighting leaves room for investment in research and lighting projects, compared to Cape Verde.

In fact, this public lighting plant project is a first approximation to this investment, and can be compared with the public lighting project in the city of Ribeira Grande de Santiago in Cape Verde based on photovoltaics (Varela, 2021, p.53) and the lighting project for the 3 de Fevereiro neighborhood in Maputo, Mozambique (Macita, 2022).

This comparison shows a similarity in the use of isolated photovoltaic systems and technical differences in the sizing and loads for lighting, where the present project has 11,6250W, operating over 12 hours, the Cape Verde project has 11,268W (9.6% of Centrality), operating over 11 hours and the Mozambique project has 8051W (6.9% of Centrality) and operates over 12 hours.

Thus, the percentage of Cape Verde's lighting project at 9.6% and Mozambique's at 6.9% makes this project more ambitious and with a greater positive impact on reducing the levels of polluting gas emissions and greater social and economic relevance.

The projects in Cape Verde and Mozambique, although focused on public lighting, clearly show a partial approach to taking advantage of the enormous potential in photovoltaic energy. Thus, one way of supporting the reduction of polluting gas levels would be the need for more comprehensive projects. That's why, in comparison, the Centralidade project is a production plant, while the others focus on integrated use of the lampposts.

Another comparison at country level can be made with the photovoltaic plant project for the Ngongoinga neighborhood in the province of Huambo in Angola, which is more comprehensive and has a total load of 2MW (Pinto, 2024), which produces 6% more than the present project, due to its total coverage of the neighborhood's load.

However, since Moçâmedes produces 71.8MW from fossil fuels, supplied by the Xitoto 2, 3 and Aeroporto thermal power plants (PRODEL, 2025). Thus, this project, with a production margin of 265600W in the critical month, shows a considerable decrease of 0.37%.

Thus, this 0.37% reduction in fuel used by thermal power stations is of considerable socio-economic value in the municipality and in Angola, since it redirects this percentage of fuel to other purposes, as well as reducing the levels of polluting gases in the atmosphere and bringing the country onto the scale of countries firmly committed to environmental decarbonization.

From the annual and monthly irradiation values provided, it can be seen that the global irradiation at the angle equal to the latitude (15^0) is the most significant as it has the highest value among the other irradiation values. This result reinforces the idea that the inclination of the modules, when equal to the latitude of the location, makes it possible to use energy that makes photovoltaic systems economically viable.

This inclination not only allows the system to make high use of energy, but also allows the system to be self-maintaining, based on the self-cleaning of the modules by action, waste and rainwater.

In fact, the average local temperature can satisfy photovoltaic objectives, since when the high and low temperature curves are analyzed, it is possible to see limits of no more than 26 °C and no less than 18 °C.

The system is suitable for orientation to the northern hemisphere, and as it is located in a desert and rocky area, there is no room for shading. As for significant losses due to dust, this is not expected, but in a variety of situations, regular maintenance could prevent them. On the other hand, with a $15.^{0}$ slope, the effect of dust accumulation will be less, as the module can be cleaned in the rain (Silva, et al., 2018, p. 15).

Therefore, temperature has a great influence on energy generation, and increasing it to levels above the laboratory conditions of 25^{0}C decreases the considerable levels. Thus, according to Almeida (2012, cited by Silva, et al., 2018, p. 16), the power of the photovoltaic generator drops by between 0.3 and 4% with each increase of 1 °C.

In this context, depending on local temperature conditions, the modules have losses of around 1.6% (6W). The module thus provides a significant load of over 98% (394W) of the 400W of nominal power.

Wiring losses throughout the system were estimated at 7309 W. This figure does not constitute losses that compromise the system or the possibility of meeting demand. This constitutes a power of 19 modules working with power related to temperature loss (394W), in a system with a demand of 603 modules in the critical month and with an availability of 664 modules in generation.

The project is economically viable, as the investment of 92,036,332.8Kz (92,036.33 Euro) is amortized in 11 years, compared to the Huambo project with an investment of 1,604,241,750 Kz (1,604,241.75 Euro), which is viable in 18 years (Pinto, 2024), while the Maputo project is amortized in 9 years (Macita, 2022, p.51)finally, the Cape Verde project is unviable, as it has not been amortized after 25 years (Varela, 2021, p. 78).

The current environmental situation is worrying. This concern, the result of anthropogenic activities, makes the energy sector, based on fossil fuels, one of the main villains. In this context, there is a common desire among states to reverse the situation by creating public or private energy policies based on renewable energies. In this way, the choice of clean source must be based on an in-depth study of structural issues, with a focus on the availability of the resource, a real dimensioning and the social and economic impacts of the region.

The Angolan state has already made use of renewable energies, the result of which are the various projects that have been implemented and the various ongoing studies to make available resources called new renewables. In order to meet local and global objectives, this article locates the solar source as the most viable and tries to size the plant to take advantage of the enormous photovoltaic potential available in Moçâmedes (ALER, 2022).

From these allegations it can be concluded that photovoltaic energy, characterized by its daily renewability, has the potential that, when harnessed with the most up-to-date photovoltaic components, provides energy to meet the energy needs demanded.

In another conclusion, the centrality of Praia Amélia, due to the difficulties caused by irregular public lighting, is in need of an auxiliary supply that could come from making use of the available solar resource.

On the other hand, it can be concluded that the sizing of the plant was based on the criteria of assessing the solar resource, assessing the energy needs for lighting and studying the losses inherent in the system. Therefore, the sizing has met the demand, as the solar resource is usable, the needs have been met and possible losses have been taken into account, without compromising energy generation at adequate levels.

With regard to the plant's economic viability, it can be concluded that the NPV, being positive over the plant's lifetime, shows that the plant is viable. In another case, however, the payback shows that the project will be amortized in approximately 11 years, a considerable amount of time for photovoltaic generation systems.

Important limitations include seasonality and constant changes in meteorological information, which can have a significant impact on irradiation parameters.

Another limitation is the possibility of implementing this project, since any photovoltaic plant project initially involves a high economic outlay. This means that it is often not financed, especially in a country that is mostly dependent on oil for immediate energy generation.

Another limitation to implementation is the significant differences in their state of government. This slows down the embryonic energy prospects of using renewable energies with a photovoltaic focus. Another limitation is the cost of electricity in Angola, which is considered very low, making projects take longer to become viable.

Some of these limitations have been taken into account, especially possible variations in irradiation levels and possible dust levels. These limitations are of little relevance, as the region has favorable weather conditions and with the safety margin considered in the design, these limitations can be overcome. As for the economic analysis, the plant is viable and can therefore be financed because, according to Pinho and Galdinho (2014, p. 477), photovoltaic projects have a useful life of 25 years of normal operation and can reach 30 years.

However, this project opens up a broad vision for other future projects. In the future, a hybrid renewable power plant (solar, wind) that could supply all the centrality's loads could support and continue this research project.

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Conflict of Interest

The article is wholly owned by the author who outlined all the activities individually and there is no link to other authors.

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