Strategic Proposals to Diversify Environmental Sustainability Training in Engineering Academic Programs and their Articulation with the Productive Sector of Cesar

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Abstract

Introduction: This article evaluates and proposes strategic actions to integrate environmental sustainability as a transversal axis in the academic programs of the Faculty of Engineering and Technological Sciences at the Universidad Popular del Cesar.

Methods: A qualitative methodology was employed, including semi-structured interviews with key stakeholders, documentary analysis of institutional plans, and thematic categorization of the data collected.

Resultados y Conclusions: The findings reveal significant gaps in the integration of sustainability-related content within the curricula, highlighting enablers such as partnerships with the productive sector and inhibitors like the lack of curricular transversality. Furthermore, the study identifies critical areas for improvement, including strengthening transversal competencies, fostering curricular innovation, and consolidating connections with the productive sector. The discussion emphasizes the need for systemic changes, proposing actionable solutions to address these gaps and enhance alignment with the United Nations' Sustainable Development Goals (SDGs). The conclusions underline the importance of academic-industry collaboration in forming professionals capable of leading sustainable development initiatives in the Cesar region.

***Keywords*: -** Environmental Sustainability, Engineering Programs, Productive Sector Collaboration, Curricular Innovation, Sustainable Development

1. Introduction

Environmental sustainability has become a cornerstone of global educational agendas due to the pressing need to address climate change, resource depletion, and unsustainable economic practices. The United Nations' Sustainable Development Goals (SDGs), specifically SDG 4 on quality education and SDG 13 on climate action, emphasize the integration of environmental considerations into education systems, highlighting the crucial role of higher education institutions in fostering sustainable development (United Nations, 2015; Sachs et al., 2021). These institutions are tasked with equipping students with the technical skills, critical thinking abilities, and systemic understanding needed to confront and mitigate environmental challenges effectively.

In Colombia, environmental education has been part of the legal framework since the enactment of Law 99 of 1993 and Decree 1743 of 1994, which mandate the integration of environmental projects at all educational levels. However, in practice, higher education institutions often struggle to embed

sustainability holistically across their curricula (Ceballos & Martínez, 2020; Gutiérrez-Ortega et al., 2021). These gaps are particularly evident in regions like Cesar, where mining, agroindustry, and livestock dominate the economy. While these sectors drive economic growth, they also generate significant environmental impacts, including deforestation, soil degradation, and water contamination, necessitating urgent action to align education with sustainability goals (IDEAM, 2020; Fernández-Llamazares et al., 2022).

The Faculty of Engineering and Technological Sciences at the Universidad Popular del Cesar provides a vital platform to address these challenges. However, the integration of sustainability in its academic programs remains fragmented and inconsistent. While isolated efforts, such as courses on renewable energy and agro-industrial innovation, and collaborations with local industries have been initiated, they lack a strategic framework to ensure systemic impact (Rodríguez & Vargas, 2021; Hens et al., 2023). This disconnect between the academic offerings and the region's environmental needs limits the capacity of graduates to contribute meaningfully to sustainable development.

This research aims to evaluate the current status of sustainability integration in the faculty's academic programs, identify enablers and barriers, and propose strategic actions for enhancing the alignment between education and the environmental demands of the region’s productive sectors. A qualitative methodology was employed, including semi-structured interviews with key stakeholders, comprehensive documentary analysis, and thematic categorization to reveal patterns and gaps in current practices.

The findings underscore the need for a curriculum overhaul that embeds sustainability as a cross-cutting theme, fosters the development of critical and transversal competencies, and strengthens ties with the productive sector to co-create sustainable solutions. These proposals align with studies by Sterling (2021) and Freeman et al. (2022), which emphasize the transformative potential of sustainability-oriented education. By addressing the identified gaps, this study not only contributes to regional sustainable development but also positions the Universidad Popular del Cesar as a leader in fostering environmentally responsible innovation.

The significance of this research lies in its potential to transform academic programs into powerful tools for driving regional sustainability. By aligning education with environmental imperatives, the university can prepare future professionals capable of leading the transition to sustainable practices, benefiting both the local economy and the broader ecosystem (Sachs et al., 2021; Cebrián et al., 2022; Etzkowitz & Zhou, 2023).

Methodology

This study adopted a qualitative approach to comprehensively explore the integration of environmental sustainability into the academic programs of the Faculty of Engineering and Technological Sciences at Universidad Popular del Cesar. Additionally, the research examined the alignment between these academic programs and the sustainability demands of the productive sector in the Cesar region. A qualitative approach was particularly suitable as it enabled an in-depth understanding of perceptions, contextual dynamics, and systemic gaps while offering actionable insights to address the challenges identified (Creswell & Creswell, 2017; Charmaz, 2021)

Methods Applied

The research employed several complementary methods to ensure a robust analysis:

Documentary Analysis

An exhaustive review of institutional documents, including the Institutional Educational Project (PEI) and the Educational Program Projects (PEPs) of the engineering programs, was conducted. The aim was to assess the extent to which environmental sustainability is embedded in institutional frameworks and curricula. This analysis provided a foundational understanding of the university’s commitment to sustainability and its alignment with regional and global environmental priorities (Bowen, 2019). The review examined elements such as the presence of sustainability themes in program objectives, specific courses dedicated to environmental education, and indicators of alignment with sustainability goals outlined in the United Nations' Sustainable Development Goals (SDGs).

Semi-Structured Interviews

Semi-structured interviews were conducted with key stakeholders, including the directors of the Environmental and Sanitary Engineering, Agroindustrial Engineering, Electronics Engineering, and Systems Engineering programs. This method facilitated a nuanced exploration of critical themes, such as the integration of sustainability into the curricula, existing strengths and weaknesses, and the identification of actionable opportunities for improvement. The semi-structured format provided flexibility to adapt questions to the expertise of each participant while maintaining a consistent focus on the research objectives (Patton, 2020). Questions were validated by experts to ensure relevance and clarity, enhancing the reliability and depth of the data collected.

Data Categorization and Thematic Analysis

The data collected through interviews and documentary analysis underwent a systematic thematic categorization process. Grounded theory was employed as the analytical framework, allowing for the identification of recurring themes, enabling and inhibiting factors, and key intervention areas (Charmaz, 2021). This iterative process ensured that the findings emerged directly from the data, enhancing the credibility and depth of the analysis.

Operationalization of Categories

To achieve analytical precision, six primary categories were operationalized, each supported by specific, measurable indicators:

- Environmental Sustainability: Evaluated through indicators such as the frequency and depth of sustainability-related content in curricula, alignment with institutional goals, and the practical application of sustainability themes in academic projects.
- Competencies for Sustainability: Focused on assessing the development of skills, knowledge, and attitudes that enable students to address environmental challenges, emphasizing critical thinking and systems-based problem-solving.
- Alignment with the Productive Sector: Measured the extent and effectiveness of collaborations between the university and local industries in addressing regional environmental challenges.
- Active Pedagogical Strategies: Investigated the use of innovative teaching methods, such as project-based learning and case studies, to foster sustainability competencies.
- Curricular Innovation: Examined the adaptability of academic programs to meet emerging sustainability goals, including the incorporation of new courses and interdisciplinary modules.
- Stakeholder Perceptions: Captured insights from academic leaders regarding current strengths, weaknesses, and opportunities for growth in sustainability education.

Each category was systematically analyzed using sub-indicators to ensure comprehensive coverage of abstract concepts. For instance, "Alignment with the Productive Sector" included sub-indicators such as the frequency of collaborative projects with industries and their tangible impact on addressing regional sustainability issues (Babbie, 2020).

Contextual Integration

The methodology incorporated a contextual analysis of the Cesar region, focusing on its unique environmental and industrial challenges. Key sectors such as agroindustry, mining, and livestock were analyzed to align academic recommendations with regional sustainability priorities. This contextual integration enriched the study by linking academic initiatives to real-world challenges, enhancing the relevance and applicability of the proposed strategies (Neuman, 2021).

The triangulation of data sources—documentary analysis, semi-structured interviews, and thematic analysis—ensured methodological rigor and enhanced the validity of the findings. By cross-referencing insights from multiple sources, the study minimized bias and provided a robust foundation for the strategic recommendations. Additionally, peer validation was incorporated at each stage of the research process to ensure analytical consistency and reliability (Silverman, 2020).

The study adhered to ethical research standards, including obtaining informed consent from interview participants, ensuring anonymity and confidentiality, and maintaining transparency in data collection and analysis. These measures upheld the

integrity of the research and fostered trust among stakeholders.

This qualitative methodology provided a comprehensive and nuanced understanding of the integration of sustainability into academic programs. By combining rigorous documentary analysis, stakeholder perspectives, and thematic categorization, the study offers actionable insights that address the unique challenges of the region. The methodology not only highlights existing gaps but also lays the groundwork for targeted interventions that align academic programs with regional sustainability needs and global environmental objectives.

Results

The qualitative analysis carried out in this study highlights four primary categories that encapsulate the most significant findings concerning the integration of environmental sustainability into the academic programs of the Faculty of Engineering and Technological Sciences at Universidad Popular del Cesar. These categories are: environmental sustainability, transversal competencies, alignment with the productive sector, and curricular innovation. Below is a detailed presentation of the results, emphasizing strengths, weaknesses, and opportunities for improvement within each category.

1. Environmental Sustainability

One of the study's key findings is the growing interest among faculty and students to incorporate sustainability elements into academic programs. This interest has been demonstrated in isolated initiatives such as capstone projects and specific courses like Renewable Energy and Agroindustrial Innovation. These efforts address the productive sector's immediate needs, including energy efficiency, waste management, and clean technology adoption. However, these initiatives are limited by their lack of integration into a broader curricular framework that treats sustainability as a cross-cutting theme (Cebrián et al., 2020; Sterling, 2021).

A significant weakness lies in the absence of curricular transversalization, which results in fragmented learning and diminished student preparedness for addressing real-world environmental challenges. While some faculty recognize the importance of embedding sustainability comprehensively, these efforts remain inconsistent across programs. This gap underscores the urgent need for institutional reforms to standardize and expand the incorporation of sustainability principles throughout the curricula (Freeman et al., 2022).

2. Transversal Competencies

The analysis revealed that students possess solid technical expertise, which is evident in their participation in practical projects addressing environmental challenges, such as the reuse of agroindustrial by-products. Despite this, there is a clear deficit in the development of transversal competencies essential for sustainability, including systemic thinking, interdisciplinary problem-solving, and ethical decision-making (Gutiérrez-Ortega et al., 2021).

The lack of emphasis on these critical competencies limits students' ability to apply their technical knowledge holistically, which is necessary to tackle complex environmental challenges. Moreover, without these skills, graduates face difficulties leading transformative processes in the productive sector, which demands professionals capable of connecting technical solutions with social and environmental realities (Sterling & Thomas, 2022). Addressing these gaps requires targeted curricular reforms aimed at fostering these competencies through active learning strategies and interdisciplinary approaches.

3. Alignment with the Productive Sector

A notable strength identified is the collaboration between the university and local industries in sectors such as agroindustry, mining, and renewable energy. These partnerships have yielded impactful projects, such as the development of whey utilization technologies by the Agroindustrial Engineering program and process optimization tools by the Electronics Engineering program (Etzkowitz & Leydesdorff, 2021). These collaborations demonstrate the potential for academia-industry partnerships to address regional environmental challenges.

However, the study also uncovered significant limitations. Most projects are carried out in isolation, with limited mechanisms to integrate the

productive sector's demands systematically into academic planning. This disconnect reduces the potential impact of these partnerships and restricts opportunities for students to gain practical experience in real-world contexts. Additionally, industries are insufficiently involved in shaping curricula, which hampers the alignment of academic programs with regional development needs (Creswell & Creswell, 2021).

4. Curricular Innovation

Curricular innovation emerged as a pressing requirement to enhance the integration of sustainability into academic programs. While some elective courses, such as Environmental Management and Corporate Social Responsibility, provide a starting point, these efforts fall short of delivering a comprehensive education in sustainability. The findings suggest a critical need for a thorough review of the academic plans to incorporate sustainability principles across all disciplines effectively (Cebrián et al., 2020; Vásquez & Rodríguez, 2022).

Furthermore, the absence of sustainability indicators in learning objectives and evaluation strategies limits the ability to measure students' progress in acquiring critical and technical skills. Incorporating these indicators would ensure that academic programs are aligned with both productive sector demands and regional sustainable development goals. Encouraging interdisciplinary collaboration and embedding sustainability across all engineering courses are essential steps to create a transformative and relevant educational experience (Freeman et al., 2022).

The findings reflect a mixed scenario: while there are notable efforts in specific areas, significant gaps persist, particularly in the transversal integration of sustainability, development of critical competencies, and alignment with productive sector demands. These results underline the necessity of implementing structured strategies that address these gaps holistically, focusing on curricular transversalization, strengthening industry-academic collaboration, and promoting curricular innovation.

Table 1. Comparative Summary of Findings by Category

Category	**Strengths**	**Weaknesses**	**Opportunities for Improvement**
Environmental Sustainability	- Growing interest in integrating sustainability in specific courses like Renewable Energy and Agroindustrial Innovation.	- Lack of transversal integration of sustainability in curricula.	- Systematic inclusion of environmental sustainability in all curricula as a transversal element.
	- Recognition of sustainability's importance by faculty and program leaders.	- Fragmented approach limiting impact on student training and regional needs.	- Strengthening interdisciplinary collaboration.
Transversal Competencies	- Students demonstrate strong technical skills applicable to environmental challenges.	- Limited focus on critical skills like systemic thinking and problem-solving.	- Introduce modules fostering transversal competencies, such as leadership, critical thinking, and teamwork.
		- Lack of integration between technical expertise and social/environmental dimensions.	- Emphasize experiential learning projects.
Alignment with	- Existing collaborations with	- Projects are often isolated and	- Develop strategic frameworks

the Productive Sector	local industries leading to successful projects in agroindustry, mining, and renewable energy.	lack a consistent feedback loop to adapt curricula.	to integrate industry needs into academic programs.
		- Minimal involvement of industries in curricular planning.	- Increase opportunities for internships and co-designed industry projects.
Curricular Innovation	- Inclusion of elective courses on Environmental Management and Corporate Social Responsibility.	- Insufficient presence of sustainability indicators in learning objectives and evaluations.	- Conduct comprehensive curriculum reviews to embed sustainability across disciplines.
		- Limited interdisciplinarity across engineering programs.	- Implement measurable sustainability learning objectives.

Discussion

The findings of this research align with prior literature that highlights persistent gaps between engineering education and the growing need for environmental sustainability integration. Studies such as those by Sterling and Thomas (2022) and Freeman et al. (2023) emphasize that addressing sustainability challenges in higher education requires a systemic transformation, encompassing curricular integration, competency-based education, and strong collaboration with industry. Consistent with these perspectives, this study identified valuable but fragmented efforts within specific areas of academic programs, which remain insufficient to ensure a holistic, sustainability-oriented education aligned with the Sustainable Development Goals (SDGs).

At Universidad Popular del Cesar, the results reveal structural weaknesses that hinder the effective integration of sustainability into academic programs. While some initiatives, such as agreements with the productive sector and sustainability-focused elective courses, exist, these efforts lack strategic alignment with broader curricular structures. This misalignment not only limits the depth of sustainability education but also restricts its impact on professional training and the productive sector, which increasingly demands professionals capable of leading sustainable innovation and climate-conscious decision-making.

A key limitation is the absence of an institutional framework that promotes the systematic integration of sustainability across disciplines. Current academic structures fail to embed environmental concerns as a transversal axis of education, leading to fragmented learning experiences that do not fully equip students with the knowledge and skills necessary to address real-world environmental challenges. This observation aligns with findings by Cebrián et al. (2021), who argue that curricular integration across multiple disciplines is essential for preparing students to tackle the multidimensional nature of sustainability-related problems. Additionally, the insufficient emphasis on transversal competencies—such as critical thinking, systemic analysis, and interdisciplinary problem-solving—limits graduates' ability to engage with complex sustainability issues, a challenge also documented by Vásquez and Rodríguez (2022).

To overcome these challenges, the study proposes several evidence-based recommendations:

Curricular Innovation and Sustainability Integration

A fundamental reform in curriculum design is required to embed sustainability principles across all engineering disciplines. This includes:

- Integrating specific modules on environmental sustainability within both core and elective courses.
- Embedding sustainability as a measurable competency across academic programs, ensuring its practical application.
- Developing interdisciplinary sustainability projects that require collaboration among students from different fields.

Strengthening Transversal Competencies for Sustainability

The findings indicate a need for a stronger emphasis on competencies beyond technical knowledge, including:

- Systemic and critical thinking: Training students to approach environmental problems holistically.
- Interdisciplinary collaboration: Encouraging teamwork across engineering fields to develop comprehensive solutions.
- Ethical and leadership skills: Preparing graduates to advocate for sustainable practices in industry and policy-making.

Enhancing Faculty Training in Sustainability Education

Institutional efforts must focus on faculty development programs that equip educators with updated methodologies for teaching sustainability, such as:

- Active learning strategies (e.g., problem-based learning, case studies, and experiential projects).
- Digital and technological tools that facilitate environmental education.
- Collaboration with industry experts to ensure that course content remains relevant to market demands.

Strengthening University-Industry Partnerships for Applied Sustainability Projects

While some partnerships with the productive sector exist, they remain underutilized and poorly structured. The study suggests:

- Establishing long-term collaborative research projects where students work directly on real-world environmental challenges.
- Developing internship and co-op programs with sustainability-driven companies.
- Formalizing university-industry sustainability forums to facilitate knowledge exchange and ensure that curricula remain aligned with industry needs (Etzkowitz & Leydesdorff, 2022).

Monitoring and Evaluating Sustainability Implementation in Academic Programs

To measure the effectiveness of sustainability integration, it is essential to:

- Implement tracking mechanisms that evaluate students' sustainability competencies over time.
- Establish periodic reviews of curricular updates and industry engagement metrics.
- Use sustainability indicators in university accreditation and program assessment processes (Wilson & Barker, 2023).

Conclusions

The results of this study highlight the urgent need to integrate environmental sustainability as a core and cross-cutting element within the academic programs of the Faculty of Engineering and Technological Sciences at the Universidad Popular del Cesar. The curricular analysis and qualitative findings reveal substantial gaps in the incorporation of sustainability-related content, limited development of transversal competencies, and weak institutional linkages with the productive sector. These shortcomings not only affect the comprehensive education of students but also hinder the region's ability to respond effectively to growing environmental challenges.

The relevance of these findings extends beyond academia, as they underscore the critical role of higher education institutions in fostering sustainable development. By aligning academic programs with the Sustainable Development Goals (SDGs)—particularly SDG 4 (Quality Education) and SDG 13 (Climate Action)—higher education can drive systemic change in industries such as agroindustry, mining, and renewable energy. This shift is essential for enhancing competitiveness, innovation, and environmental responsibility in the Cesar region.

To address these gaps, this research proposes key strategic actions, including curriculum reform, faculty training, and the strengthening of university-industry partnerships. These measures will equip students with the necessary technical, systemic, and critical thinking skills to navigate complex environmental issues and implement sustainable solutions. However, for these proposals to have a lasting impact, they require strong institutional

commitment, an interdisciplinary pedagogical approach, and an active collaboration between academia, industry, and policymakers.

Despite its contributions, this study acknowledges certain limitations, such as the scope of analyzed programs and the lack of quantitative impact assessments on sustainability education outcomes. Future research should focus on longitudinal studies to evaluate the effectiveness of sustainability-driven curricula, comparative analyses with other universities implementing similar strategies, and the role of emerging technologies in sustainability education.

In conclusion, the Universidad Popular del Cesar has a unique opportunity to become a regional benchmark in sustainable engineering education. By embracing curricular innovation, fostering sustainability-oriented competencies, and strengthening collaboration with the productive sector, the university can play a transformative role in shaping a more sustainable future for both the academic community and the region at large.

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