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University transitions towards sustainability in Latin America: a comparative analysis of six higher education institutions

Transiciones universitarias hacia la sostenibilidad en América Latina: un análisis comparativo de seis instituciones de educación superior

Transições universitárias rumo à sustentabilidade na América Latina: uma análise comparativa de seis instituições de ensino superior

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ABSTRACT Facing the current paradigmatic polycrisis and the global environmental crisis, universities, as epicenters of knowledge, demonstrate the inherent capacity to exacerbate or mitigate these challenges. Although traditional hegemonic approaches have limited their adaptability in the face of an emerging civilizational crisis, sustainability-oriented Higher Education Institutions stand as a fundamental pillar for change. This study, framed within the Latin American context, aimed to examine the notions of sustainability present in six prominent universities in the region, encompassing teaching, research, management, and community engagement, in order to contrast discourses and practices and demonstrate their importance in stimulating alternatives for development. Methodologically, a critical documentary review of the regulations and institutional documents of each university was conducted, complemented by interviews with the heads of sustainability units or their equivalents. The interviewees were: Eduardo Vega, Coordinator – University Coordination for Sustainability, and Delfina Corsi, Deputy Director of Sustainable Campus and community engagement of Universidad Nacional Autónoma de México; Paúl Vanegas Peña, Research Professor of the Sustainability Group, Mogrovejo Daniela, Sustainability Analyst – Sustainability Unit, and Jiménez Amparo, Sustainability Analyst – Sustainability Unit of Universidad de of Cuenca; Anahí Urquiza, Director

of Innovation, Universidad de Chile; Adriana Rodríguez, Dean of the Faculty of Agronomy, Universidad de Buenos Aires; Fernanda Fernández, Technical Advisor to the Office of the Superintendent of Environmental Management at the Universidade de Sao Paulo. Four key topics were analyzed: conception of the environment, conception of sustainability, inclinations toward critical thinking, and environmental criteria in institutional decision-making. The fuzzy logic tool "Mental Modeler" facilitated the explication of causal relationships (positive, negative, or null) between these topics, based on both documentary information and interviews. The resulting metrics allowed for the comparison of the identified mental models and the construction of a gradient illustrating universities' transitions toward sustainability. The results of this work elucidate that sustainability represents a virtuous opportunity to reimagine higher education, fostering greater integration of principles and equity in educational programs.

Keywords: university sustainability; transitions toward sustainability; higher environmental education; mental models; Latin America.

RESUMEN

Las universidades, epicentros de conocimiento, tienen la capacidad inherente de exacerbar o mitigar los desafíos de la actual policrisis paradigmática y la crisis ambiental global. A pesar de que los enfoques hegemónicos tradicionales han limitado su adaptabilidad frente a una crisis civilizatoria emergente, las Instituciones de Educación Superior orientadas a la sostenibilidad se erigen como un pilar fundamental para el cambio. Este estudio, enmarcado en el contexto latinoamericano, se propuso examinar las nociones de sostenibilidad presentes en seis universidades destacadas de la región, abarcando la docencia, investigación, gestión y vinculación con el medio, a fin de contrastar discursos y prácticas y evidenciar su importancia para estimular alternativas al desarrollo. Metodológicamente, se realizó una revisión crítica documental de las normativas y documentos institucionales de cada universidad, complementada con entrevistas a los responsables de las unidades de sostenibilidad o sus equivalentes, siendo los entrevistados los siguientes: Eduardo Vega, Coordinador – Coordinación universitaria para la sustentabilidad, y Delfina Corsi, Subdirectora de Campus sustentable y vinculación, de la Universidad Nacional Autónoma de México; Paúl Vanegas Peña, Docente Investigador del Grupo de sostenibilidad, Mogrovejo Daniela, Analista de sostenibilidad – Unidad de sostenibilidad, y Jiménez Amparo, Analista de sostenibilidad – Unidad de sostenibilidad de la Universidad de Cuenca; Anahí Urquiza, Directora de Innovación, Universidad de Chile; Adriana Rodríguez, Decana Facultad de Agronomía, Universidad de Buenos Aires; Fernanda Fernández, Asesora técnica de gabinete de la superintendencia de gestión ambiental de la Universidad de Sao Paulo. Se analizaron cuatro tópicos clave: concepción del ambiente, concepción de la sostenibilidad, inclinaciones hacia el pensamiento crítico y criterios ambientales en la toma de decisiones institucionales. La herramienta de lógica difusa "Mental Modeler" facilitó la explicitación de relaciones causales (positivas, negativas o nulas) entre estos tópicos, tanto a partir de la información documental como de las entrevistas. Las métricas resultantes permitieron contrastar los modelos mentales identificados y construir una gradiente que ilustra las transiciones de las universidades hacia la sostenibilidad. Los resultados de este trabajo elucidan que la sostenibilidad representa una posibilidad virtuosa para reimaginar la educación superior, fomentando una mayor integración de principios y equidad en los programas educativos.

Palabras clave: sostenibilidad universitaria; transiciones hacia la sostenibilidad; educación ambiental superior; modelos mentales; América Latina.

RESUMO

Diante da atual policrise paradigmática e da crise ambiental global, as universidades, como epicentros do conhecimento, demonstram a capacidade inerente de exacerbar ou mitigar esses desafios. Embora as abordagens hegemônicas tradicionais tenham limitado sua adaptabilidade diante de uma crise civilizacional emergente, as Instituições de Ensino Superior voltadas para a sustentabilidade se posicionam como um pilar

fundamental para a mudança. Este estudo, enquadrado no contexto latino-americano, teve como objetivo examinar as noções de sustentabilidade presentes em seis universidades de destaque na região, abrangendo ensino, pesquisa, gestão e engajamento ambiental, a fim de contrastar discursos e práticas e demonstrar sua importância no estímulo a alternativas de desenvolvimento. Metodologicamente, foi realizada uma revisão documental crítica dos regulamentos e documentos institucionais de cada universidade, complementada por entrevistas com os responsáveis pelas unidades de sustentabilidade ou seus equivalentes. Quatro tópicos principais foram analisados: concepção de meio ambiente, concepção de sustentabilidade, inclinações para o pensamento crítico e critérios ambientais na tomada de decisões institucionais. A ferramenta de lógica fuzzy "Mental Modeler" facilitou a explicação das relações causais (positivas, negativas ou nulas) entre esses tópicos, com base em informações documentais e entrevistas. As métricas resultantes permitiram a comparação dos modelos mentais identificados e a construção de um gradiente que ilustra as transições das universidades rumo à sustentabilidade. Os resultados deste trabalho elucidam que a sustentabilidade representa uma oportunidade virtuosa para reimaginar o ensino superior, promovendo maior integração de princípios e equidade nos programas educacionais.

Palavras-chave: sustentabilidade universitária; transições rumo à sustentabilidade; educação ambiental superior; modelos mentais; América Latina.

1. Introduction

The current paradigmatic and environmental polycrisis (Morin, 2010) places Latin American universities at a crucial crossroads (Sáenz *et al*., 2018). Beyond their traditional role of producing and reproducing knowledge, these institutions have the potential to be key players in the co-creation of more sustainable futures (Morin, 2010), avoiding exacerbating crises if they limit themselves to economic approaches or hegemonic paradigms. In line with this need for transformation, this paper seeks to delve into the diverse notions of sustainability that coexist in Latin American Higher Education Institutions (HEIs), seeking to understand how their discourses and practices can promote alternatives to conventional development and respond to global challenges. The transition from environmental education to education for sustainability has entailed the design of comprehensive approaches that transcend mere environmental protection (Chacón *et al*., 2009). This shift responds, for example, to the need to equip students with critical and systemic skills that enable them to address global challenges. The so-called "Decade of Education for Sustainability" (2005-2014), promoted by the United Nations, consolidated the role of HEIs in developing engaged citizens (Chacón *et al*., 2009). However, in Latin America, sustainability is not merely a theoretical concept but a practical necessity in the face of inequalities, environmental problems, and economic tensions (Ahmed & Abo-Khalil, 2024). It is essential to understand sustainability not as a static concept, but as a living process that requires critical reflection and constant dialogue (Probst, 2022), promoting interdisciplinary collaboration and projects that involve diverse disciplines in problem-solving.

Latin American HEIs are emerging as transformative agents by integrating sustainable principles into their operations, curricula, and community engagement. A study by Leal Filho *et al*. (2021) of 157 universities across 13 countries demonstrated a significant commitment to resource management,

with over 80% of universities showing progress. Strategies such as problem-based and project-based learning are considered highly effective in developing sustainability competencies and fostering interaction with external communities. However, challenges such as lack of funding, institutional support, resistance to change, and an incomplete understanding of the importance of the topic among faculty and students persist (Park, 2024). Despite this, the integration of sustainability also strengthens the reputation of universities (Ahmed & Abo-Khalil, 2024). In this transformative context, HEIs have unique potential as "free spaces" that foster co-creation and interdisciplinary experimentation (Galdos & Villalobos, 2023). The evolution of the university role has been aligned with co-creation processes, adopting increasingly integrative methodological approaches (Mohammadi *et al.*, 2023). The methodological evolution in the study of sustainability transitions in HEIs has been profound and multifaceted, reflecting a progression from initial approaches to complex and critical ones. Pioneering studies on the environmental dimension of Latin American higher education, such as the "Panorama of Higher Environmental Studies in Latin America" and the "First Diagnosis of the Incorporation of the Environmental Dimension in Higher Education in Latin America and the Caribbean", are characterized by their descriptive-exploratory nature and predominantly quantitative data collection on educational offerings. These investigations laid the groundwork for historical periodizations of the field and were part of projects on educational policies and political regimes, utilizing documentary analysis. As Latin American environmental thought matured, the methodology was enriched with more critical approaches. In this regard, Leff's (2008) reflections have been crucial. He articulated the need for a "dialogue of knowledge" and an "environmental rationality", implicitly promoting interpretive methodologies that transcend positivism. Floriani (2018) exemplified this transition with a qualitative longitudinal case study on the construction of an interdisciplinary graduate program (PPGMADE-UFPR), based on the program's history and curricular analysis. Silvina Corbetta (2019) used a qualitative literature review of Latin American critical environmental thought and pointed to the use of case studies on environmental conflicts, suggesting the combination of qualitative content analysis and narratives of struggles. Eschenhagen (2021) proposed a conceptual framework for alternative environmental education, implying the need for participatory and action research methodologies. Escobar (2012) advocated for a transdisciplinary agenda for pluriversity, prioritizing relationality and situated practice.

Current research tends to adopt mixed methods and transdisciplinary perspectives. For example, a clear preference for mixed methods has been shown in the study of university policies and environmentalization, combining statistical data analysis with regulatory analysis and qualitative case studies that include interviews and process monitoring, emphasizing institutional self-reflexivity. In the study of co-creation for sustainability, Trencher *et al*. (2014) conducted an empirical and qualitative study based on exhaustive data collection (web, literature, conferences, databases) and semi-structured interviews. Soini *et al*. (2018) employed an exploratory mixed methods study, combining quantitative analysis of surveys with qualitative content analysis of websites. Castillo Longoria *et al*. (2021) proposed a co-creation model using a mixed-methods approach

structured in five phases (Double Diamond Process), which included face-to-face questionnaires, rapid social media surveys, and co-creation sessions (virtual and face-to-face) using creativity techniques. Villa-Enciso *et al*. (2023) investigated the role of Latin American universities in Transformative Innovation Policy (TIP) through a predominantly qualitative exploratory case study centered on an experimental event ("La Factoría") that facilitated the generation of policy proposals through workshops, games, and reflection (Galdos & Villalobos, 2023). In summary, the methodological trajectory in the study of sustainability transitions in Latin American HEIs has evolved from basic diagnoses to complex and multifaceted approaches. The constant is the recognition of the need for interdisciplinarity and transdisciplinarity to address the complexity of the transformative role of the university, which prioritizes the active participation of multiple actors from the university community and society at large (Galdos & Villalobos, 2023). This reinforces the idea that HEIs, beyond mere instruction, must prepare students with critical and human skills to face sustainability challenges creatively and effectively (Probst, 2022), thus contributing to the construction of a more just and balanced future through teaching, research, and community engagement CE.

2. Methodology

Our research was framed within a qualitative-comparative approach, complemented by semi-quantitative analyses, constituting a mixed-method design. This methodological approach was fundamental to exploring, contrasting, and conceptualizing the diverse notions of sustainability that coexist in Latin American Higher Education Institutions (HEIs). The choice of a mixed-method design allowed for a comprehensive understanding that encompassed both the depth of qualitative discourses and practices and the semi-quantitative modeling of causal relationships between key topics. This approach aligns with the methodological evolution in the study of sustainability transitions in HEIs, which has progressed from descriptive-exploratory diagnoses to more complex, critical, and multifaceted approaches, incorporating mixed methods and transdisciplinary perspectives. The study focused on the analysis of teaching, research, management, and community engagement, key components for understanding university sustainability.

The study sample consisted of six Latin American universities recognized in the region for their recognition and expertise in sustainability. The selected institutions were Universidad Nacional Autónoma de México (National Autonomous University of Mexico) (Mexico), Universidad de Cuenca (University of Cuenca) (Ecuador), Universidad de los Andes (University of the Andes) (Colombia), Universidade de São Paulo (University of São Paulo) (Brazil), Universidad de Chile (University of Chile) (Chile), and Universidad de Buenos Aires (University of Buenos Aires) (Argentina). Specific selection criteria included their recognition in international rankings and their prior experience in sustainability projects, information obtained through their institutional websites. This intentional selection guaranteed the relevance of the institutions for a comparative study of this nature by ensuring that they were relevant players in the field of university sustainability in Latin America.

A triangulation of sources was carried out for data collection and a comprehensive understanding

of university sustainability, combining documentary analysis (RA) with in-depth interviews (IA).

• Critical Document Analysis (RA): A critical review of regulations, institutional policies, and sustainability reports from each of the selected universities was carried out. The sources consulted included official documents available in university repositories. This analysis allowed us to identify the institutions' formal discourses and stated intentions regarding sustainability.

• Interviews (IA): Interviews were conducted with the heads of sustainability units or their equivalents at each university. Contact with these key stakeholders was facilitated by international networks such as the Alliance of Ibero-American University Networks for Sustainability and the Environment (ARIUSA). The interviews were crucial for capturing the perceptions, experiences, and practices of key stakeholders, offering a complementary and enriching perspective to the documentary information.

Both types of sources (documents and interviews) addressed four key topics of analysis: the concept of the environment, the concept of sustainability, inclinations toward critical thinking, and environmental criteria in institutional decision-making.

The data analysis and modeling process was carried out in several phases:

1. Thematic coding and systematization: The information collected (from documents and interviews) was thematically coded and included in a two-way matrix (Figure 1). This systematization process, along with coding, allowed for the identification of narrative and conceptual patterns surrounding sustainability, as well as the discovery of emerging and recurring themes in the universities' discourses and practices.

2. Construction of a prior qualitative gradient: With the systematic and coded information, a qualitative gradient of possibilities for transitioning toward sustainability was constructed for the six universities. This initial gradient laid the groundwork for subsequent analysis using the modeling tool.

3. Modeling with the fuzzy logic software "Mental Modeler": This software was used to create conceptual maps and analyze relationships. This tool allowed for the structure of analytical axes that guided the understanding of the conceptual relationships among 16 topics of interest. The topics were organized around four key areas (conceptualization of the environment, conceptualization of sustainability, inclinations toward critical thinking, and environmental criteria in decision-making) applied to the fields of university teaching, research, management, and CE. The research team equated the 16 topics of interest to the notion of components used in the fuzzy logic modeling language. Edge relationships between pairs of components were defined, assigning a positive or negative forcing relationship between them. The guiding question during this process was: "In a sustainability transition process, which topic seems to have the greatest/least influence on the other?". Subsequently, using the two-way matrix (Figure 1) to characterize the relationships, the qualitative terms were transformed into quantitative values ranging from -1 to +1. This conversion was performed as follows: strong negative impact: -1; medium negative impact: -0.67; weak negative impact: -0.33; unimportant impact

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FIGURE 1 – Matrix for evaluating influences based on systematized information. This matrix was applied to both the information collected through interviews and the information obtained from the review of institutional documents.

SOURCE: prepared by the authors.

(no relationship between topics): 0; weak positive impact: 0.33; medium positive impact: 0.67; strong positive impact: 1. The values obtained from the influence assessment were transferred to a CSV (Comma Separated Values) file to ensure compatibility with the Mental Modeler software. This allowed for the construction of an adjacency matrix, which brought together all existing relationships between topics or components, visualizing the degree of influence (or weight) of each topic on the others, based both on the analysis of regulations and the interviews. Likewise, Mental Modeler facilitated the explication of three types of causal relationships: positive causality (> 0), negative causality (< 0), and the absence of relationships ($= 0$); it also allowed for the determination of degree centrality in each HEI model, a crucial metric that indicates the importance or influence of a topic within the network.

4. Construction of the final gradient: Finally, the metrics resulting from the analysis with "Mental Modeler" were used to contrast the identified mental models and to construct a gradient that illustrates

and adjusts the degree of transition of universities towards sustainability.

Regarding ethical considerations, interviewees were identified by name, along with their positions and affiliations, in the results tables and the acknowledgments section, suggesting explicit consent for their identification in the study.

The research team equated the 16 topics of interest to the notion of components used in the fuzzy logic modeling language. Thus, and based on an adaptation of the methodology used in the works of Rocha *et al*. (2020) and Gray *et al*. (2013), the edge relationships between pairs of components (or topics of interest) were further defined.

3. Results

Although all the HEIs studied share a common foundation in their commitment to sustainability and the environment, their discourses reveal nuances in the specificity of their programs, the explicitness of their reference frameworks (such as the SDGs), and methodological approaches (interdisciplinarity vs. transdisciplinarity), as well as in the type of management evidence they choose to highlight. From the regulation analysis (RA), it is observed that there is a consistency in the way universities conceive the environment, generally adopting a comprehensive vision that emphasizes the interconnection between ecological, social, and economic aspects (Comparison Table 1).

The six universities seek to help students understand the complexity of environmental problems and their impact on society. Interview analysis (IA) identified commonalities and differences in discourses on sustainability, considering the areas of teaching, research, management, and community engagement (Comparison Table 2). From the IA, it is evident that the universities differ in the maturity of their governance structures, the extent of curricular integration, the specificity of their research lines, and the focus of their community engagement strategies. These differences reflect the distinct institutional contexts, stages of development, and strategic priorities of each university in addressing the challenge of sustainability.

Thus, the Latin American HEIs studied, although with diverse trajectories and levels of formalization, demonstrate a commitment to sustainability, conceiving it as a transformative axis that runs through teaching, research, management, and community engagement. The uniform recognition of sustainability as a complex and multidimensional paradigm and the emphasis on training change agents with critical thinking highlight their capacity not only to respond to current environmental and social challenges but also to actively stimulate alternatives to traditional development. Their efforts, whether through formalized policies, specific programs, or the transversal integration of environmental criteria, position these universities as crucial players in building more just and sustainable societies.

Considering the research objective, the interview analysis (IA) with sustainability program leaders and the analysis of university regulations (RA) at the six universities demonstrate the existence of a unified institutional commitment and a fundamentally comprehensive and transversal understanding of sustainability, despite differences in the maturity of their implementations and specific

COMPARISON TABLE 1 – Analysis of university regulations and policies on sustainability (RA).

University	Policies/Regulations in the field of Teaching	Policies/Regulations in a Research Context	Policies/Regulations in a Management Context	Policies/Regulations in a CE Context
Universidad Nacional Autónoma de México (UNAM)	ERES UNAM strategy for 2024-2027, which promotes the updating of curricula in virtually all programs with a focus on sustainability and incorporates courses on sustainable development.	Prioritizes projects that assess compliance with the SDGs and the 2030 Agenda. Develops strategies to create research catalogs or inventories to centralize knowledge.	ERES UNAM Strategy for 2024-2027, which is a cross-cutting principle that guides all institutional actions and decisions, integrating explicit environmental criteria into physical and budgetary management.	Guides their community interactions and projects to promote sustainable development through education, research, and social action.
Universidad de Cuenca	In the process of developing a learning path on sustainability within its Institutional Sustainability Plan.	No research prioritization or formalization policies are specified in the sources provided, beyond the general conception of sustainability.	It has undertaken a comprehensive sustainability process by creating the Strategic Sustainability Committee (CESUC) and preparing an Institutional Sustainability Plan (currently pending approval).	It focuses on university entrance training programs (e.g., "Prepare for UCuenca," "Rural Youth"), with a clear focus on equity and access.
Universidad de los Andes	It fosters a comprehensive education for students with critical and proactive skills in addressing environmental and social challenges, promoting a transdisciplinary approach.	Generating knowledge to address environmental and social challenges in a comprehensive manner, with an interdisciplinary approach.	It recognizes the historical lack of environmental criteria in decision-making but has made progress in implementing policies and practices for efficient resource use.	Commitment to contributing to the well-being of communities through responsible and sustainable practices.
Universidade de São Paulo (USP)	Sustainability is a cross-cutting principle in all academic activities, seeking to train professionals capable of proposing innovative and sustainable solutions.	Sustainability is a fundamental principle that guides research in various disciplines, seeking a balance between human development and conservation.	It has had environmental policies in place since 2018 and a structure of guidelines issued by the rector's office [conversation]. It seeks a balance between academic development and conservation.	Sustainability is a multidimensional approach that encompasses ecological, social, and economic aspects in community interactions.
Universidad de Chile	It understands sustainability as an approach that integrates environmental, social, and economic dimensions into the educational process.	It seeks to generate knowledge applicable to solving environmental and social problems. It faces the challenge of centralizing and making its research visible.	It is currently in the process of mobilizing to establish a Sustainability Committee and secure the commitment of the faculties to sustainable campus management. It seeks to balance institutional development with environmental and social responsibility.	A commitment to generate a positive impact on the community and the environment through the university's actions.
Universidad de Buenos Aires (UBA)	It focuses on integrating the Sustainable Development Goals (SDGs) into academic projects.	Sustainability is an approach that should guide all academic projects, contributing to the conservation and improvement of the environment. Their research focuses on the environmental issues surrounding the impact of activities.	It focuses on integrating responsible practices that minimize environmental impact and promote efficient use of resources. It demonstrates adaptability to national economic and political challenges in its management.	Commitment to contributing to the sustainable development of communities. Implements specific programs such as "UBA Verde" and "UBA en Acción" for community engagement.

SOURCE: Prepared by the authors based on the Municipal Government of São Paulo (2021); Red UAGAIS *et al.* (2018); Universidad de Buenos Aires (2024, n.d.); Universidad de Chile (2012, 2017, n.d.); Universidad de Cuenca (2021, 2024); Universidad de Los Andes (2023); Universidad Nacional Autónoma de México (2024); Universidade de São Paulo (2024).

COMPARISON TABLE 2 – Characteristics identified in the interview analysis (IA).

Characteristics / Appearance	Regularities / Similarities	Differences by University
Institutional commitment and vision of sustainability	The six HEIs demonstrate a commitment to sustainability and an understanding of its complexity and importance. Sustainability is viewed as a paradigm under construction and multidimensional, encompassing economic, social, and environmental dimensions. The environment is recognized as a complex and multidimensional concept, going beyond biotic and abiotic factors and is understood as a social representation of complex systems affected by human activity.	Approach to the concept of sustainability: Universidad de Cuenca views it as a "paradigm under construction" and a cross-cutting goal with economic, social, and environmental dimensions. Universidad de Buenos Aires (UBA) addresses it more directly through applied lines of study such as sustainable agriculture and waste management. USP integrates it through concrete elements such as ecological reserves and bioenergy projects.
Transversality in University functions	Sustainability is considered a cross-cutting goal that should guide teaching, research, management, and community engagement, promoting practices and knowledge that reduce environmental impacts and foster resilience. Some institutions integrate it directly into their institutional mission.	Degree of formalization and scope of sustainability policies: UNAM presents a very detailed and formalized strategy (ERES UNAM 2024-2027), integrating explicit environmental criteria into all substantive functions and management. Universidad de Cuenca has an Institutional Sustainability Plan (prepared and in the process of approval), including a learning path. USP has had environmental policies since 2018 and a structure of guidelines issued by the rector's office. UChile is in a more recent process, seeking to establish a Sustainability Committee and seeking the commitment of its faculties. Universidad de los Andes recognizes the historical lack of environmental criteria in decision-making, although it has seen progress.
Promotion of Critical Thinking	There is a clear inclination toward fostering critical thinking in all areas (teaching, research, management, and networking). This is promoted through the analysis of environmental impacts and the search for sustainability-based solutions, integrating a multidisciplinary approach. Students and researchers are encouraged to reflect on the university's role in sustainability.	No significant differences were identified between the six universities.
Operational environmental management	A strong emphasis is placed on management with specific environmental criteria in university operations, including reducing paper consumption, energy efficiency, waste management, water conservation, and promoting sustainable mobility.	No explicit differences in the type of operational environmental management are detailed.
Research and search for external impact	Research and outreach focus on environmental issues and their results, hoping to have an impact on the public and private sectors, responding to the needs of society. The goal is to highlight what is being done in training, development, and research.	Scope of research and visibility: UNAM and Universidad de Chile conduct broad research (e.g., ecology, conservation, SDG assessment) and recognize the challenge of maintaining an up-to-date and centralized overview of all research, developing strategies to create catalogs. The UBA, for its part, focuses its research on environmental issues related to the impact of activities and on specific areas such as sustainable agriculture and waste management.

Community engagement and external collaboration	Community engagement is highlighted by seeking to impact the local environment, promoting collaboration with external networks and other institutions, such as the Sustainable Campus Network.	Community engagement strategies: While Universidad de Cuenca focuses on university entrance training programs ("Prepárate UCuenca" and "Jóvenes rurales") focused on equity and access, Universidad de los Andes and Universidad de Buenos Aires (UBA) place greater emphasis on translating their research to decision-makers and influencing the public and private sectors. Universidad de Buenos Aires (UBA) also implements specific programs such as "UBA Verde" and "UBA en Acción" to engage with the local community.
Sustainability training	Sustainability seeks to train professionals committed to a just, diverse, and sustainable society, capable of being agents of transformation.	Comprehensive teaching of sustainability: UNAM promotes the updating of curricula for "virtually all programs" focused on sustainability, aiming for broad integration. UBA focuses on teaching with a focus on environmental impact, "specifically in programs such as Agronomy and Environmental Sciences," suggesting more focused integration. USP: Notes that sustainability can be addressed by each discipline according to its nature, without necessarily being included in the course content, which could indicate a more flexible or less standardized approach.
Level of Self-Reflection on Challenges	In general, universities describe progress or future plans.	Level of self-reflection on challenges: Universidad de los Andes stands out for its high level of self-criticism, mentioning that environmental criteria in decision-making have been "historically neglected." This is less evident at other universities. Universidad de Buenos Aires (UBA) demonstrates a proactive approach, adapting to challenges such as economic crises and changes in national policies during its administration.

SOURCE: Prepared by the authors based on interviews and personal communications with representatives of the Universidad Nacional Autónoma de México (Vega, Corsi), Universidad de Cuenca (Vanegas, Mogrovejo, Jiménez), Universidad de Chile (Urquiza), Universidad de Buenos Aires (Rodríguez) and Universidade de São Paulo (Fernández).

approaches. This finding is broken down into five key regularities:

1) a comprehensive commitment to and understanding of sustainability as a complex and multidimensional paradigm,

2) the conception of sustainability as a cross-cutting goal for teaching, research, management, and engagement,

3) the promotion of critical thinking in all areas,

4) the training of change agents and the pursuit of external influence, and

5) the integration of environmental criteria into decision-making. These regularities, along with the identified differences (Comparison Tables 1 and 2), are the foundation for the typologies developed.

Despite these commonalities, universities differ in the maturity of their governance structures, the breadth of curricular integration, the specificity of their research lines, and the orientation of their community engagement strategies. These differences reflect each university's distinct institutional contexts, stages of development, and strategic prio-

rities in addressing the challenge of sustainability. Variations include the degree of formalization and scope of sustainability policies, the approach to the concept of sustainability, the comprehensiveness of sustainability teaching, the scope and visibility of research, community engagement strategies, the level of self-reflection on challenges, explicit mention of the SDGs and the 2030 Agenda, the existence of institutional certifications, and the emphasis on transdisciplinarity.

Considering the results of the IA and RA analyses on similarities and differences among the institutions studied, it is possible to group the universities according to their degree of maturity and the dominant characteristics of their transition toward sustainability. In summary, UNAM positions itself as a pioneering university due to its highly detailed and formalized sustainability strategy; Universidad de Cuenca demonstrates a comprehensive commitment and considerable progress in formalization; Universidad de Buenos Aires (UBA) displays a strong applied approach and explicit integration of the SDGs; USP presents established environmental policies and integration through concrete elements; Universidad de Chile is in an active process of mobilization and consolidation; and Universidad de los Andes stands out for its critical self-reflection and transdisciplinary approach, although it faces historical challenges in integrating environmental criteria into decision-making. Table 3 summarizes these main characteristics and the grouping of universities according to their degree of transition toward sustainability.

3.1 Gradient of possibilities for transition to sustainability

Based on the observed degree of policy formalization, the transversality of integration in substantive functions, the explicitness of alignment with global frameworks (such as the SDGs), the maturity of governance and the capacity for self-criticism for continuous improvement, a "gradient of possibilities for transition towards sustainability" was constructed for the six universities (Figure 2):

• UNAM (Mexico): Greater transition possibilities. It leads with its ERES UNAM 2024-2027 strategy, which is the most detailed and formalized. Its approach is comprehensive and explicitly transversal to all substantive functions and operational and budgetary management. The updating of curricula in "virtually all programs" and the prioritization of research projects that evaluate SDG compliance demonstrate a deep institutional commitment and a robust infrastructure for the transition (Universidad Nacional Autónoma de México, 2024).

• Universidad de Cuenca (Ecuador): Very good transition prospects. Although its Institutional Sustainability Plan is awaiting approval, the existence of the Strategic Sustainability Committee (CESUC) and the multiple certifications obtained demonstrate an advanced institutional commitment and a solid foundation for managing and formalizing sustainability. They have undertaken a comprehensive process with a learning path (University of Cuenca, Institutional Sustainability Plan, 2024; University of Cuenca, Strategic Sustainability Committee – CESUC, 2024).

TABLE 3 – Synthesis.

University	Main feature of transition towards sustainability
UNAM	It is positioned as a pioneering university due to its highly detailed and formalized sustainability strategy, with a comprehensive and cross-cutting approach across all its substantive and budgetary functions.
Universidad de Cuenca	It demonstrates a comprehensive commitment and considerable progress in formalization, with an Institutional Sustainability Plan under approval and an emphasis on concrete environmental management and equity.
UBA	It demonstrates a strong applied focus and explicit integration of the SDGs (Sustainable Development Goals), concentrating its efforts on related disciplines and influencing the public and private sectors.
USP	It presents established environmental policies and integration through concrete elements such as ecological reserves and bioenergy and photovoltaic projects, understanding sustainability as a cross-cutting principle in all its academic activities.
Universidad de Chile	It is actively mobilizing and consolidating, seeking institutional formalization and implementing iconic projects in sustainable campus management, such as urban gardens and recycling programs.
Universidad de los Andes	It stands out for his critical self-reflection and transdisciplinary approach to sustainable solutions, recognizing historical challenges in integrating environmental criteria into institutional decision-making.

SOURCE: Prepared by the authors based on interviews and personal communications with representatives of Universidad Nacional Autónoma de Mexico (Vega, Corsi), Universidad de Cuenca (Vanegas, Mogrovejo, Jiménez), Universidad de Chile (Urquiza), Universidad de Buenos Aires (Rodríguez), Universidade de São Paulo (Fernández) and Universidad de los Andes, 2023.

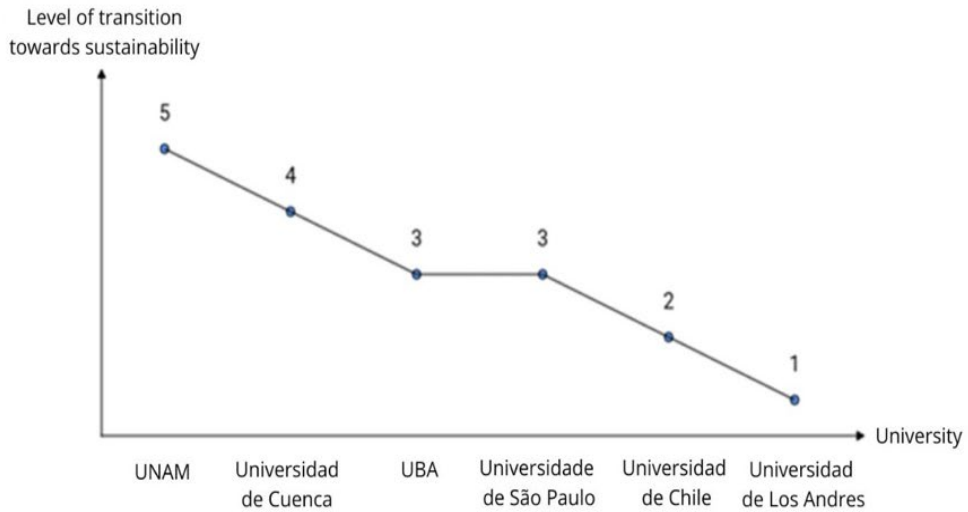

FIGURE 2 – Gradient of possibilities for transitioning to sustainability.
SOURCE: Prepared by the authors based on data analysis.

• UBA (Argentina): Good transition prospects. Its explicit integration of the SDGs into teaching and research, along with a strong focus on research applied to specific environmental problems (e.g., sustainable agriculture, waste management) and active outreach programs (UBA Verde, UBA en Acción), position it favorably. Its management is proactive and adapts to challenges, which is a good indicator of resilience and capacity for progress (Fernández, personal communication, 2024).

• Universidade de São Paulo (USP) (Brazil): Good transition prospects. It has had environmental policies since 2018 and rectoral guidelines, indicating a formal framework. Its integration of sustainability through concrete elements (ecological reserves, bioenergy projects) and its promotion of critical thinking are strengths. Flexibility in teaching, allowing sustainability to be addressed from each discipline, can be both an advantage (organic integration) and a challenge (less standardization) (Universidade de São Paulo, 2018; Fernández, personal communication, 2024).

• Universidad de Chile: Possibilities under development and consolidation. It is currently undergoing a more recent process of mobilization, seeking to consolidate a Sustainability Committee and secure the commitment of its faculties. Although it has iconic projects and a clear understanding of sustainability as a comprehensive approach, the "mobilization" phase suggests that full transversality at the institutional level is still under construction and requires greater cohesion across its various faculties (Urquiza, personal communication, 2024).

• Universidad de los Andes (Colombia): Fewer immediate possibilities for a comprehensive transition. Despite its advanced focus on "transdisciplinary education" and specific research programs (seedbed, deforestation), the university explicitly criticizes itself by mentioning that environmental criteria in decision-making have been "historically neglected." This recognition, although positive for its honesty, indicates a deeper structural challenge in the institutionalization of sustainability in general decision-making, which could slow the institution's comprehensive transition compared to others. This does not detract from its academic or research efforts but suggests a weaker management foundation in the past that must be overcome (Universidad de los Andes, 2023).

3.2. Typology of universities in transition towards sustainability

This typology is based on the gradient of transition possibilities previously established for each HEI, which assesses the degree of formalization, mainstreaming, alignment with global frameworks, governance maturity, and capacity for self-criticism. It was complemented by the semi-quantitative analysis provided by the "Mental Modeler" software, which included connectivity, density, and centrality, based on the values obtained through RA and IA. The ideal is for each university to achieve the highest possible number of connections between the 16 topics of interest, along with a high centrality measure. Table 4 presents the main metrics resulting from this analysis, including the connectivity, density, and centrality of the mental models.

This typology was based on the previously established gradient of transition possibilities for each HEI, which assesses the degree of formalization, mainstreaming, alignment with global frameworks, governance maturity, and capacity

TABLE 4 – Main metrics of Universities' mental models: university transitions towards sustainability.

	UNAM		UCuenca		U de los Andes		U Sao Paulo		U Chile		UBA	
	RA	**IA**	**RA**	**IA**	**RA**	**IA**	**RA**	**IA**	**RA**	**IA**	**RA**	**IA**
Total connections	240	238	41	22	240	0	240	239	240	202	240	239
Density	1	0.99	0.17	0.09	1	0	1	0.99	1	0.84	1	0.99
Connections	15	14.87	2.56	1.38	15	0	15	14.93	15	12.62	15	14.93
Measure of centrality	19.04	52.36	9.01	3	21.71	0	28.68	26.68	28.68	25.34	20.36	19.03

SOURCE: prepared by the authors

for self-criticism. It was complemented by the semi-quantitative analysis provided by the "Mental Modeler" analysis of connectivity, density, and centrality, based on the values obtained through RA and IA. The ideal is for each university to achieve the highest possible number of connections between the 16 topics of interest, along with a high centrality measure. This mixed approach allowed not only a qualitative assessment of sustainability trajectories but also provided quantitative metrics that validated or qualified these observations. The connections, density, and centrality of the software-derived mental models illustrated how formalization and systemic integration translate into a more robust network of influence, revealing structural gaps or strategic strengths that qualitative observation alone might not have captured with the same precision.

Total connections: This metric reflects the raw number of connections or relationships identified between the topics of interest. In the RA, most universities (UNAM, Universidad de los Andes, Universidade de São Paulo, Universidad de Chile, and UBA) show the same maximum number of connections, while the Universidad de Cuenca is significantly lower. In the IA, Universidade de São Paulo and UBA lead by a narrow margin. Universidad de los Andes stands out with 0 connections, suggesting a complete lack of activity or registration in this metric for this specific context.

Density: Density is a measure of the proportion of existing connections relative to the total number of possible connections, indicating how complete or interconnected a network is within each HEI. A value of 1 indicates a HEI with a fully connected network, i.e., with very good potential for the transition to sustainability. In the RA, a density of 1 is observed in all HEIs, except for Universidad de Cuenca, which has a much lower density. For the IA, UNAM, Universidade de São Paulo, and UBA show almost perfect densities, indicating high interconnectedness. Universidad de Chile follows with a still considerable density. Again, Universidad de los Andes registers 0, reinforcing the observation of a lack of connections in this context.

Connections: Connections indicate the direction of causality, accompanied by the associated sign, which can be positive or negative. For example, the relationship between "Conception of the Environment in University Teaching" and "Conception of Sustainability in Research" was

characterized as moderately positive, indicating that an improvement in environmental education, given current conditions, will result in an improvement in environmental research. In general, the trend of the previous metrics is repeated in the number of connections, with most universities reaching a maximum value, and Universidad de Cuenca falling significantly behind. For the IA, Universidade de São Paulo and Universidad de Buenos Aires (UBA) lead the way with a very similar number of connections per component, closely followed by UNAM. Universidad de los Andes again ranks last.

Centrality measure: The centrality measure is crucial in the analysis with Mental Modeler, as it indicates the importance or influence of a node (in this case, a topic of interest) within the network. Higher values suggest greater influence or a more central role. For the RA, Universidade de São Paulo and Universidad de Chile share the highest centrality position, indicating strong influence. Universidad de Cuenca has the lowest centrality. UNAM and UBA share the same centrality, while Universidad de los Andes, logically, also has 0 centrality. These metrics and their visualization of the centrality measure in the mental models are detailed in Figure 3 and Figure 4, respectively.

From the above, four key topics were obtained, which determine the behavior of the set of variables:

• C3: Inclinations toward critical thinking in "University Teaching".

• C8: Environmental criteria included in decision-making in "Research".

• C7: Inclinations toward critical thinking in "Research".

• C10: Conceptions of sustainability in "Management".

This resulted in a typology of HEIs in transition towards sustainability:

1. Leading and highly transversal universities: These institutions demonstrate the greatest and most promising potential for transitioning toward sustainability, with deeply formalized strategies and explicitly transversal integration in all their substantive functions and operational management. They exhibit a high degree of interconnectedness and density in their networks in both contexts (RA and IA). The university in this category is UNAM (Mexico), showing a high number of "Total connections" (240 in RA, 238 in IA) and a near-perfect "Density" (1 in RA, 0.99 in IA). Its "Centrality Measure" is solid (19.04 in RA, 19.03 in IA). Universidade de São Paulo (USP) (Brazil): in the RA context, it presents the same maximum number of "Total connections" (240) and "Density" (1) as the leaders. In the IA context, it leads or is among the first in "Total connections" (239), "Density" (0.99), and "Connections per component" (14.93). It shared the highest "Centrality Measure" position in RA (28.68) and maintains a high centrality in IA (26.68). UBA (Argentina): Its network metrics are very similar to those of USP, leading or sharing the lead in "Total Connections" (239 in IA), "Density" (0.99 in IA), and "Connections per Component" (14.93 in IA). Its "Centrality Measure" is also high (20.36 in RA, 19.03 in IA), sharing the latter with UNAM.

2. Strategic and focused impact universities: Despite having a lower volume of connections or

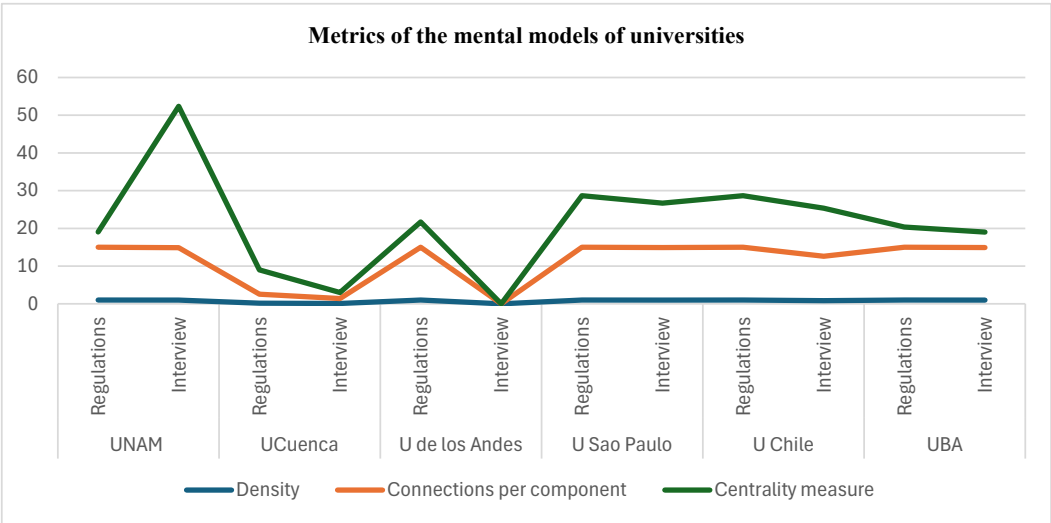

FIGURE 3 – Metrics of universities' mental models.
SOURCE: prepared by the authors.

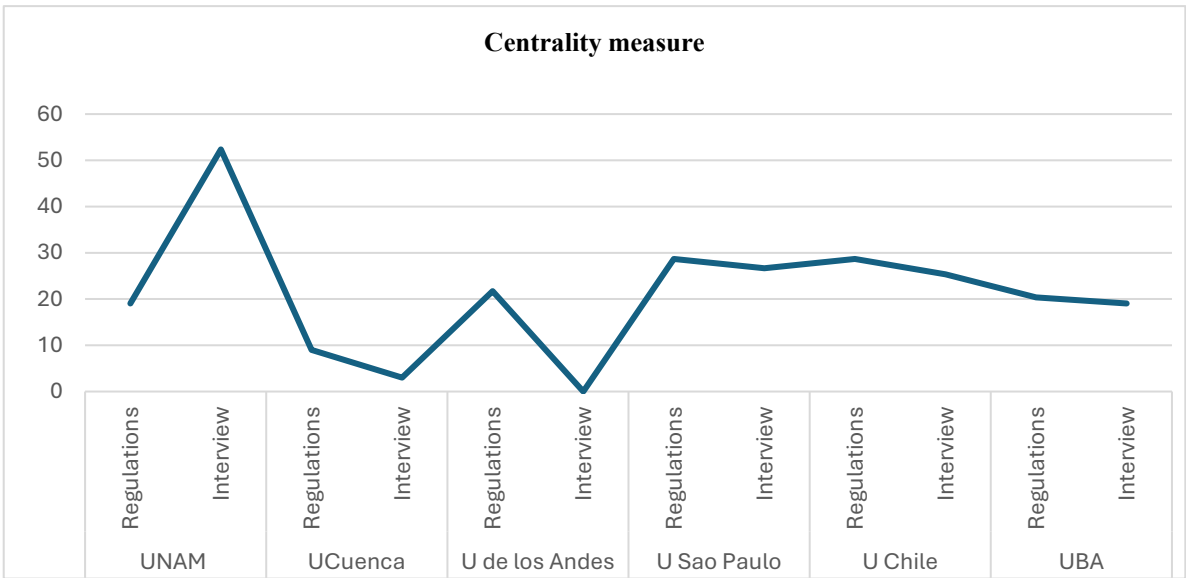

FIGURE 4 – Centrality measure
SOURCE: prepared by the authors.

total density in their networks, these universities stand out for their exceptionally high "Centrality Measure" in the strategic context (IA). This suggests that, while their network may not be as extensive as that of the leaders, their position within the network is strategically very influential or central, allowing them to have a significant impact. The university in this category is Universidad de Cuenca (Ecuador). Quantitatively, while its "Total Connections" (41 in RA, 22 in IA), "Density" (0.17 in RA, 0.09 in IA), and "Connections per Component" (2.56 in RA, 1.38 in IA) values are the lowest in both contexts, its "Centrality Measure" in the IA context is extraordinarily high (52.36). This contrast is key, indicating that, despite a lower volume of connections, their influence or central role is very pronounced in the strategic sphere.

3. Universities in consolidation and development: These institutions are in a more recent process of mobilizing and consolidating their governance structures for sustainability. Their network metrics are solid, but do not always reach the maximums of the leading universities. The university in this category is Universidad de Chile. The analysis shows a high number of "Total connections" (240 in RA, 202 in IA) and a perfect "Density" in RA (1) and considerable in IA (0.84). In the RA context, it shares the highest "Centrality Measure" position (28.68) with USP and maintains a good centrality in IA (25.34).

4. Universities with systemic integration challenges: While they may have academic strengths or specific research in sustainability, these institutions recognize structural challenges in the holistic integration of environmental criteria into their institutional decision-making. This is quantitatively manifested in an absence or zero performance on network metrics in the strategic context (IA). The university in this category is Universidad de los Andes (Colombia). Its network metrics in the IA context, where it registers zero ("0") in "Total connections", "Density", "Connections per component", and "Centrality measure", indicate a significant gap in its activity or record in the strategic area of network connections, despite having high values in the RA context.

4. Discussion

The research reveals a complex interplay between institutional commitment, internal practices, and the visibility of sustainability in the Latin American HEIs studied. The analysis of the regulations (RA) and interviews (IA) reveals significant nuances in their maturity, formalization, and strategic scope. The observed regularities are essential for understanding the shared starting point of these HEIs in their transition. For example, the unified institutional commitment to sustainability, conceived as a multidimensional "paradigm under construction", the transversality across all university functions, the promotion of critical thinking, the training of change agents with external influence, and the integration of environmental criteria into decision-making all indicate a solid foundation and a common purpose in the region, laying the groundwork for collective action and the development of alternatives to the traditional model. However, despite these regularities, differences in maturity and implementation are notable and directly correlate with the categories of the proposed typology. These variations are manifested in key aspects such as the degree of policy formalization, the breadth

of curricular integration, the specificity of the lines of research, community engagement strategies, the level of institutional self-reflection (such as the "historical neglect" at Universidad de los Andes), the explicit mention of the SDGs, and the emphasis on transdisciplinarity.

The interrelationship between the qualitative "gradient of transition possibilities" and the metrics of the "Mental Modeler" software is key to understanding the typology. Leading and Highly Transversal Universities (UNAM, USP, UBA) not only demonstrate the greatest or very good possibilities for transition qualitatively, with deeply formalized strategies and explicitly transversal integration in all their substantive functions and operational management. UNAM, for example, stands out for its ERES UNAM 2024-2027 strategy, the most detailed and formalized, with a comprehensive and transversal approach in virtually all its functions and operational management. Quantitatively, UNAM, USP, and UBA show a high number of "Total Connections" and a nearly perfect "Density" in both contexts (RA and IA), indicating a robust and highly interconnected network. The solid and consistent "Centrality Measure" of these universities, especially USP and UBA, which lead in several IA metrics, reflects their influence and central role within the network of universities in transition toward sustainability. Their ability to integrate the SDGs and adapt their management to economic and political challenges (like UBA) is an indicator of resilience and progress.

The Strategic and Focused Impact Universities category, represented by Universidad de Cuenca, presents a special result. Although its Institutional Sustainability Plan is under approval and the Strategic Sustainability Committee (CESUC) is established, quantitatively, its "Total Connections", "Density", and "Connections by Component" values are the lowest in both contexts. However, its "Centrality Measure" is exceptionally high in the interview context (IA). This contrast is key: it suggests that, while its network connections may be smaller, its position within the network is strategically very influential or central. This could be because, despite being in the process of formalization, the existence of key structures positions it as a node with great potential to direct or influence the strategic sustainability agenda, maximizing its impact even with a seemingly smaller network scale.

The University in Consolidation and Development, Universidad de Chile, is in a more recent process of mobilization and consolidation. Qualitatively, it seeks to consolidate a Sustainability Committee and the commitment of its faculties, reflecting a transversality under construction. Its network metrics are solid, with high "Total Connections" and "Density", even perfect in the RA context, and a "Centrality Measure" that, while good in IA, is shared with leaders in RA, indicating strong potential and an ongoing process to achieve systemic maturity among leading universities. Its iconic projects in sustainable campus management are a good reflection of its efforts in this phase. Finally, the category of Universities with Systemic Integration Challenges, exemplified by Universidad de los Andes, presents the most striking contrast. Despite its critical self-reflection and advanced focus on transdisciplinary education and specific research, the university explicitly criticizes itself by mentioning that environmental criteria in decision-making have been "historically neglected". This qualitative challenge is dramatically manifested in the analysis using "Mental Modeler", where it records zero in all metrics (Total Connections,

Density, Connections per Component, Centrality Measure) in the interview context (IA). This indicates a significant gap in their activity or record in the strategic area of network connections, suggesting that, despite academic strengths, the holistic institutionalization of sustainability at the level of systemic management and general decision-making still faces significant barriers that must be overcome for a comprehensive transition.

In summary, the discussion of results underscores that the transition toward sustainability in Latin American HEIs is a heterogeneous process, but one with an underlying commitment. The combination of qualitative and quantitative analysis allows for a nuanced view of strengths and challenges, revealing that leadership is not only defined by scale or formalization, but also by strategic positioning and the capacity for self-criticism to address gaps in systemic integration.

5. Conclusions

This research on the notions of sustainability in six Latin American Higher Education Institutions (HEIs) reaffirms the crucial role of universities as knowledge centers and transformative agents in the context of the current paradigmatic and environmental polycrisis. Their inherent capacity can exacerbate or mitigate these challenges.

The analysis revealed a unified institutional commitment and a fundamentally comprehensive and cross-cutting understanding of sustainability across all the HEIs studied. All participating universities view sustainability as a complex and multidimensional paradigm encompassing economic, social, and environmental dimensions. This concept should comprehensively guide teaching, research, management, and community engagement. A central objective is to promote critical thinking and the training of change agents, seeking to empower professionals and citizens to address and propose solutions to complex environmental and social problems. This shared understanding positions Latin American universities as indispensable actors in stimulating alternatives to traditional development and fostering greater integration of equity principles into their educational programs.

However, the results also highlighted significant differences in the maturity of their implementations and specific approaches. The typology developed in the study provides a detailed snapshot of these diverse trajectories, allowing for the identification of strengths and areas for improvement:

• Leading and highly transversal universities (UNAM, USP, UBA): These institutions stand out for their deep formalization, institutional transversality, and robust network interconnectedness. Their leadership is manifested in detailed strategies, an explicit integration of sustainability into all substantive functions and operational management, and a high density of connections that underscores their influence and central role in the regional sustainability network. For example, UNAM stands out for its ERES UNAM 2024-2027 strategy, the most detailed and formalized. Quantitatively, UNAM, USP, and UBA show a high number of total connections and near-perfect density in the normative analysis (RA) and interviews (IA), with a solid and consistent centrality measure.

• Strategic and focused-impact universities (Universidad de Cuenca): Despite having a lower volume of connections, this university demonstrates

an exceptionally high measure of centrality in the strategic context (IA). This suggests that, although its network may appear smaller in scale, its position is strategically very influential or central, allowing it to significantly impact decision-making or the direction of the movement. The existence of a Strategic Sustainability Committee (CESUC) and an approved Institutional Sustainability Plan are indicative of its potential.

• Universities in consolidation and development (Universidad de Chile): This institution is actively mobilizing and consolidating its governance structures for sustainability. It has a clear understanding of sustainability as a comprehensive approach and considerable potential for institutional consolidation of its efforts, seeking greater cohesion across its faculties and programs. Its network metrics are solid, with a high number of connections and density, indicating strong potential and an ongoing process to achieve systemic maturity among leading universities.

• Universities with systemic integration challenges (Universidad de los Andes): Despite their academic strengths and valuable critical self-reflection, these universities face the need to overcome structural gaps in the holistic institutionalization of sustainability. Universidad de los Andes, for example, explicitly criticizes itself by acknowledging that environmental criteria in decision-making have been "historically neglected". The absence of metrics in the strategic network context highlights the importance of translating academic commitments and efforts into systemic integration and more coherent and effective institutional decision-making.

In summary, the typology demonstrates that the path toward university sustainability in Latin America is multifaceted and heterogeneous. While there is a shared vision, the success of the transition depends on each institution's ability to formalize its policies, integrate sustainability across all its functions, foster mature governance, and, crucially, develop a capacity for self-criticism that allows for identifying and addressing internal challenges to systemic integration. The combination of qualitative and quantitative analysis provides a valuable tool for HEIs not only to understand their current position but also to identify strategic paths to advance their commitment to sustainability, contributing to the construction of more just, resilient, and balanced societies. The study highlights that sustainability is not a static concept, but rather a living process that requires critical reflection, constant dialogue, and ongoing methodological evolution to address the complexity of the university in its transformative role.

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