INTEGRATION OF SOCIOECOLOGICAL SYSTEMS IN THE REDESIGN OF SUSTAINABLE INDUSTRIAL PROCESSES IN LA VENTA, TABASCO

INTEGRATION OF SOCIOECOLOGICAL SYSTEMS IN THE REDESIGN OF SUSTAINABLE INDUSTRIAL PROCESSES IN LA VENTA, TABASCO

Altamirano Acosta Jesus Adrian[1], Jiménez Palma Pascual[2], Contreras Bazurto Keila[3] , Sarao Cruz Lorena del Jesus[4] , Arias Santos Nely Nayeli[5]

https://doi.org/10.61117/ipsumtec.v9i1.446

[1] National Technological Institute of Mexico/Higher Technological Institute of Villa La Venta,jaaa_07@hotmail.com , https://orcid.org/0009-0002-0437-7932
[2] National Technological Institute of Mexico/Higher Technological Institute of Villa La Venta,pascual.jimenez@itslv.edu.mx , https://orcid.org /0009-0000-3911-5612
[3] National Technological Institute of Mexico/Higher Technological Institute of Villa La Venta,kcontrerasbazurto@gmail.com , https://orcid.org /0009-0001-6502-4922.
[4] National Technological Institute of Mexico/Higher Technological Institute of Villa La Venta,lorena.sc@laventa.tecnm.mx , https://orcid.org /0009-0002-0437-7932.
[5] National Technological Institute of Mexico/Higher Technological Institute of Villa La Venta,nelyn.as@laventa.tecnm.mx , https://orcid.org /0009-0002-3840-9912

Abstract -- The region of La Venta, Tabasco, faces environmental and socioeconomic challenges caused by industrial pressure, water vulnerability, and ecosystem degradation. In this regard, the integration of socio-ecological systems (SES) into the redesign of industrial processes emerges as a strategy for advancing toward sustainability. This article aims to analyze, from a documentary and qualitative perspective, the conceptual frameworks and most recent studies related to industrial sustainability, with the purpose of identifying strategies applicable to the local and regional context, focusing on populations with similar characteristics.

A literature review was conducted based on the PRISMA (Preferred Reporting for Systematic Reviews and Meta Analyses) method, considering articles indexed in Scopus and Web of Science published between 2020 and 2025.

Ten studies with relevant information for the research were selected, including information on socio-ecological systems, industrial symbiosis, circular economy, and socio-techno-ecological transitions. The analysis used was thematic-qualitative to synthesize contributions, barriers, and elements transferable to the redesign of sustainable industrial processes in La Venta.

The study shows that the integration of SES requires coordination between technological infrastructure, ecosystem services, and community integration. The articles reviewed highlight strategies such as monitoring material and energy flows, adopting local industrial synergies, the use of green infrastructure for water management, and the implementation of multi-stakeholder governance models. The most common barriers include institutional fragmentation, lack of local data, limited economic incentives, and limited collaboration between industry, government, and society.

Sustainable redesign in La Venta must be based on socio-techno-ecological approaches that foster technological innovation, strengthen local capacities, and preserve ecosystems, promoting fair and collaborative transitions.

Keywords: Circular economy, Sustainable process engineering, Green infrastructure, Industrial symbiosis, Socio-ecological systems.

Abstract -- The region of La Venta, Tabasco, faces environmental and socioeconomic challenges caused by industrial pressure, water vulnerability, and ecosystem degradation. In this regard, the integration of socio-ecological systems (SES) into the redesign of industrial processes emerges as a strategy for advancing toward sustainability. This article aims to analyze, from a documentary and qualitative perspective, the conceptual frameworks and most recent studies related to industrial sustainability, with the purpose of identifying strategies applicable to the local and regional context, focusing on populations with similar characteristics.

A literature review was conducted based on the PRISMA (Preferred Reporting for Systematic Reviews and Meta

Analyses) method, considering articles indexed in Scopus and Web of Science published between 2020 and 2025.

Ten studies with information relevant to the research were selected, including information on socio-ecological systems, industrial symbiosis, circular economy, and socio-techno-ecological transitions. A thematic-qualitative analysis was used to synthesize contributions, barriers, and elements transferable to the redesign of sustainable industrial processes in La Venta.

The study shows that the integration of SES requires coordination between technological infrastructure, ecosystem services, and community integration. The articles reviewed highlight strategies such as tracking material and energy flows, adopting local industrial synergies, using green infrastructure for water management, and implementing multi-actor governance models. The most common barriers include institutional fragmentation, lack of local data, limited economic incentives, and limited collaboration between industry, government, and society.

Sustainable redesign in La Venta must be based on socio-techno-ecological approaches that foster technological innovation, strengthen local capacities, and preserve ecosystems, promoting fair and collaborative transitions.

Key words - Circular economy, Sustainable process engineering, Green infrastructure, Industrial symbiosis, Socio-ecological systems, Socio-techno-ecological transitions.

INTRODUCTION

The Tabasco region, including towns such as La Venta, has historically faced environmental and socioeconomic challenges linked to periodic flooding, intensive land use, agro-industrial activity, and pressures from resource extraction and transformation (recent regional reports and assessments show vulnerabilities to climate change and loss of natural capital). In contexts where industry and the community coexist, traditional strategies for improving industrial processes (energy optimization, effluent treatment, waste reduction) have tended to be addressed in a technical and sectoral manner, with little integration of the social, cultural, and ecological dynamics of the territory.

In particular, the La **Venta** area **in Tabasco** is a strategic region in southeastern Mexico due to its location on a plain that is highly vulnerable to flooding, its water wealth, and its proximity to productive and energy corridors. Studies on risks and resilience in Tabasco highlight critical challenges associated with water management, the impact of industry on the environment, and environmental degradation [1], [2]. This makes the region a priority case for implementing strategies for territorial sustainability strategies based on socio-ecological approaches.

A **socio-ecological system (SES)** arises as the intrinsic integration between human societies and the ecosystems that sustain them, where they interact through reciprocal dynamics that determine their resilience and adaptive capacity [3]. This perspective allows us to analyze how industrial processes impact ecosystem services and how environmental conditions influence security, the economy, and social well-being. Its application in industrial redesign favors solutions that articulate technology, governance, and environmental conservation.

Recent research has reinforced the view of ESS as factors that integrate social, ecological, and technological dynamics, emphasizing that transformations toward sustainability must be approached from a systemic perspective that recognizes the interdependence between human and natural systems. This approach emphasizes that industrial systems should not be viewed as isolated entities, but as components of broader complex systems, reaffirming the need to simultaneously consider material and energy flows, ecosystem services, and governmental structures in the design of policies and processes aimed at sustainability [4].

It is also important to define that a **sustainable industrial system** seeks to reduce environmental impacts, optimize resources, and promote economic and social benefits through principles of circular economy, industrial symbiosis, and multisectoral governance [5], [6]. Integrating these principles into La Venta can promote industrial transformations aligned with ecological resilience and local development.

It has been documented that, on an international scale, the transition to sustainable industrial models requires the articulation of circular economy approaches with social innovations and institutional arrangements [7].

Taking the above as a reference, we can note that the current state of the issue is as follows: Three lines relevant to this study emerge from recent literature on sustainability and industrial transition: (1) conceptual progress toward socio-ecological and socio-techno-ecological approaches that place nature as an active actor in transitions; (2) the consolidation of frameworks such as circular economy/industrial symbiosis/industrial ecosystems that promote local flows of matter and energy; and (3) studies on socio-ecological resilience and adaptation to hydrometeorological risks that require integrated solutions between "gray" and "green" infrastructures. These lines have been discussed and reviewed in

recent articles that provide conceptual frameworks and practical lessons [8].

Recent studies show that integrating the circular economy and industrial ecology into supply chains allows for the redesign of industrial processes with greater resource efficiency and waste reduction, supporting a systemic approach to achieving circularity [9].

Thus, the main objective of this research is to integrate a socio-ecological systems approach into the redesign of sustainable industrial processes in La Venta, Tabasco, through the analysis and synthesis of the results obtained in various research articles. This general objective will be achieved through the following specific objectives:

1. Review, qualitatively and documentarily, theoretical frameworks and recent experiences (last 5 years) on the integration of socio-ecological systems (SES) in the redesign of sustainable industrial processes.
2. Apply these frameworks and lessons to the context of La Venta, Tabasco, proposing criteria and lines of intervention (non-experimental) for the reconfiguration of industrial processes with a socio-ecological approach.
3. Identify opportunities, barriers, and local research priorities to advance the transition to sustainable industrial processes integrated into the territory.

The deliberate integration of socio-ecological perspectives into process engineering allows for the design of solutions that not only optimize technical variables (energy consumption, water efficiency, waste generation), but also strengthen social capital, preserve natural capital, and increase territorial resilience to extreme events. For a vulnerable territory such as La Venta, this is critical: a process redesign that ignores social and ecological factors risks being ineffective or even counterproductive. Therefore, a review and qualitative synthesis article that connects international frameworks with the local reality is useful for academics, policymakers, and industrial and community actors.

The articles analyzed address a diverse set of issues related to industrial sustainability, socio-ecological systems, and transitions to circular models.

[8] They identified the problem of fragmented approaches to sustainability transitions, where social, technological, and ecological aspects are studied in isolation. Their contribution consists of integrating these dimensions into a socio-techno-ecological approach that allows for a better understanding of the complex dynamics of sustainable change.

The study by [10] mainly addresses the lack of conceptual and methodological clarity surrounding industrial ecosystems. They find that current models are insufficient for understanding the interaction between actors, flows, and technologies. Their systematic review proposes a robust conceptual framework that resolves this theoretical dispersion and guides future research.

From a business perspective [11], they address the problem that industrial symbiosis is often analyzed solely in terms of environmental impacts, neglecting its economic value. Their business value framework fills this gap by identifying real benefits that can motivate the implementation of industrial synergies.

For their part [12], they identify diversity and lack of alignment among existing circular economy frameworks as problematic. The review offers a comprehensive framework that integrates disparate approaches and provides conceptual coherence for future industrial applications.

The issue of water risk in cities is addressed [13], which points out that traditional approaches do not adequately integrate social, ecological, and technological factors. Its SETS (Social-Ecological-Technological Systems) model resolves this limitation by offering a more comprehensive assessment of urban fragility.

The work [14] focuses on the problem of barriers to implementing industrial symbiosis in the textile industry, including lack of incentives, absence of infrastructure, and organizational resistance. Their study proposes strategies to overcome these barriers through institutional policies, cooperation, and technical training.

In the socio-ecological field, [15] addresses the problem of fragmentation in the field of research on socio-ecological systems. Their network analyses provide an understanding of how scientific entities evolve and propose ways to consolidate the area.

In the context of industrial symbiosis networks, [16] identify challenges in the coordination, governance, and continuity of collaborations. They propose practical lessons to optimize the implementation and sustainability of these networks.

Finally, [17] address the problem of inconsistency in methods for evaluating performance in the circular economy. Their methodical review provides

clarity on metrics, gaps, and opportunities for standardizing evaluations.

DEVELOPMENT

Documentary methodology (PRISMA adapted for qualitative review)

The **PRISMA** (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) **methodology** is a set of guidelines designed to improve transparency, quality, and rigor in the preparation of **systematic reviews** and **meta-analyses**. Its main objective is to ensure that the processes of selection, search, evaluation, and synthesis of scientific literature are reproducible, clear, and completely consistent [18].

PRISMA provides a **27-item checklist** and a **flowchart** that guides the researcher through four main phases:

1. **Identification**:
   Exhaustive search of sources in scientific databases.
2. **Filtering:**
   Disposal of duplicates and preliminary selection based on title and abstract criteria.
3. **Eligibility**:
   Full evaluation of articles to verify that they meet the established criteria.
4. **Inclusion**:
   Final selection of studies to be included in the qualitative or quantitative analysis.

The PRISMA method is widely used in social sciences, engineering, health, sustainability, and environmental sciences, as it is considered an international standard for systematic reviews.

A qualitative literature review was conducted, focusing on scientific articles indexed in Scopus or Web of Science published between 2020 and 2025 to capture the recent state of the art on: socio-ecological systems, industrial ecosystems/industrial symbiosis/circular economy, socio-techno-ecological approaches, and socio-ecological resilience applied to industry/territory.

The combined keywords included terms in English and Spanish: "social-ecological systems," "socio-ecological," "industrial ecosystems," "industrial symbiosis," "circular economy," "sustainability transitions," "resilience," "process redesign," and filters by year (2020–2025). Review articles and empirical studies with practical implications for process and policy redesign were prioritized.

Inclusion criteria (qualitative): articles indexed in Scopus/WoS, published between 2020 and 2025, that provided conceptual frameworks, systematic reviews, or case studies with lessons transferable to the reconfiguration of industrial processes from a socio-ecological perspective; preference for peer-reviewed journals (all references chosen meet these conditions).

As shown in Figure 1, various scientific articles published within the last five years were analyzed, with a greater number of publications relevant to the implementation of this research being those published in 2024.

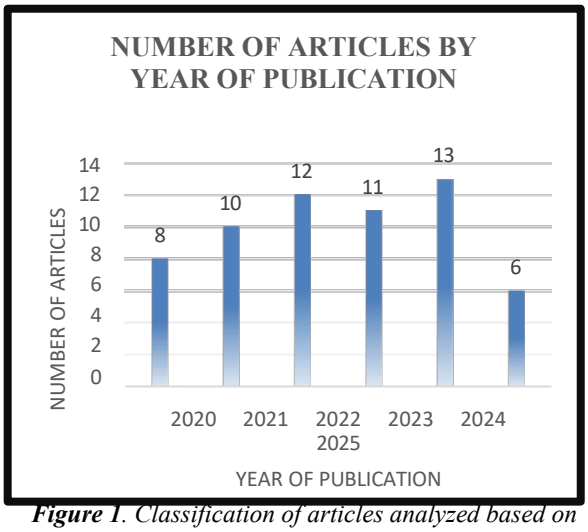

Figure 1*. Classification of articles analyzed based on year of publication.*

Exclusion criteria: publications outside the period, non-peer-reviewed documents, or strictly technical articles without a socio-ecological component or without conceptual transfer applicable to the redesign of processes at the territorial scale.

Figure 2 shows the flowchart followed for the selection process based on the use of the PRISMA methodology for selecting the articles that best suited the restriction and eligibility conditions. This was done taking into account the four main stages of the process (identification, filtering, eligibility, and inclusion).

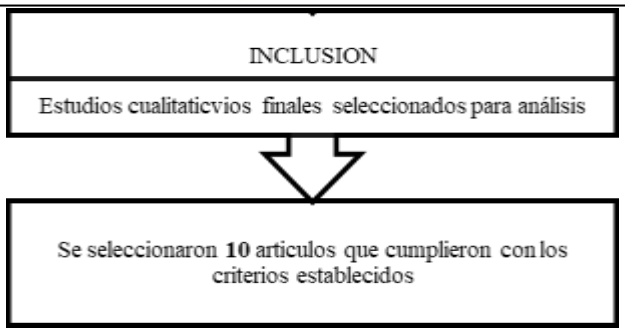

***Figure 2**. Flow chart of the PRISMA methodology for selecting articles for analysis*

Search results: final selection of 10 indexed articles (complete list in References). For the local context (La Venta/Tabasco), the review was supplemented with technical documents and state plans (used for contextualization, indicated in notes), but the 10 central sources are indexed articles as requested.

Information processing (qualitative approach)

A critical reading and thematic synthesis of each article was carried out, extracting:

a) Definition and scope of the conceptual framework (SES, socio-techno-ecological, industrial ecosystems, industrial symbiosis).

b) Main strategies for redesigning local processes

(energy, water, materials, logistics, governance).

c) Enabling conditions and barriers (technological, institutional, social).

d) Lessons learned from implementation and qualitative impact assessment.

Subsequently, thematic triangulation was performed to identify convergences and gaps applicable to the case of La Venta.

3. Discussion and analysis of results

Below is a qualitative comparative summary of the 10 selected articles (summary of contributions/insights relevant to the redesign of industrial processes with socio-ecological integration). This is followed by a discussion applied to the case of La Venta and the conclusions.

***Table 1**. Qualitative summary of relevant findings. It summarizes key characteristics of the framework or contribution, proposed redesign strategies, barriers, and actions applicable to La Venta.*

[8] Andersson et al.	Proposes a socio-techno-ecological approach for transitions, integrating nature active in systemic changes.	Design of transitions that incorporate ecological and feedback socioeconomic flows; governance multi-actor.	Disconnection between evidence and frameworks ecological services; innovation; fragmentation institutional.	Promote governance frameworks that recognize ecosystemic services and actors local; redesign of plants/processes.
[10] Burström et al.	Review systematic on **industrial ecosystems**: conceptualization and agenda research.	Promote synergies between industries (symbiosis), mapping cash flows matter and energy.	Confusion conceptual, lack of metrics standardizes, challenges for scaling to.	Mapping flows premises (water, waste organic) and evaluate potential synergies between SMEs local/industry strias.
[11] Mirata et to.	Framework for **value of business** for symbiosis industrial (J. Ind. Ecol.).	Integrate business models business regenerative as levers for redesign of processes.	Reticence entrepreneurl, perception it is risk, need of incentives.	Design incentives (tax, subsidies) and pilots who show value economic local.
[14] Hossain et al.	Identify **barriers** for implement institutional symbiosis industrial	Recommendation ones for strengthening or institutional, infrastructure and cooperation inter-company	Lack of technology, coordination and policies; low culture collaborative	Before large investments, promote capabilities and forums for local dialogue between companies and government
[12] Upadhaya	Review of the study in clothing **evolution of the circular economy concept** and emerging metrics.	Use of MFA (Material Flow Analysis), qualitative LCA qualitative; circularity indicators applicable to processes.	Difficulty in measuring social impacts and equity; lack of local data.	Implement flow diagnostics (water, waste) and qualitative LCA to prioritize interventions.
[15] Manyani et al.	Bibliometrics and evolution of the SES field: trends and gaps.	Place-based approach and participatory methodologies.	Underrepresentation of local/indigenous perspectives; insufficient funding. Fragmentation between urban and industrial sectors, lack of integrated instruments.	Adopt participatory methodologies to incorporate local knowledge of La Venta into the redesign.
[13] Khromova et al.	Proposes a **social-ecological-technological (SET)** approach to urban water vulnerability urban-water vulnerability.	Integrate green and technological infrastructure to manage water risks.		Design processes with green infrastructure measures (natural effluent treatment, artificial wetlands) to reduce vulnerability.

[16] Sellitto et al.	Lessons and challenges for **industrial symbiotic networks** (comprehensive review).	List of technical, social, and legal challenges; role of facilitators/mediators.	Need for facilitation and coordination to create effective networks.	Propose a local facilitator (university/municipality) to coordinate actors and design industrial corridors circular.
[17] Ferrante et al.	Review of performance metrics for circular economy and assessment.	Assessment tools (MFA, qualitative indicators, scenarios).	Lack of consensus on metrics; data challenges.	Prioritize simple and replicable metrics (e.g., % of recycled water, % reduction in waste sent to landfill).
[10] Burström et al.	(Synthesis) Convergence between SES, Industrial ecosystems and just transitions.	Situated redesign: technical interventions combined with institutional strengthening and equity.	Risk of solutions that do not consider social justice or job losses.	Design interventions with a just transition perspective and programs for labor retraining local.

Source: *Own elaboration*, 2025.

DISCUSSION AND ANALYSIS OF RESULTS

1. **Conceptual framework Conceptual** The most recent proposals emphasize that the transition to sustainable industrial processes must be **socio-techno-ecological**: that is, technical solutions (e.g., water recycling, heat recovery, industrial symbiosis) must be designed in dialogue with ecological dynamics (ecosystem services, local hydrology) and social and institutional structures (communities, companies, authorities). [8] and [10] show the need to break down disciplinary silos in order to achieve sustainable transitions.

2. **Technical priorities adapted to the context** For La Venta, given the prevalence of water risks and the local economy (agribusiness, micro/small industries), the priority strategies suggested by the literature are: (a) **mapping** of water and waste flows (qualitative MFA), (b) small-scale **symbiosis** between local actors (use of organic waste for biogas or compost), and (c) **green infrastructure** for natural effluent treatment and flood mitigation. Authors of reviews and case studies recommend starting with demonstration pilots that generate evidence of economic and ecological value.

3. **Socio-institutional barriers and proposed solutions** [14] and other studies point to barriers such as lack of technology, inter-company coordination, and absence of incentives. The practical lesson is that, in addition to the technical redesign of processes, **capacity building**, forums for dialogue, and incentive mechanisms (subsidies, credits, green public procurement) are required for local companies participate. Likewise, the figure of **the facilitator** or mediator (e.g., an academic actor or municipal center) is recurrent in the literature as a catalyst for synergies.

4. **Social justice and and transition transition** Contemporary literature warns of the risk of technocratic solutions that do not take into account employment, equity, and local knowledge. It is key to incorporate **place-based** participatory processes [15] and designing labor support measures. In La Venta, the adoption of sustainable processes can combine technical training for workers with support mechanisms for microenterprises.

5. **monitoring and qualitative evaluation** Recent reviews emphasize practical metrics and combining technical indicators with qualitative assessments (community perception, governance). For La Venta, simple indicators (e.g., volume of water reused per plant, number of symbiosis agreements between companies, community perception of risk reduction) and periodic participatory evaluations are recommended.

Several authors propose regionalized circular economy approaches, where strategies are designed based on the socio-ecological characteristics of the territory and local industrial trajectories, which is particularly relevant for areas such as La Venta.

Limitations detected in the evidence reviewed

- Few studies show longitudinal assessments of the socio-ecological impact of process redesigns at the municipal level.
- Specific research on La Venta in Scopus databases is scarce; the proposal here is mainly transferential, adapting global lessons to the local context.
- Methodological heterogeneity among articles makes it difficult to establish a single metric for comparison (which is why a qualitative approach was adopted).

CONCLUSIONS

1**.-Need for an integrated approach:** The redesign of sustainable industrial processes in La Venta must

Articulate through a **socio-techno-ecological** framework that combines technical interventions (resource recovery, circular economy, industrial symbiosis) with participatory governance and recognition of ecosystem services. (Objective 1 achieved).

2**.-Preferred implementation strategy:** Prioritize **local pilot projects** (e.g., biogas from agro-industrial waste; artificial wetlands for effluent treatment; flow mapping) accompanied by an **institutional facilitator** (university or municipality) to coordinate actors, measure qualitative results, and generate business and environmental evidence.

3**.-Barriers and remedial actions:** Identified main barriers—technological, institutional, and cultural—require concrete actions: technical capacity building, design of economic incentives, and creation of multi-stakeholder local governance bodies.

4**.-Evaluation and continuity:** A monitoring system with basic metrics and periodic qualitative evaluations that include community perception and social justice criteria is recommended; prioritize transparency and participation to build legitimacy.

5.-Future research: Applied research is needed to document and evaluate sustainable pilots in La Venta, focusing on socio-ecological impact, energy efficiency, and local technology adoption. It is also suggested to further develop circularity and resilience indicators adapted to the tropical context, and to model multiscale socio-ecological networks that allow for risk anticipation and strengthen territorial planning.

This work opens the door to research or project development with a sustainable approach that contributes to industrial development in a socio-ecological manner, including raising awareness of these new socio-ecological tools at both the governmental and social levels.

The **National Strategic Programs (PRONACES)** of the National Council for Humanities, Sciences, and Technologies (CONAHCYT) organize research efforts around specific national issues whose importance and severity require urgent attention and comprehensive, in-depth, and far-reaching solutions. Within this framework, the integration of socio-ecological systems into the redesign of sustainable industrial processes in La Venta, Tabasco, is directly aligned with the strategic objectives established by PRONACES, particularly in the areas of Water, Energy and Climate Change, Socio-ecological Systems and Sustainability, and Food Sovereignty, by promoting interdisciplinary approaches aimed at strengthening territorial resilience and sustainable resource management. These approaches reaffirm the need to transition towards industrial models that incorporate principles of circular economy, industrial symbiosis, and socio-environmental governance, in line with the national sustainable development priorities promoted by the Mexican State [19].

Resolution A/RES/70/1, "Transforming our world: the 2030 Agenda for Sustainable Development," establishes a global framework comprising 17 Sustainable Development Goals (SDGs) and 169 targets aimed at guiding policies and actions toward sustainable and inclusive development. In this context, the results of this study show a direct alignment with various SDGs of the 2030 Agenda, particularly with: **SDG 6 (Clean Water and Sanitation)**, **SDG 7 (Affordable and Clean Energy)**, **SDG 9 (Industry, innovation, and infrastructure)**, **SDG 11 (Sustainable cities and communities)**, **SDG 12 (Responsible consumption and production),** and **SDG 13 (Climate action)**. The study of these international frameworks reinforces the relevance of redesigning industrial processes as a means to minimize environmental impacts and maximize social benefits.
In future work, it is recommended to develop quantitative models for assessing circularity, implement multiscale analysis for local socio-ecological systems, and strengthen coordination between public, private, and community actors to accelerate the transition toward truly socio-ecological development.

ACKNOWLEDGMENTS
We extend our sincere thanks to **the Tecnológico Nacional de México campus Villa La Venta** for its full institutional support before and during the development of this research, as well as for promoting academic training focused on sustainability and innovation. We especially recognize the support of the **Master's Degree in Industrial Engineering**, whose academic and methodological guidance was fundamental to the consolidation of this work. We also extend our gratitude to the teachers, researchers, and collaborators who, with their guidance and contributions, enriched the analysis and strengthened the scientific quality of the study. Their commitment to educational excellence has been an essential pillar in our training process.

BIBLIOGRAPHY
[1] T. Haer, W. J. W. Botzen, J. Zavala-Hidalgo, C. Cusell, and P. J. Ward, “Economic evaluation of climate risk adaptation strategies: Cost-benefit analysis of flood protection in Tabasco, Mexico,” Atmósfera, vol. 30, no. 2, pp. 101–120, 2017, doi: 10.20937/ATM.2017.30.02.03.
[2] Zurich Flood Resilience Alliance, “Executive summary: Learning from the 2020 floods in Tabasco,

Mexico," *Post-Event Review Capability (PERC)*, Zurich, Switzerland, 2023. [Online]. Available: https://preparecenter.org/resource/executive-summary-learning-from-the-2020-floods-in-tabasco-mexico/

[3] E. Ostrom, "A general framework for analyzing sustainability of social-ecological systems," *Science*, vol. 325, p , no. 5939, pp. 419–422, Jul. 2009, doi: 10.1126/science.1172133.

[4] I. Souliotis and N. N. Voulvoulis, "Sustainability transitions: The role of systems thinking in improving planetary health and human prosperity," Frontiers in Environmental Science, vol. 13, Art. no. 1730692, 2025, doi: 10.3389/fenvs.2025.1730692.

[5] M. R. Chertow, "Industrial symbiosis: literature and taxonomy," *Annual Review of Energy and the Environment*, vol. 25, pp. 313–337, Nov. 2000, doi: 10.1146/annurev.energy.25.1.313.

[6] A. A. Feil, D. Schreiber, C. Haetinger, V. J. Strasburg, and C. L. Barkert, "Sustainability indicators for industrial organizations: Systematic review of literature," *Sustainability*, vol. 11, no. 3, art. no. 854, Feb. 2019, doi: 10.3390/su11030854.

[7] J. Carreño-Ortiz, M. Escobar-Sierra, and F. Lopez-Perez, "Theoretical relationship between circular economy and social innovation from a sustainable development perspective," Humanities and Social Sciences Communications, vol. 12, Art. no. 1549, 2025, doi: 10.1057/s41599-025-05862-0.

[8] J. Andersson, T. T. Lennerfors, and H. Fornstedt, "Towards a socio-techno-ecological approach to sustainability transitions," Environmental Innovation and Societal Transitions, vol. 51, Art. no. 100846, 2024, doi: 10.1016/j.eist.2024.100846.

[9] R. Geetha, "Circular economy through integrated industrial ecology: Innovations in resource recovery and process re-design," Biotechnology Notes, vol. 6, pp. 245–259, 2025, doi: 10.1016/j.biotno.2025.10.005.

[10] T. Burström, T. Lahti, V. Parida, and J. Wincent, "Industrial ecosystems: A systematic review, framework and research agenda," Technological Forecasting and Social Change, vol. 208, p. 123656, 2024, doi: 10.1016/j.techfore.2024.123656.

[11] M. Mirata, A. Lindfors, and M. L. Kambanou, "A business value framework for industrial symbiosis," Journal of Industrial Ecology, vol. 28, no. 6, pp. 1541–1553, 2024, doi: 10.1111/jiec.13545.

[12] S. Upadhayay et al., "Development in the circular economy concept," Sustainability, vol. 16, no. 4, p. 1500, 2024, doi: 10.3390/su16041500.

[13] S. Khromova et al., "A social-ecological-technological vulnerability approach for assessing urban hydrological risks," Ecological Indicators, 2025, doi: 10.1016/j.ecolind.2025.113334.

[14] M. Hossain et al., "Exploring the barriers to implementing industrial symbiosis," Heliyon, vol. 10, no. 13, Art. no. e34156, 2024, doi: 10.1016/j.heliyon.2024.e34156.

[15] A. Manyani, R. Biggs, L. Hill, and R. Preiser, "The evolution- -of- -social-ecological- -systems- -research," Ecology and Society, vol. 29, no. 1, p. 33, 2024, doi: 10.5751/ES-14694-290133.

[16] M. A. Sellitto et al., "Exploring industrial symbiotic networks," Sustainability, vol. 17, no. 4, p. 1509, 2025, doi: 10.3390/su17041509.

[17] M. Ferrante, M. Vitti, and C. Sassanelli, "The evolution of circular economy performance assessment," Renewable and Sustainable Energy Reviews, 2025, doi: 10.1016/j.rser.2025.115757.

[18] M. J. Page, J. E. McKenzie, P. M. Bossuyt, I. Boutron, T. C. Hoffmann, C. D. Mulrow, L. Shamseer, J. Tetzlaff, E. A. Akl, R. Brennan, B. Chou, E. Glanville, E. Grimshaw, A. Hróbjartsson, A. Lalu, T. Li, A. Loder, Q. Mayo-Wilson, A. McDonald, J. A. McGuinness, D. Moher, L. R. Stewart, and J. M. Welch, "The PRISMA 2020 statement: An updated guideline for reporting systematic reviews," *BMJ*, vol. 372, p. n71, 2021, doi: 10.1136/bmj.n71.

[19] National Council for Humanities, Sciences, and Technologies, "National Strategic Programs (PRONACES)," Government of Mexico, n.d. [Online]. Available:https://www.gob.mx/cms/uploads/attachment/file/448752/Programas_Nacionales_Estrat_gicos.pdf

[20] United Nations General Assembly, "Transforming our world: the 2030 Agenda for Sustainable Development," Resolution A/RES/70/1, 2015.

Contribution Role Table

Role	Author(s)
Conceptualization	Jesus Adrian Altamirano Acosta, Pascual Jiménez Palma.
Research	Keila Contreras Bazurto.
Methodology	Lorena del Jesús Sarao Cruz, Jesus Adrian Altamirano Acosta
Project management	Lorena del Jesús Sarao Cruz, Nely Nayeli Arias Santos.
Supervision	Nely Nayeli Arias Santos, Pascual Jiménez Palma, Keila Contreras Bazurto.