TẠP CHÍ KHOA HỌC
TRƯỜNG ĐẠI HỌC QUY NHƠN

Các rào cản đối với đổi mới sinh thái trong chuỗi cung ứng tôm: tổng quan hệ thống theo PRISMA 2020 và đề xuất khung phân tích đa tầng

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Ngày nhận bài: 19/05/2025; Ngày sửa bài: 05/08/2025;
Ngày nhận đăng: 17/09/2025; Ngày xuất bản: 28/12/2025

TÓM TẮT

Đổi mới sinh thái đang ngày càng được xem là định hướng chiến lược quan trọng nhằm thúc đẩy phát triển bền vững trong ngành nuôi trồng thủy sản. Tuy nhiên, chuỗi cung ứng tôm, đặc biệt tại các quốc gia đang phát triển với nguồn lực hạn chế và thể chế phân mảnh, vẫn đối mặt với nhiều rào cản trong việc triển khai các sáng kiến đổi mới này. Nghiên cứu này thực hiện tổng quan hệ thống 45 bài báo khoa học được bình duyệt theo phương pháp PRISMA 2020, đồng thời tích hợp ba cách tiếp cận lý thuyết: lý thuyết thể chế, lý thuyết dựa trên nguồn lực (RBV), và hệ thống đổi mới. Kết quả phân tích xác định sáu nhóm rào cản chính có tính chất đan xen và tương tác lẫn nhau: (1) thể chế – chính sách, (2) công nghệ – vận hành, (3) tài chính, (4) tổ chức – nhận thức, (5) thị trường – chuỗi giá trị, và (6) các yếu tố đặc thù của ngành tôm. Các rào cản này liên kết chặt chẽ trong một hệ sinh thái ràng buộc lẫn nhau, nơi các điểm nghẽn thể chế thường làm trầm trọng hơn hạn chế tài chính và công nghệ, cản trở việc mở rộng quy mô đổi mới sinh thái. Trên cơ sở đó, nghiên cứu đề xuất một khung phân tích đa tầng gồm ba cấp độ: vi mô (doanh nghiệp, hộ nuôi), tầng trung gian (cấu trúc chuỗi giá trị) và vĩ mô (môi trường chính sách và thể chế). Khung này không chỉ cung cấp nền tảng lý luận có hệ thống cho các nghiên cứu tiếp theo mà còn hỗ trợ hoạch định chính sách nhằm thúc đẩy chuyển đổi bền vững trong chuỗi cung ứng tôm.

Từ khóa: *Đổi mới sinh thái, chuỗi cung ứng tôm, rào cản có tính hệ thống, PRISMA 2020, khung phân tích đa tầng.*

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https://doi.org/10.52111/qnjs.2025.19610

QUY NHON UNIVERSITY
JOURNAL OF SCIENCE

Barriers to eco-innovation in the shrimp supply chain: a systematic review using PRISMA 2020 and a proposed multi-level analytical framework

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Received: 19/05/2025; Revised: 05/08/2025;
Accepted: 17/09/2025; Published: 28/12/2025

ABSTRACT

Eco-innovation has emerged as a critical approach for achieving sustainability in aquaculture systems. Nonetheless, the shrimp supply chain, particularly in developing contexts characterized by institutional fragmentation and limited resources, continues to encounter substantial barriers in adopting such innovations. This study conducts a systematic literature review (SLR) of 45 peer-reviewed articles following the PRISMA 2020 protocol and synthesizes insights from institutional theory, the resource-based view (RBV), and innovation systems theory. The analysis identifies six interrelated categories of barriers: (1) institutional and policy constraints, (2) technological and operational limitations, (3) financial barriers, (4) organizational and cognitive challenges, (5) market and value chain inefficiencies, and (6) shrimp-specific contextual factors. Findings reveal that these barriers form a complex and self-reinforcing ecosystem, in which weaknesses at the institutional level often exacerbate financial and technological constraints, ultimately reducing the scalability of eco-innovation initiatives across the supply chain. Based on this analysis, the study proposes a multi-level analytical framework encompassing the micro level (producers and firms), meso level (supply chain structures), and macro level (institutional and policy environment). This framework reflects the systemic nature of innovation constraints, and highlights the interdependencies across levels. It offers both a systematic conceptual basis for future research and a practical foundation for designing coordinated policy interventions to support sustainable transformation in shrimp supply chain.

Keywords: *Eco-innovation, shrimp supply chain, systemic barriers, PRISMA 2020, multi-level analytical framework.*

1. INTRODUCTION

The intensifying urgency of environmental issues ranging from climate change to biodiversity loss has underscored the global imperative for sustainable production systems. In this context, eco-innovation has emerged not merely as a technological upgrade but as a systemic approach that integrates environmental goals into innovation processes.[1,2] Drawing on the conceptualization by Kemp and Pearson,[3] eco-innovation refers to innovations in products, processes, marketing, organization, or institutions that result in a reduction of environmental impacts across the lifecycle,

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https://doi.org/10.52111/qnjs.2025.19610

whether the benefits are intentional or not. Unlike traditional cleaner production, eco-innovation reflects systemic change, often involving shifts in value chains, user behavior, and regulatory frameworks.[4,5] In contemporary literature, it is widely defined as innovations that minimize natural resource consumption and emissions throughout a product's lifecycle, spanning design, use, reuse, and recycling stages.[6] Aligned with the UN Sustainable Development Goals, particularly SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action) and SDG 14 (Life Below Water), eco-innovation is now central to national and global policy agendas.[7]

The shrimp aquaculture sector represents a critical yet under examined frontier in this sustainability transition. While this sector contributes significantly to economic growth and supports millions of smallholders in developing countries,[8] it has also been associated with serious ecological consequences such as pollution, habitat degradation and increased vulnerability to disease. Unlike more vertically integrated aquaculture systems, such as those found in salmon or pangasius farming, shrimp production is characterized by high fragmentation, informal practices, and limited coordination.[9] These institutional and structural features make shrimp supply chain particularly prone to complex innovation barriers.

Growing international demand for traceable, eco-certified products places new pressures on the sector to innovate sustainably. However, actual adoption of eco-innovation remains limited due to a web of interrelated technological, institutional, financial, and behavioral barriers.

Existing research has extensively addressed eco-innovation in sectors such as manufacturing, agriculture, and energy,[1,10] but its application in fisheries particularly fragmented aquaculture value chains remains under-researched and conceptually limited. Studies on shrimp supply chain have largely centered on technical solutions or isolated best practices, often overlooking the structural and multi-level nature of the barriers involved.[11,12] Moreover, existing literature tends to adopt actor-centric or technology-driven perspectives, rarely addressing the dynamics across value chain actors or institutional layers.[13,14] Although pilot efforts such as digital traceability and eco-certification have been introduced, their scalability is constrained by foundational gaps in policy coherence, financing, and capacity building.[15] This limited perspective reflects deeper structural gaps in the current literature. First, studies are fragmented across regions and disciplines, inhibiting theoretical accumulation and cross-contextual learning.[9] Second, few adopt an integrated multilevel framework that links micro-level firm constraints with meso-level chain dynamics and macro-level policy institutions.[16,17] Third, there is a prevailing techno-centric bias, with insufficient attention to how socio-institutional, financial, and governance-related factors constrain the diffusion and legitimacy of eco-innovation.[18,19] This leaves a significant research gap in understanding how eco-innovation in fragmented aquaculture systems, particularly shrimp value chains, is constrained not by single or isolated factors, but by a web of interdependent and mutually reinforcing barriers.

To address this research gap, the present study systematically examines the key barriers to eco-innovation within the shrimp supply chain by conducting a systematic literature review (SLR) guided by the PRISMA 2020 protocol[20] and Tranfield's evidence-based framework.[21] By synthesizing insights from 45 peer-reviewed articles, the study identifies, categorizes, and interprets the key barriers impeding eco-innovation in shrimp aquaculture. Furthermore, it explores how these barriers interact across levels and proposes a multi-layered analytical framework tailored to the socio-technical dynamics of the shrimp supply chain.

The study is structured around three core objectives: (i) to synthesize empirical insights across multi-level barrier categories; (ii) to examine their recursive interactions and systemic nature; and (iii) to propose a structured analytical framework capable of informing both future research and targeted policy design. By integrating insights from institutional theory, the resource-based view (RBV), and innovation systems theory, this study offers a diagnostic and conceptual foundation for understanding how systemic constraints can be overcome. It contributes to current debates on sustainable aquaculture by proposing an integrative framework that reflects the realities of fragmented governance, uneven capacities, and ecological uncertainty particularly in resource-constrained, export-oriented shrimp sectors.

2. THEORETICAL BACKGROUND

Eco-innovation has gained growing scholarly attention as a systemic strategy to address environmental degradation, particularly in ecologically intensive sectors. Unlike conventional innovation, which often centers on economic outcomes, eco-innovation integrates environmental integrity across product life cycles and requires simultaneous shifts in technology, behavior, and institutional arrangements.[1,5] This multidimensional nature makes it highly relevant to shrimp aquaculture supply chains, where ecological fragility, institutional fragmentation, and socio-economic vulnerability converge.[22-24] In the shrimp sector, eco-innovation holds significant promise for mitigating coastal degradation and advancing sustainability goals. However, its adoption is not simply a matter of firm-level decision-making; rather, it is shaped by a constellation of interdependent barriers embedded across the entire value chain. These barriers interact dynamically across institutional, organizational, and systemic levels, forming what may be considered a chain-wide structure of constraints. Capturing this complexity requires an integrated theoretical foundation that synthesizes multiple perspectives, each corresponding to a distinct level of analysis. While these frameworks have informed studies in sectors such as manufacturing and energy, they remain underutilized in fragmented and resource-sensitive contexts like aquaculture.[25,26] The need for an integrated, multi-level framework that captures cross-cutting and chain-wide interactions is especially urgent in the shrimp sector, where biological seasonality, global market dependence and institutional volatility co-exist.

This theoretical foundation underpins the present study's effort to assess eco-innovation barriers through a comprehensive lens connecting institutional, organizational, and systemic dimensions across the entire supply chain. It informs the design of the systematic literature review and guides the development of an analytical framework tailored to aquaculture's structural realities. Institutional theory, originally developed by North[27] and expanded by Scott,[28] provides the first pillar of this synthesis by explaining how formal rules, normative expectations, and uneven enforcement mechanisms shape organizational behavior in ways that can either enable or inhibit eco-innovation.[29,30] In many shrimp-producing contexts, fragmented regulatory regimes and inconsistently applied export standards create institutional rigidities so-called "lock-ins" that prevent alignment between sustainability mandates and operational realities. These reflect macro-level constraints that often operate beyond the control of individual firms. To complement this external lens, the RBV, first introduced by Wernerfelt[31] and further developed by Barney,[32] shifts the analytical focus inward, to the firm level, revealing how limited financial capital, managerial competencies, and access to environmental knowledge constitute core internal constraints.[32,33] These limitations are especially acute for smallholders and SMEs, who often lack

https://doi.org/10.52111/qnjs.2025.19610

the absorptive capacity needed to implement capital-intensive green technologies or comply with complex sustainability certifications. Such firm-level limitations represent micro-level capability barriers that directly affect the potential for eco-innovation uptake.

Finally, the innovation systems perspective formulated by Carlsson & Stankiewicz[34] and later expanded by Hekkert et al.,[35] adds a third, meso-level dimension, emphasizing the role of interaction, learning, and network dynamics in shaping innovation outcomes. Rather than viewing innovation as a linear or isolated process, this perspective conceptualizes it as the result of systemic interactions among heterogeneous actors operating within broader institutional and knowledge infrastructures.[34,35] In fragmented shrimp supply chains, these learning processes are frequently hampered by poor vertical integration, power asymmetries among actors, and weak mechanisms for knowledge diffusion. Consequently, localized innovations often fail to scale or embed into the broader system. By illuminating meso-level coordination and feedback failures, the innovation systems lens enriches the understanding of chain-wide blockages that transcend both firm-level resources and macro-institutional design.

Together, these three perspectives provide a complementary lens to decode systemic constraints: institutional theory sheds light on regulatory and governance rigidities; RBV focuses on resource limitations and internal firm capabilities; and innovation systems theory explains how weak coordination and feedback across networks obstruct systemic learning. This layered approach enhances explanatory depth and provides a coherent foundation for developing system-sensitive interventions. In doing so, it contributes a contextualized and adaptive framework for diagnosing eco-innovation barriers in fragmented, resource-constrained agri-food systems such as smallholder aquaculture.

3. METHODOLOGY

3.1. Systematic review design

This study employs the SLR to identify and analyze barriers to eco-innovation in the shrimp supply chain. The review is structured according to the PRISMA 2020 guidelines and the evidence-based management methodology developed by Tranfield et al.,[21] which is widely acknowledged in management and public policy research.

Unlike traditional narrative reviews that often lack consistency and are prone to selection bias, PRISMA's structured criteria and four-phase flowchart guide the process from identification to inclusion, minimizing bias and increasing consistency. This is suitable for this topic due to its multidisciplinary nature and the multilevel interactions involved ranging from technological and financial factors to institutional and social dimensions. The barriers under investigation span the entire value chain from production and processing to consumption and are strongly shaped by local contexts, national policy regimes, and global market dynamics.[36,37] Given that relevant studies are dispersed across diverse domains such as agriculture, sustainability, innovation, and policy studies, a structured and quality-controlled synthesis process is essential.[38]

Given the multidisciplinary nature of eco-innovation spanning technological, institutional, and financial dimensions, SLR is well suited for synthesizing fragmented insights across the aquaculture value chain.[36,38]

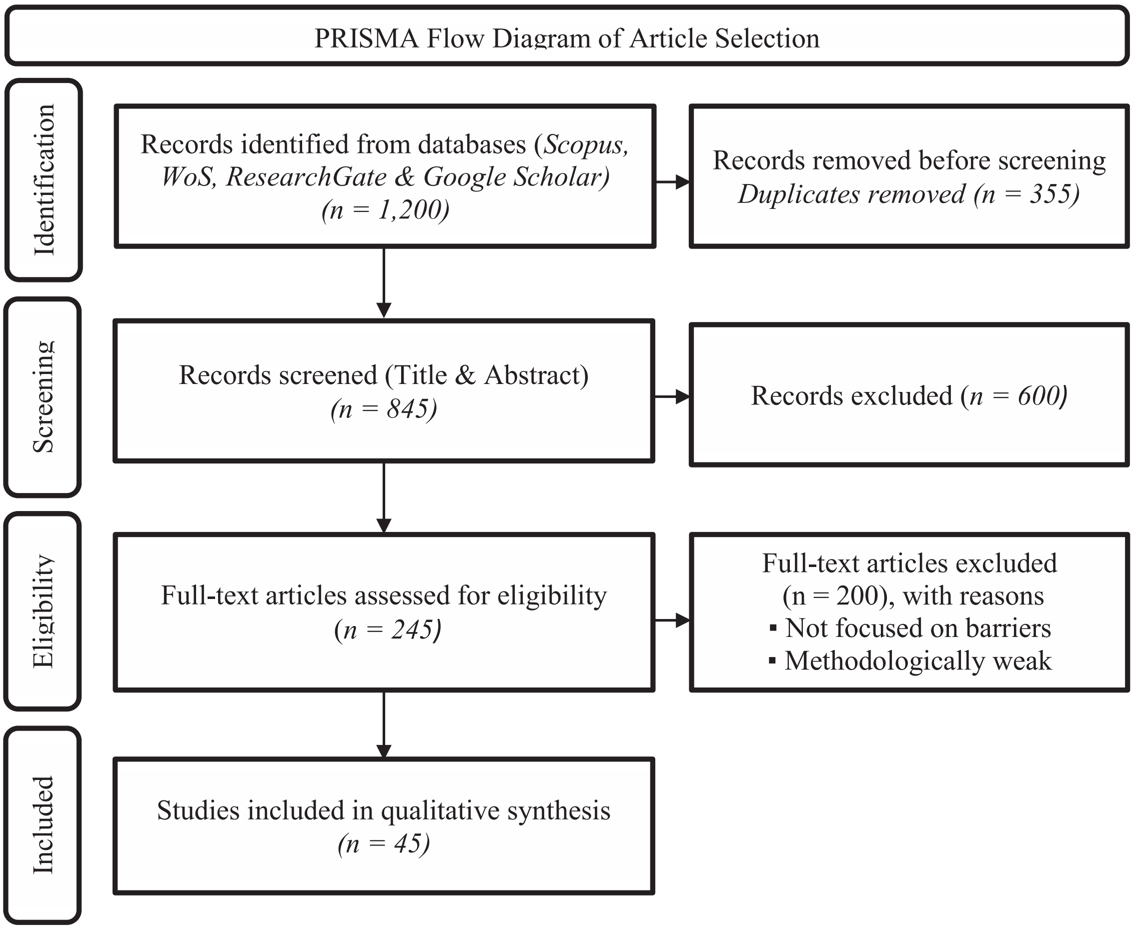

Figure 1. PRISMA-based flow diagram of article selection process for systematic literature review.

3.2. Research questions

Despite growing interest in eco-innovation, adoption in shrimp supply chain remains uneven due to a constellation of multifaceted and interdependent barriers. While existing literature has addressed key constraints such as regulatory fragmentation, technological limitations, and financial inaccessibility many studies tend to examine these factors in isolation, often overlooking their systemic interrelations and feedback dynamics across levels of analysis.[25,26] To address this fragmentation and guide the design of a methodologically robust review, the study is structured around three interrelated research questions that serve both analytical and conceptual purposes:

RQ1: What are the primary barriers to eco-innovation in the shrimp supply chain as identified in peer-reviewed literature?

RQ2: How do these barriers interact across institutional, technological, financial, organizational, and market domains?

RQ3: What research gaps remain, and how can an integrated analytical framework support future inquiry and policy formulation?

The progression of these three research questions ensures not only logical and methodological rigor, but also a balance between exploratory inquiry and theoretical contribution, an essential dual goal in systematic literature reviews that meet international academic standards.[21,39]

3.3. Search strategy and data sources

A structured search protocol was developed, combining PRISMA 2020 and Tranfield's approaches. The core databases, Scopus and Web of Science were selected for their extensive peer-reviewed coverage. In addition to formal databases, Google Scholar and ResearchGate were also screened to identify emerging insights and grey literature, provided sources met academic standards.[39]

Search terms were structured around three conceptual domains:

(1) *Eco-innovation (e.g., "green innovation", "environmental innovation", "sustainable innovation");*

(2) *Shrimp/aquaculture supply chain including both production terms ("shrimp", "aquaculture", "seafood") and structural terms ("supply chain", "value chain");*

(3) *Barriers and challenges (e.g., "constraints", "obstacles").*

These terms were combined using Boolean logic to maximize both sensitivity and specificity. A typical query used was: ("eco-innovation" OR "green innovation" OR *"sustainable innovation"*) AND ("shrimp" OR "aquaculture" OR "Seafood") AND ("barriers" OR "challenges" OR *"constraints"* OR *"obstacles"*) AND ("supply chain" OR "value chain").

The search was restricted to English-language, peer-reviewed articles published between 2000 and 2024 to reflect contemporary eco-innovation discourse.[5,40]

3.4. Inclusion and exclusion criteria

Records retrieved were screened using clearly defined inclusion/exclusion criteria to ensure academic rigor and contextual relevance.[21,41]

3.4.1. Inclusion criteria

Studies were included if they satisfied all of the following conditions:

(1) Scholarly validity: Articles were peer-reviewed and published in journals indexed by Scopus or Web of Science. Publications accessed via ResearchGate or Google Scholar were included only if their peer-reviewed status was verifiable through DOI, journal indexing, or publisher records.

(2) Language: Only studies published in English were considered to ensure terminological consistency and analytical clarity.

(3) Topical relevance: Studies addressed eco-innovation, encompassing technological, institutional, organizational, or social dimensions of environmentally sustainable practices.

(4) Sectoral scope: Included works focused on shrimp aquaculture or comparable agri-food value chains with similar structural and governance characteristics.

(5) Analytical focus: Studies explicitly examined barriers to eco-innovation, such as regulatory gaps, limited financing, technological inertia, or organizational constraints.[2,26]

(6) Publication period: Only articles published between 2000 and 2024 were retained, capturing key developments in eco-innovation and sustainability transitions.[5]

3.4.2. Exclusion criteria

Studies were excluded if they met any of the following criteria:

(1) Lack of academic credibility: Materials not peer-reviewed, including white papers, theses, technical reports, blogs, or documents lacking verifiable academic provenance.

(2) Irrelevant innovation focus: Studies addressing innovation without environmental relevance, such as purely commercial product or business model innovations.

(3) Sectoral misalignment: Research situated in sectors unrelated or structurally incompatible with shrimp aquaculture (e.g., automotive, construction, or digital manufacturing).

(4) Lack of analytical depth: Publications that discussed innovation conceptually but did not examine empirical barriers or implementation constraints.

(5) Duplicate or redundant entries: Articles repeated across databases or preprints of already published journal papers.

3.5. Screening and coding procedures

Following the database search and preliminary data organization, a structured screening and coding process was undertaken to ensure the analytical integrity and thematic relevance of the final literature set. The procedure adhered to the PRISMA 2020 protocol[20] and followed systematic review standards in management and innovation research.[39,42] It was designed to be transparent, replicable, and methodologically consistent with the multidisciplinary and applied nature of eco-innovation studies in agri-food systems.

3.5.1. Two-stage screening

Screening was conducted in two sequential phases. First, after removing 355 duplicates from the initial 1,200 records, 845 unique articles were screened by title and abstract. Studies that lacked a clear focus on eco-innovation, failed to address supply chains, or omitted discussion of innovation barriers were excluded resulting in the removal of 600 records.

In the second stage, 245 full-text articles were reviewed in depth. Exclusion at this phase was based on one or more of the following: insufficient attention to eco-innovation barriers, lack of methodological clarity, or absence of extractable content for thematic analysis. A final set of 45 peer-reviewed articles was selected for qualitative synthesis. Screening decisions followed a documented and replicable protocol to ensure transparency, reduce bias, and maintain academic rigor throughout the selection process.

3.5.2. Qualitative coding strategy

The selected studies were analyzed using a hybrid coding approach, combining deductive and inductive logic to allow both theory-grounded interpretation and responsiveness to sector-specific patterns. Deductive codes were derived from prior literature on eco-innovation barriers, including institutional and regulatory constraints,[1,2] technological limitations, financial obstacles, organizational resistance, and supply chain dynamics.[25]

In parallel, inductive coding was used to surface contextual nuances specific to the shrimp supply chain such as biosecurity risks, seasonal production cycles, traceability demands, and dependence on export markets. This dual coding framework ensured both conceptual coherence and empirical sensitivity. Coding was conducted manually using structured matrices to facilitate theme identification and cross-case comparison. A hybrid approach of deductive and inductive logic guided the process, ensuring conceptual coherence and empirical relevance.

To ensure analytical rigor, all included studies were assessed using adapted criteria from the Critical Appraisal Skills Programme (CASP), focusing on methodological clarity, relevance to the research questions, and the depth of empirical evidence. Only studies meeting a minimum threshold of design transparency and analytical robustness were retained for coding. To enhance the trustworthiness of the coding process, researcher reflexivity was applied throughout the analysis. Coding decisions were documented systematically, and emerging themes were iteratively reviewed to minimize personal bias and enhance conceptual clarity.

The resulting thematic structure is presented in Table 1, outlining first- and second-order codes, thematic categories, definitions, and associated references. This analytical framework forms the foundation for the subsequent findings and discussion.

Table 1. Detailed coding structure of eco-innovation barriers in shrimp supply chain.

First-order code	Second-order theme	Description	Supporting literature
1. Institutional and Policy Barriers	Lack of regulatory incentives	Absence of targeted subsidies or eco-innovation stimulus programs for shrimp producers	Carrillo-Hermosilla et al.[2]; Horbach et al.[1]; Joffre et al.[18]; Rennings[4]
	Regulatory uncertainty	Frequent changes in environmental laws and export standards create investment risks	Triguero et al.[43]; Chaparro-Banegas et al.[43]
	Weak enforcement mechanisms	Existing policies poorly implemented or monitored, reducing their effectiveness	De Jesus & Mendonça[26]; Hamam et al.[44]
2. Technological and Operational Barriers	Inappropriate technology scale	Green technologies designed for industrial scale, incompatible with smallholders	De Marchi[40]; Betanzo-Torres et al.[45]; Campuzano et al.[46]
	Infrastructure limitations	Inadequate waste and water treatment systems, especially in rural shrimp farms	FAO[8]; Joffre et al.[18]
	Low technical capacity	Lack of trained labor or technical support to operate sustainable systems	Betanzo-Torres et al.[45]; Hamam et al.[48]; OECD[7]
3. Financial Barriers	Limited access to green finance	Shrimp farmers and SMEs unable to obtain soft loans or green investment	OECD[7]; Horbach et al.[1]; Sara Hornborg et al.[49]
	High upfront investment	High capital cost and long return periods deter eco-tech adoption	Bosma et al.[50]; Kumar et al.[51]
	Lack of environmental risk insurance	No mechanisms to mitigate loss from eco-tech failure due to environmental shocks	Lebel et al.[52]; Joffre et al.[18]
4. Organizational Culture and Cognitive Barriers	Short-termism in decision-making	Focus on immediate cost–benefit undermines long-term environmental returns	Beltrán-Lugo et al.[53]; F. Silva et al.[36]
	Internal resistance to change	Rigid corporate structures or traditional practices discourage innovation	Carrillo-Hermosilla et al.[2]; Eirin Bar[54]
5. Market and Supply Chain Barriers	Lack of traceability and transparency	Limited ability to prove sustainability credentials to global buyers	Ilias Vlachos[55]; Naylor et al.[56]
	Export market dependence	Eco-innovation shaped by external demands, not local industry readiness	Joffre et al.[18]; Gupta et al.[57]
	Fragmented supply networks	Poor coordination and trust between actors hinders systemic innovation	Kilelu et al.[70]; Aarstad et al.[74]
6. Shrimp-Specific Contextual Barriers	Disease risk and climate volatility	High unpredictability discourages long-term investments	Joffre et al.[18]; Gupta et al.[57]
	Seasonality and natural dependency	Innovation limited by cycles of shrimp farming and environmental conditions	Ansari et al.[58]
	Lack of local technical support	Absence of accessible advisory services for eco-innovation implementation	Betanzo-Torres et al.[45]; Hamam et al.[44]

4. RESULTS ANALYSIS

A comprehensive synthesis of 45 peer-reviewed articles reveals that barriers to eco-innovation in the shrimp supply chain form a complex systemic structure. Rather than existing as discrete, independent factors, institutional, technological, financial, organizational, and market-related constraints are deeply interwoven amplifying one another through recursive feedback loops. In contrast to more standardized industrial value chains, the shrimp sector operates as a dynamic barrier ecosystem, shaped by high levels of fragmentation, ecological dependency, and biological risk. In such contexts, constraints tend to accumulate and self-reinforce in the absence of coordinated interventions.[18]

Several studies emphasize that innovation barriers function not as isolated obstacles, but as interdependent elements in a causal network, where one barrier can trigger or intensify others.[59] Limited coordination among actors, over-reliance on volatile international markets without corresponding domestic support mechanisms, and rigid policy frameworks contribute to system-level lock-ins. In such cases, micro-level innovation potential fails to translate into systemic transformation.[25,36]

To visualize the thematic concentration of key concepts across the reviewed literature, a keyword co-occurrence word cloud was generated in Figure 2. This visualization offers a heuristic snapshot of dominant terms associated with eco-innovation barriers in the shrimp supply chain, capturing both frequency and conceptual prominence. Terms such as "innovation," "capacity," "green," and "governance" appear most frequently, reflecting the systemic nature of constraints that span technical, institutional, and behavioral domains.

Notably, the co-occurrence of keywords like "finance," "policy," "technology," and "transfer" suggests that innovation bottlenecks are not isolated within any single domain but instead form part of an interlocking ecosystem of challenges. The emergence of context-specific terms like "shrimp," "aquaculture," and "asymmetry" further underlines the sectoral specificity of the barriers, distinguishing them from those in more standardized agri-food systems. While word clouds are inherently exploratory, this visualization reinforces the multi-scalar and cross-sectoral character of the constraint ecosystem, offering an empirical bridge between textual data and the analytical framework introduced in Section 5.

Figure 2. Keyword Co-occurrence word cloud reflecting core eco-innovation barriers in the shrimp supply chain.

https://doi.org/10.52111/qnjs.2025.19610

4.1. Data overview

Among the 45 studies reviewed, 38 are empirical, with a strong regional focus on major shrimp-producing countries such as Vietnam, Thailand, India, Bangladesh, and Ecuador, nations that not only anchor global supply chains but also face significant pressure to comply with evolving sustainability standards.[60,61] Approximately 62% of studies are situated in Southeast Asia, reflecting a growing shift of academic attention toward producer contexts. This geographic pattern suggests that findings from this review are particularly grounded in Southeast Asian realities, where shrimp aquaculture is characterized by smallholder prevalence, institutional fragmentation, and export-oriented governance models. By contrast, although less numerous, studies from North America and Europe play a pivotal role in shaping global expectations through certification systems and normative frameworks.[35,62]

However, when transferred to developing country contexts, these externally defined standards can become counterproductive imposing unrealistic compliance demands, inflating costs, and incentivizing performative or evasive behavior.[63] This disjunction illustrates the need for more context-sensitive governance mechanisms that account for local institutional and production realities.

Methodologically, the literature reflects significant diversity. Around 40% of studies employed in-depth qualitative designs, while 30% used mixed methods. This suggests that the field remains in a theory-building phase and underscores the value of this review as an integrative effort to bridge multi-level, interdisciplinary knowledge.

4.2. Typology of barriers to eco-innovation

The analysis of 45 peer-reviewed studies reveals six interrelated categories of barriers to eco-innovation in the shrimp supply chain. These span macro (institutional), meso (supply chain), and micro (firm-level) levels, forming a multi-scalar structure of constraints rather than discrete obstacles.

Institutional and policy barriers: These are the most frequently cited and foundational. Incoherent regulations, fragmented governance, and a lack of policy instruments such as environmental subsidies, technical extension, or credit incentives often result in ineffective or contradictory outcomes.[59,63,64] The absence of enforcement mechanisms and misalignment between domestic and international standards further reduces trust and participation among producers.

Technological and operational barriers: Eco-innovations like biofloc systems or closed-loop recirculating aquaculture often originate in large-scale, industrial contexts, rendering them poorly suited to smallholder settings.[40,62,65] Inadequate technical support and weak local adaptation strategies create gaps between innovation availability and on-the-ground feasibility.

Financial barriers: Limited access to green finance due to collateral requirements, lack of tailored financial products, or underdeveloped environmental credit markets restricts adoption of eco-innovations, particularly among SMEs and household producers. High initial investment costs and delayed returns reinforce risk aversion and low absorptive capacity.[1,26]

Organizational and cognitive barriers: Non-material barriers such as short-termism, low innovation literacy, and habitual risk aversion are prevalent among small-scale actors. These constraints often arise from experience-based learning systems and are compounded by limited exposure to environmental awareness campaigns or managerial training.[66,67]

Market and value chain barriers: Weak vertical integration, opaque pricing structures, and an uneven distribution of value across the chain disincentive investment in eco-innovation.

Compliance costs are disproportionately borne by producers, who are often excluded from certification design and lack bargaining power.[68,69]

Shrimp-specific contextual barriers: Sector-specific factors such as climatic variability, disease outbreaks, and seasonal production cycles amplify uncertainty. These dynamics not only hinder strategic planning but also increase vulnerability to shocks, particularly in under-capitalized farming regions.[70,71]

These categories collectively represent an ecosystem of constraints that operate across and between levels, requiring systemic rather than isolated responses.

4.3. Interdependencies among barriers

The barriers identified above do not function independently but form a tightly interconnected system. Thematic co-occurrence across the reviewed literature highlights critical couplings, particularly between institutional, financial, and technological constraints.

Institutional barriers were present in 84% of studies, often co-appearing with financial (64%) and technological (71%) barriers. This reflects how weak regulatory frameworks often limit access to finance, which in turn hampers technological adoption and internal capability building.[25,72] The interaction between technological and cognitive barriers identified in nearly half the sources suggests that even when appropriate technologies exist, adoption may falter due to limited skills, behavioral inertia, or insufficient contextualization.[40,70] Without mechanisms for adaptive learning, technological solutions risk becoming ineffective or even counterproductive.

A notable pattern emerges at cross-level intersections: macro-level issues (e.g., regulatory uncertainty, lack of green finance) intersect with micro-level limitations (e.g., technical capacity, innovation culture). The absence of coordinating institutions at the meso level such as cost-sharing platforms or traceability systems, further weakens the linkages needed for systemic learning and scaling.[73] A conceptual network map (Figure 3) positions policy barriers at the core of the constraint system, given their high degree of connectivity. Financial, technological, and supply chain-related barriers radiate outward but remain structurally dependent on the institutional context. The co-occurrence of finance, technology, and cognition barriers points to a "capability nexus" where deficiency in one area amplifies fragility in others. Although cited less frequently, contextual factors such as seasonality or climate risks were present across all major barrier clusters. These background variables act as amplifiers, exacerbating financial risk, delaying investment, and constraining planning horizons especially in resource-constrained environments. This interconnected structure suggests that addressing barriers in isolation is unlikely to produce durable results. Instead, multi-level and cross-actor interventions are required to disrupt the self-reinforcing cycles that maintain systemic inertia.[64,74]

This interconnected structure suggests that addressing barriers in isolation is unlikely to produce durable results. Instead, multi-level and cross-actor interventions are required to disrupt the self-reinforcing cycles that maintain systemic inertia.

These interdependencies reflect the systemic nature of innovation inertia, consistent with institutional theory's emphasis on regulatory uncertainty and weak coordination as structural inhibitors. The "capability nexus" also aligns with the RBV, which suggests that firms facing deficits in complementary capabilities (e.g., finance, knowledge, technology) struggle to absorb innovations effectively. Moreover, the absence of supportive meso-level infrastructure mirrors constraints typically highlighted in innovation systems theory. Thus, a multi-level diagnosis is not only empirically grounded but also theoretically coherent with the triadic framework employed in this study.

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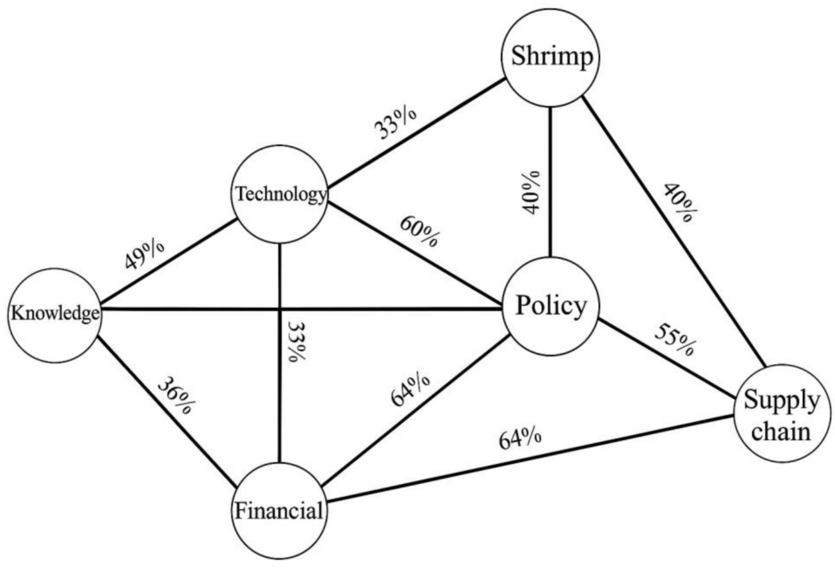

Figure 3. Co-occurrence network of barriers to eco-innovation identified across the shrimp supply chain literature.

4.4. Barrier ecosystem architecture

To synthesize these insights, a tri-layered framework is proposed to conceptualize the eco-innovation barrier system in shrimp aquaculture. It distinguishes three interdependent levels:

(1) Micro-level (Internal capabilities): Includes firm-level constraints such as low technical skills, limited innovation culture, and behavioral resistance. These are most evident among SMEs and smallholders

(2) Meso-level (Supply chain structures): Encompasses weak horizontal and vertical coordination, fragmented knowledge exchange, and limited traceability systems. These structural inefficiencies limit feedback and incentive alignment.

(3) Macro-level (Institutional and policy environment): Encompasses policy instability, regulatory gaps, and underdeveloped green finance mechanisms. These factors establish the enabling or disabling, context for eco-innovation.

The interactions among these levels are non-linear and often recursive. For example, a new technology may fail not because of technical flaws, but due to absent policy support or insufficient user readiness. Similarly, well-intended policies may underperform without organizational capacity or supply chain alignment.

To assess prevalence and structural importance, a frequency analysis of the selected studies confirms that institutional and policy barriers dominate (84%), followed by technological (71%) and financial (67%) constraints. Organizational and behavioral factors are increasingly emphasized in recent literature, reflecting a shift toward systemic thinking and integrated governance. Patterns of co-occurrence reveal high-impact pairings especially between institutional and financial barriers (64%), and between technological and organizational/cognitive ones (49 - 52%). These relationships indicate that eco-innovation failure is rarely the result of a single obstacle but emerges from compounded, mutually reinforcing barriers.

Finally, while shrimp-specific contextual factors are not as dominant in frequency, their widespread co-occurrence underscores their amplifying role in shaping the barrier landscape. These findings call for interventions that operate across multiple dimensions and levels targeting leverage points where systemic coordination, incentive redesign, and capacity building intersect. The proposed barrier ecosystem framework (illustrated in Section 5) builds on this multi-scalar understanding, offering a structured lens for diagnosing and disrupting constraint patterns that hinder eco-innovation in the shrimp supply chain.

5. DISCUSSION AND PROPOSED ANALYTICAL FRAMEWORK

The synthesis of 45 peer-reviewed studies confirms that barriers to eco-innovation in the shrimp aquaculture sector constitute a structurally interdependent system. Rather than isolated bottlenecks, these barriers coalesce into a dynamic "constraint ecosystem," spanning micro-level capabilities, meso-level supply chain relations, and macro-level institutional frameworks. This complexity is particularly pronounced in shrimp aquaculture, a sector marked by ecological volatility, biosecurity risks, and fragmented governance where innovation failures cannot be adequately explained through linear or siloed models.[18,75] The eco-innovation barriers identified in this review correspond to three complementary theoretical perspectives. At the micro level, constraints such as limited technical know-how and weak absorptive capacity among producers align with the RBV. At the macro level, the Institutional Theory helps illuminate how regulatory inconsistencies, informal norms, and enforcement gaps create structural disincentives for sustainable practices. Meanwhile, the Innovation Systems approach captures meso-level failures in coordination, knowledge diffusion, and network integration across the supply chain. Taken together, these lenses offer a more integrated explanation of why eco-innovation remains fragmented and difficult to scale in shrimp aquaculture.

Unlike more standardized agricultural domains, shrimp supply chain operates within export-driven value chains influenced by external standards and asymmetric market dependencies. The literature reveals that while technological and financial constraints are widely acknowledged, their interaction with institutional voids, weak coordination mechanisms, and behavioral rigidities creates recursive feedback loops that undermine innovation diffusion.[76,77] In this context, the failure of eco-innovation is less a function of technical infeasibility and more a symptom of systemic misalignment.

Small-scale producers, who dominate shrimp supply chains in Southeast Asia and Latin America, often operate under severe resource constraints and volatile policy environments. Even when sustainable technologies or certification schemes are available, adoption is frequently stalled by cognitive lock-ins, short-term decision norms, or perceived risks of non-compliance. Although international eco-standards are designed with good intentions, their implementation can unintentionally marginalize smallholders especially when these standards are applied without context-specific support. In the absence of locally grounded mechanisms such as technical assistance or financial incentives, producers may experience innovation fatigue or adopt strategic withdrawal as a rational coping response.[78,79] To advance a more holistic understanding of this complexity, this study proposes a three-tiered analytical framework grounded in the Innovation Systems Approach. Synthesizing empirical insights across the reviewed literature, the framework captures the layered nature of constraints and offers a strategic lens to identify leverage points for system-wide change.

At the micro level, eco-innovation is constrained by firm-level limitations including low technical capacity, risk aversion, and organizational inertia. These are frequently reinforced by weak extension services, experiential learning biases, and lack of exposure to evidence-based practices.[66,4]

The meso-level highlights structural issues in the value chain fragmented coordination, poor traceability, and inequitable value distribution.

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A notable deficit is the absence of effective intermediaries, such as producer cooperatives or certification hubs, which could otherwise facilitate knowledge exchange and collective upgrading.[75,79]

At the macro level, policy fragmentation, inconsistent regulation, and risk-averse financial institutions form critical system-level barriers. Many sustainability-oriented producers face disincentives due to unstable or misaligned policy regimes and financial tools that fail to accommodate the capital cycles of small aquaculture enterprises.[1,18,80]

A distinctive contribution of this framework is its attention to inter-scalar enablers, mechanisms that bridge vertical and horizontal gaps within the system. Three such cross-cutting levers are identified:

- **Value chain integration**: Enhances vertical coordination and feedback loops, enabling actors at different nodes to align incentives and co-evolve solutions.[18]
- **Co-creation**: Promotes participatory innovation, ensuring technologies are embedded in local practices and responsive to user needs.[81]
- **Green finance**: Facilitates access to resources for experimentation, reducing risk aversion and aligning financial flows with sustainability objectives.[82-84]

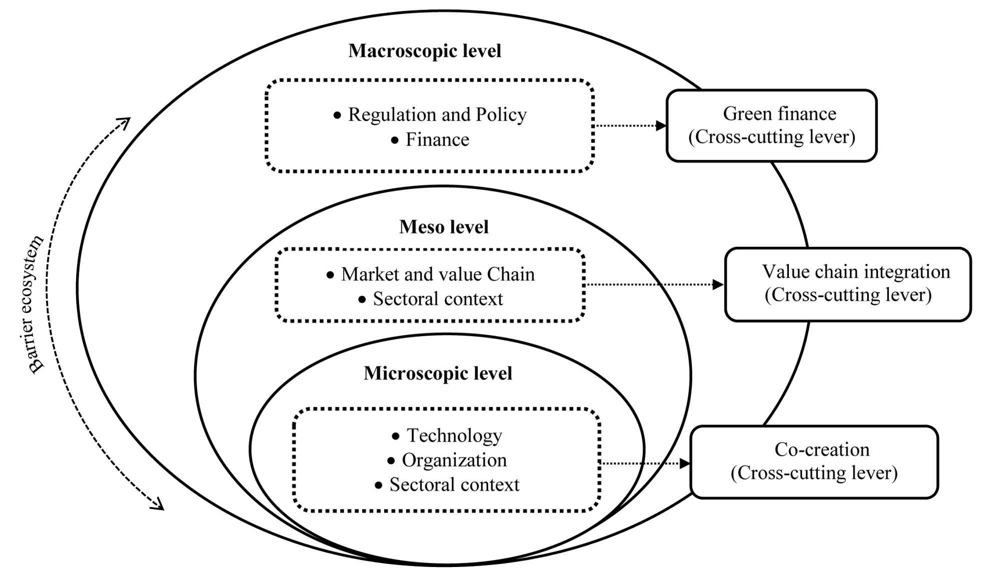

Figure 4. Proposed Multi-Level Analytical Framework for identifying and addressing eco-innovation barriers in the shrimp supply chain.

This integrative framework offers dual value. Theoretically, it contributes to transition literature by emphasizing barrier interdependence and cross-level dynamics. Practically, it equips policymakers and practitioners with a diagnostic tool to design targeted interventions ranging from financial instruments and institutional reform to grassroots capacity building. These insights underscore the need for future research to move beyond static categorizations of barriers and toward dynamic, system-sensitive inquiry. The proposed framework while conceptually grounded and analytically structured must now be subjected to empirical testing across diverse aquaculture contexts. Validation in underrepresented regions such as Sub-Saharan Africa and Latin America would help assess its transferability, especially in environments with distinct institutional architectures and ecological vulnerabilities. Moreover, the framework invites expansion into adjacent domains that remain underexplored in the current literature. These include the role of digital innovation in traceability systems, adaptive responses to

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compound climate shocks, and the evolution of transboundary biosecurity threats. Developing longitudinal or multi-sited case studies could illuminate how barriers shift over time and interact with changing governance regimes, market dynamics, and environmental pressures.

Future research should also focus on operationalizing this framework through the development of measurable indicators, diagnostic tools, or decision-support systems so that it can inform actionable policy and program design. In doing so, researchers and practitioners can not only identify where constraints lie, but also build capacity for systemic coordination, feedback learning, and inclusive innovation in the shrimp aquaculture sector.

Given the predominance of Southeast Asian contexts in the reviewed literature, the findings are especially applicable to regions like Vietnam, Thailand, and Indonesia, where institutional fragmentation and smallholder dominance are most evident.

The systematic synthesis conducted under the PRISMA 2020 protocol revealed a persistent fragmentation in how eco-innovation in shrimp aquaculture is conceptualized and analyzed. Most existing studies adopt a firm-centric or technology-specific focus, addressing isolated interventions without sufficiently accounting for the relational and institutional dynamics that shape innovation adoption across the supply chain. This piecemeal approach tends to obscure the interdependencies between actors, processes, and governance structures that often inhibit system-wide transformation.

By reframing the findings through a supply chain-oriented, multi-level analytical lens identifies how innovation barriers interact recursively across micro-level actors (e.g., farmers), meso-level dynamics (e.g., buyer-driven standards, coordination failures), and macro-level institutions (e.g., policy incoherence, regulatory voids). This perspective highlights that barriers are not merely additive, but systemic amplified by weak vertical integration, asymmetrical power relations, and broken feedback loops.[16,17] As such, the study offers a theoretically grounded and operationally relevant framework that moves beyond traditional, siloed analyses, contributing to a more integrated understanding of sustainability transitions in agri-food supply chains.

6. CONCLUSION

Eco-innovation in shrimp aquaculture represents both a necessity and a systemic challenge. This study departs from reductionist interpretations by situating innovation barriers within the broader institutional, organizational, and technical dynamics that define the shrimp value chain. Through a multi-level analytical lens, it reframes eco-innovation not as a linear process of technological diffusion, but as a negotiated outcome shaped by interlocking constraints across micro-level capacities, meso-level chain structures, and macro-level policy and finance systems.

What emerges is a picture of structural entanglement: technical limitations are rarely independent of financial exclusion; regulatory gaps often reinforce behavioral inertia; and fragmented market linkages weaken learning feedbacks essential for scaling innovation. Recognizing these mutual reinforcements, the study emphasizes the need for cross-cutting leverage points particularly value chain integration, co-creation, and green finance as catalysts to synchronize systemic functions.

This framework does not prescribe universal solutions. Instead, it helps actors identify where and why innovation stalls and what leverage points might shift the system. For policymakers and stakeholders, this implies that transformative change cannot be orchestrated from any single level, but must instead emerge from deliberate alignment across institutional scaffolding, supply chain architecture, and local agency. In doing so, eco-innovation becomes not

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only a technical agenda, but a strategic pathway toward inclusive and resilient sustainability transitions in aquaculture. Beyond its practical relevance, this study also contributes to theoretical advancement by integrating three disciplinary perspectives, resource-based view, institutional theory, and innovation systems into a cohesive framework for diagnosing eco-innovation barriers in aquaculture. What distinguishes this framework from prior models lies in its explicit attention to fragmented governance, institutional incoherence, and meso-level disarticulation, factors often underrepresented in existing innovation system theories. By foregrounding the interplay of these dynamics in a structurally disjointed commodity chain, the framework advances a more context-sensitive theorization of eco-innovation blockages in Global South aquaculture. The proposed multi-level schema offers an operationalizable basis for future empirical validation and adaptation across commodity chains.

Future research can deepen this work in several directions: (i) empirically testing the proposed framework in diverse geographies and production models; (ii) applying the diagnostic lens to other agri-food sectors with similar systemic blockages; and (iii) exploring the dynamic interactions between green finance instruments, policy incentives, and producer behavior under shifting environmental regimes.

By laying a conceptual foundation for structurally-aware innovation policy, this study invites a broader conversation on how transitions toward sustainable aquaculture can be aligned through multi-actor coordination, institutional learning, and long-term systemic support.

Acknowledgement

This research is conducted within the framework of science and technology projects at institutional level of Quy Nhon University under the project code T2024.871.42.

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