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THE EVOLUTION OF HELIX MODELS AND THEIR CONTRIBUTION TO THE DEVELOPMENT OF INNOVATION ECOSYSTEMS

Abstract

This paper explores the evolution of helix innovation models, progressing from the Triple Helix (3TH) through the Quadruple Helix (4QH) to the Quintuple Helix (5QH), and examines their contribution to the development of innovation ecosystems (IES). Building on theoretical insights and institutional practices, it highlights the increasingly significant role of key actors in shaping, consolidating, and enhancing the efficiency of IES. The findings indicate that the integration of civil society within the 4QH model and the inclusion of the natural environment within the 5QH model have had a substantial impact on the evolution of IES. Furthermore, the growing levels of collaboration, inclusiveness, and sustainability characteristic of helix models enhance innovation capacity, strengthen social responsibility, and ensure the long-term resilience and sustainability of contemporary IES. In other words, the contribution of the helix approach to IES development lies not only in expanding the number of actors but also in their interdependence, ability to generate synergy, and capacity to address challenges of inclusiveness and sustainability.

Key words: *innovation, helix innovation models, innovation ecosystems*

JEL classification: *031, 032*

ЕВОЛУЦИЈА ХЕЛИКС МОДЕЛА И ЊИХОВ УТИЦАЈ НА РАЗВОЈ ИНОВАЦИОНИХ ЕКОСИСТЕМА

Апстракт

Рад истражује еволуцију хеликс иновационих модела, напредујући од троструког хеликса (Triple Helix – 3TH), преко четвороструког хеликса (Quadruple Helix - 4QH), до петоструког хеликса (Quintuple Helix - 5QH), и испитује њихов допринос развоју иновационих екосистема – ИЕС (Innovation Ecosystems - IES). Ослањајући се на теоријска сазнања и институционалне праксе, рад наглашава све значајнију улогу кључних актера у хеликс иновационим моделима у обликовању, консолидацији и унапређењу ефикасности функционисања ИЕС. Налази показују да је интеграција цивилног друштва унутар модела 4QH и укључивање природног окружења

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унутар модела 5QH имала значајан утицај на еволуцију ИЕС. Даље, растући степен сарадње, инклузивности и одрживости, који карактерише хеликс моделе, унапређује иновациони капацитет, јача друштвену одговорност и обезбеђује дугорочну отпорност и одрживост савремених ИЕС. Другим речима, допринос хеликс приступа развоју ИЕС није само у проширењу броја актера, већ и у њиховој међузависности, способности за генерисање синергије и капацитету да одговоре на изазове инклузивности и одрживости.

Кључне речи: *иновације, хеликс иновациони модели, иновациони екосистеми*

Introduction

Since the 1980s, a prominent place in the study of knowledge creation and transfer processes within the context of innovation has been occupied by the so-called helix models. The origins of these models trace back to the mid-1990s with the emergence of the 3TH concept, which brought together universities, industry, and government within a single analytical framework. Soon afterward, this structure evolved into the 4QH through the inclusion of civil society as a fourth actor, and later into the 5QH with the addition of the natural environment as a fifth dimension-signaling a growing plurality of stakeholders. This evolutionary path reflects the rising complexity of innovation processes and underlines the importance of engaging a broader range of participants in shaping sustainable innovation strategies. The IES can be understood as an intricate network of organizations, activities, and relationships whose interaction enables the generation and diffusion of new ideas. Functioning as a dynamic system, it relies on institutional support, spatial proximity, shared objectives, and continuous adaptability-all of which underpin sustainable innovation. In today's knowledge-driven societies, innovation success depends not only on individual actors but on the cohesion and resilience of the entire ecosystem that connects them.

The most recent development in innovation ecosystems is the concept of the fractal innovation ecosystem. It refers to an agglomeration of resources operating within a regime of collaboration, co-specialization, and co-evolution, aimed at enhancing the efficiency and effectiveness of knowledge and innovation creation, allocation, and utilization (Carayannis & Campbell, 2009). The structural architecture and topology of these ecosystems are manifested through innovation networks and knowledge clusters, grounded in the principles of proximity, attraction, density, and similarity. Their evolutionary dynamics give rise to self-similar structures, confirming the fractal nature of such ecosystems. This self-similarity enables multi-level innovation efficiency and increases the likelihood of strategic knowledge discovery, as well as the assessment and optimization of innovation processes (Ivanova & Leydesdorff, 2015).

This review paper provides a comprehensive analysis of the evolution of helix innovation models, with particular emphasis on their role in enhancing both the conceptual and practical design of IES. The primary objective of the study is to address the key research question: "How have helix models evolved, and in what ways do they contribute to the shaping and improvement of innovation ecosystems?"

Through a systematic examination of relevant scientific and professional literature, the study identifies the key actors, their interrelationships, and the institutional

transformations resulting from the implementation of the helix approach, as well as their contribution to the development, adaptability, and long-term sustainability of IES. Special attention is given to differentiating individual helix models and evaluating their theoretical and practical significance in the context of understanding and improving innovation processes in the contemporary economy, while simultaneously providing an overview of potential directions for future research and application.

Helix innovation models serve as essential theoretical lenses for studying the dynamics of modern IES. Their development illustrates an ever-more intricate interplay among academia, industry, government institutions, civil society, and the natural environment. Over recent decades, these models have become a cornerstone for formulating innovation policies in economies pursuing inclusiveness, sustainability, and stronger cross-sector cooperation. Yet, despite extensive descriptive literature, there remains a shortage of deeper analyses exploring actor interdependencies, institutional frictions, and implementation challenges. Moreover, international policy papers often adopt helix terminology without adequate theoretical grounding or critical discussion. In this context, the contribution of this paper lies in the development of a conceptual model that links the evolution of key actors and the thematic focuses of helix models-collaboration, social inclusiveness, and ecological sustainability-with their direct and indirect impacts on the development of innovation ecosystems.

The study is based on a qualitative methodology encompassing two complementary analytical dimensions. The first dimension involves a theoretical literature analysis, examining studies related to the 3TH, 4QH, and 5QH models. Sources were selected according to predefined criteria of relevance, temporal coverage (1993–2025), methodological rigor, and academic citation, enabling the identification of actors, their interrelationships, and the institutional transformations arising from the application of the helix approach. The second dimension involves a review of institutional practices through the analysis of strategic documents, policies, and reports issued by key international actors, such as the OECD and the European Commission, with a particular focus on mechanisms of collaboration in practice. This methodological framework allows for an integrated consideration of both theoretical and practical aspects of the phenomenon, systematically addressing the research question and providing a deeper understanding of the role of helix models in the development of IES.

Based on the conducted analysis, a conceptual model has been developed that illustrates the interdependence of industry, academia, government, civil society, and the natural environment, identifies thematic focuses within the 3TH, 4QH, and 5QH models, and proposes guidelines for designing IES that foster actor collaboration, enhance social inclusiveness, and address the increasingly urgent demands of ecological sustainability. In doing so, the paper not only synthesizes existing knowledge but also contributes to the advancement of both theoretical and practical understanding of this complex phenomenon.

Although this research does not contain empirical testing, its methodological design allows for future expansion-most notably through comparative case studies examining the application of 4QH and 5QH frameworks across different regions. Accordingly, the paper outlines a comparative perspective on IES dimensions rooted in sustainability and participatory governance, contrasting the experiences of Scandinavian and Southeast European countries. This comparison helps clarify how core elements

of helix models influence ecosystem performance and serves to validate the theoretical propositions discussed here. Future studies could further incorporate quantitative indicators measuring the depth and effectiveness of cooperation among helix actors.

1. Theoretical Framework: Understanding Helix Innovation Models and the Concept of IES

The conceptual foundations of helix innovation models and IES are grounded in evolutionary economics, which provides a solid theoretical base for examining their structure, functionality, and co-evolution. This approach recognizes innovation as a dynamic and complex process shaped by institutions, culture, and adaptive policymaking that encourages collaboration among diverse stakeholders. In doing so, it both clarifies the principles behind helix models and reinforces their practical relevance for advancing innovation ecosystems.

Unlike the neoclassical paradigm-built on assumptions of rational actors, equilibrium, and linear innovation trajectories-evolutionary economics stresses that technological and institutional progress follows historically specific paths and unfolds through uncertainty and non-linearity (Nelson & Winter, 1982). Actors learn through interaction and experimentation, while innovation is influenced by social norms, policy environments, and cultural factors that determine how knowledge circulates and cooperation takes place (Edquist, 1997).

From this standpoint, technological change co-evolves with institutional and social settings; innovation occurs under conditions of limited rationality and continuous adjustment. It is thus a socially embedded, institutionally mediated process-an understanding vital to grasping the complexity of contemporary IES. The evolutionary lens allows for a richer exploration of helix models and the IES concept, highlighting multilayered collaboration among universities, firms, government bodies, civil society, and the environment. Their co-evolution mirrors core evolutionary principles such as network interaction and experiential learning.

Key assumptions underpinning this perspective include:

- the non-linear and interactive character of innovation,
- the co-development of knowledge, institutions, and technology,
- the necessity of flexible, adaptive, and context-sensitive innovation policies, and
- the view of innovation as a socially rooted process that extends beyond market boundaries.

Evolutionary economics contributes to the understanding of the development of the IES concept by recognizing the importance of historical and cultural context in shaping innovation capacities. It highlights the role of informal networks and social capital in knowledge creation and transfer, and promotes learning as a central driver of innovativeness. Its emphasis on nonlinearity, complexity, and adaptive learning enables the formulation of more effective and flexible innovation policies adapted to diverse societal contexts.

The concept of IES began to take shape and gain prominence in the early 2000s, drawing significantly on Moore's (1993) work on business ecosystems. Its theoretical foundations can be traced to the ideas of national innovation systems (Freeman, 1992). After 2010, IES became an integral part of innovation policies in economically advanced countries, with a focus on linking actors in the processes of knowledge creation, exchange, and commercialization (OECD, 2019).

The theory of helix models offers an approach that situates the creation and commercial valorization of knowledge within a broader, transdisciplinary context-one in which innovation users also play a significant role. In an environment marked by increasing diversity and heterogeneity of innovation processes, creativity, and networking among actors from all segments of society become increasingly important in the creation and commercialization of knowledge and innovations.

2. Evolution of Helix Innovation Models

The 3TH model is one of the most influential conceptual frameworks for understanding contemporary IES. Developed by Etzkowitz & Leydesdorff (1996), it emerged in response to the growing need of modern societies to integrate the activities and relationships of universities, industry, and government. Its goal is to foster innovation and economic development more effectively.

Each actor plays a distinct role and contributes unique resources, while their joint engagement is essential for the successful development of innovations. Universities generate knowledge and educate skilled personnel; industry transforms this knowledge into products and services; and government provides the institutional and regulatory framework that enables their cooperation.

The 3TH model transcends traditional linear models of knowledge transfer by establishing dynamic, nonlinear, and multilayered networks of communication and co-creation that stimulate innovation. Collaboration within this model extends beyond formal partnerships, encompassing informal networks, cultural interactions, and joint initiatives. This fosters synergy and accelerates innovation cycles.

Knowledge creation is a multidisciplinary process that facilitates the translation of theoretical insights into practical applications. Such interaction contributes to the development of innovations that are better aligned with market demands and societal challenges.

The 4QH model is based on the assumption that universities, industry, government, and civil society are guided by principles of open knowledge circulation, continuous learning, and mutual communication and collaboration (Cvetanović et al., 2025). These spiral linkages foster multidimensional relationships that enable the transformation of knowledge into marketable innovations. Within this framework, civil society acts as a catalyst for initiatives that enhance the design, alignment, and operational efficiency of public institutions, universities, and enterprises-along with their strategies, policies, and practices.

The 4QH model has a significant impact on the organization of research and development at the regional level. Its core premise is that markets should serve societal interests, while society should prioritize the well-being of its citizens. This model

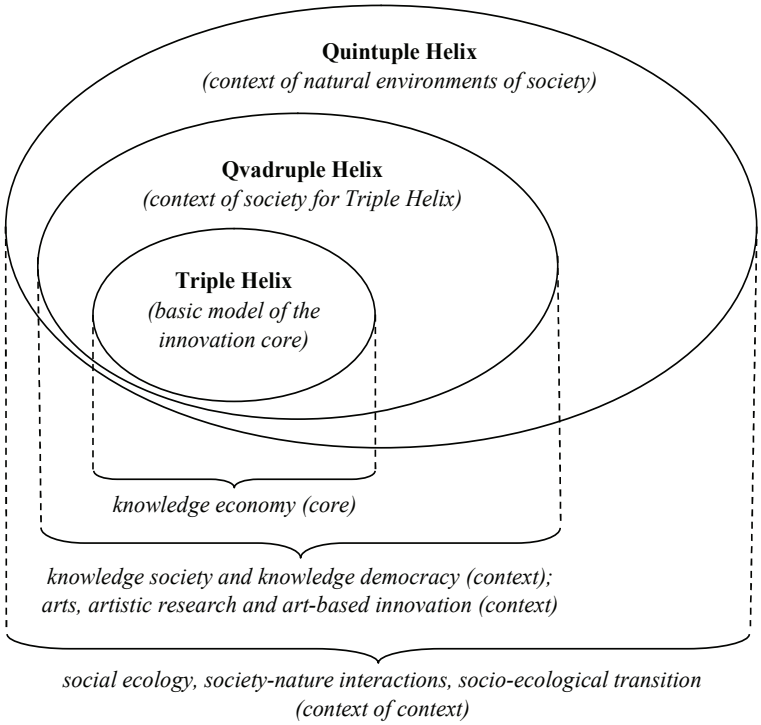
emphasizes the role of individuals in innovation processes. Carayannis & Campbell (2009) argue that the coexistence of plural knowledge systems in developed democracies gives rise to knowledge clusters that form coherent configurations, unconstrained by geographic or sectoral boundaries-particularly in the context of social media.

The model broadens the dynamics of IES by incorporating civil society and media into the processes of knowledge creation, transfer, and commercialization. This approach promotes an open and participatory culture of innovation in which citizens, local communities, and non-governmental organizations play an active role in defining socially relevant innovation priorities. The implementation of the 4QH framework within the *Living Labs* concept across Europe demonstrates that participatory forms of innovation significantly contribute to the development of sustainable urban solutions and the responsible governance of emerging technologies (Olbertz, 2025; Starkbaum, 2024).

The 5QH model further advances our understanding of contemporary innovation systems by positioning sustainability and social engagement at the core of knowledge generation and exchange. It directs innovation toward holistic development that intertwines technological advancement, social equity, and ecological responsibility. A central premise of the 5QH framework is that innovation should not be understood merely as a technical or economic outcome but as a socially and environmentally embedded process. In this model, innovation emerges through the co-creation of five interdependent actors-universities, industry, government, civil society, and the natural environment-who jointly address complex global challenges such as climate change, sustainable energy, and inclusive growth (Carayannis et al., 2012). By integrating diverse knowledge bases-scientific, technological, traditional, and local-the model fosters the creation of solutions that are not only effective but also enduring and context-sensitive. Recent European research underscores the importance of systematically aligning the objectives of the green transition and the circular economy with helix innovation models, giving rise to what has been termed the *eco-helix* approach (van Bueren, 2025).

Carayannis and Campbell (2009) emphasize the multifaceted benefits of helix models in promoting economic growth, improving regional competitiveness, and addressing environmental challenges (see Figure 1). The original 3QH model was based on the interplay among universities, industry, and government, highlighting their collective role in driving innovation and fostering economic development. The more advanced helix frameworks expand this foundation by introducing new dimensions to the innovation process. The 4QH model stresses the importance of continuous, interactive collaboration among stakeholders and investors, ensuring that citizens remain central participants in innovation activities. Building on this, the 5QH model embeds sustainability principles deeply within the processes of knowledge creation and innovation, marking a decisive step toward more inclusive and ecologically conscious innovation paradigms.

Figure 1: The benefits of helix models in the terms of economic growth, attractiveness, and addressing environmental challenges



Source: Carayannis et al., 2012.

When viewed as a whole, the 3TH, 4QH and 5QH models together outline a comprehensive framework for an innovation paradigm that is inclusive, participatory, and environmentally responsible-one that reflects the key values of the 21st century. The next stage in the evolution of these helix models is being shaped by several transformative forces: the pervasive digital transformation of economies and societies, the accelerated progress of artificial intelligence, and the growing adoption of open innovation practices. Collectively, these developments suggest that the future trajectory of innovation ecosystems will hinge on how effectively helix models are contextualized, digitalized, and integrated with the principles of sustainability.

The digital era has significantly enhanced the potential of helix models. Advances in digital technologies have expanded their capabilities, enabling greater dynamism and adaptability in fostering innovation. Digital platforms, collaborative tools, big data, and artificial intelligence facilitate faster and more efficient knowledge exchange among the key actors of helix models (Carayannis et al., 2019). Moreover, digital transformation has enabled the emergence of new actors-such as startups, user communities, and innovation networks-actively engaged in creating knowledge and transforming it into marketable innovations. As a result, the complexity of innovation ecosystems has steadily increased, along with their capacity to generate sustainable and inclusive solutions.

Digital transformation represents a profound and ongoing process of change through which organizations, institutions, and societies harness digital technologies to redefine business models, generate new value, and improve overall efficiency. Within the framework of IES, it serves as a driving force that connects a wide array of actors-from academia and industry to the public sector and citizens-thus fostering an integrated environment for co-creation and the practical application of knowledge (Vial, 2019). In such ecosystems, digital infrastructure functions as a pivotal resource, enabling agile experimentation and the rapid iteration of innovation processes (Autio et al., 2018).

However, the significance of digital transformation extends well beyond its technological aspects. It encompasses profound cultural and organizational adjustments, including the cultivation of digital competencies, the transformation of educational systems, the redefinition of leadership roles, and the enhancement of digital literacy. Together, these shifts nurture the rise of "digitally mature" innovation ecosystems that are capable of addressing challenges of sustainability, global competitiveness, and social inclusion (European Commission, 2020; Kane et al., 2019). Looking ahead, digital transformation will serve not merely as a technological enabler but as a strategic and systemic force connecting open innovation, artificial intelligence, and sustainable development-underpinning the evolution of resilient, cooperative, and inclusive knowledge-based societies.

Artificial Intelligence (AI) increasingly occupies a central position in the evolution of modern IES, transforming the ways in which knowledge is created, shared, and applied within the global economy. As a set of technologies designed to emulate human cognitive functions-learning, reasoning, language comprehension, and decision-making-AI accelerates innovation cycles and deepens collaboration among ecosystem participants (Brynjolfsson & McAfee, 2017; Russell & Norvig, 2021). Its integration across sectors such as research, education, healthcare, and industry supports the emergence of "intelligent ecosystems," characterized by continuous interconnections between data, knowledge, and innovation (Chesbrough, 2020).

Beyond simply improving the efficiency of innovation processes, AI fundamentally reshapes their structure and the nature of relationships among actors. Through applications such as big data analytics, predictive modeling, and personalized learning, innovation ecosystems become increasingly adaptive, effective, and capable of addressing complex societal issues. The future development of IES will depend largely on the capacity of societies to integrate AI technologies ethically and securely. Among the key challenges are data protection, algorithmic transparency, accountability in automated decision-making, and the prevention of bias or misuse (Floridi & Cowls, 2021). Equally important is the establishment of robust regulatory and educational frameworks that strengthen human capabilities and build public trust in intelligent systems (European Commission, 2021).

Open innovation forms the third cornerstone of contemporary IES. Departing from the notion that organizations can rely solely on internal resources, open innovation promotes active engagement with external partners-including universities, research institutions, startups, users, and even competitors (Chesbrough, 2003). It is built on a reciprocal flow of knowledge, allowing organizations not only to absorb external ideas and technologies but also to share their own innovations in the co-creation of value (West & Bogers, 2017).

The role of open innovation will grow even more crucial in the transition toward sustainable, digital, and green economies. By bridging diverse sectors and stakeholders, it enables the joint creation of solutions to complex global challenges-ranging from energy efficiency and climate adaptation to digital inclusion and the development of future skills. Hence, open innovation evolves beyond a technological approach into a strategic framework for socially responsible transformation.

Its greatest strength lies in the ability to merge internal and external sources of creativity and expertise, creating a dynamic, flexible system that promotes entrepreneurship, accelerates technology diffusion, and enhances economic resilience amid global change (Chesbrough & Bogers, 2014). In the years ahead, this capacity to transcend organizational and sectoral boundaries through collaboration will remain a decisive factor in ensuring both the competitiveness and sustainability of innovation ecosystems.

3. Development of the IES Concept

The origins of the IES concept can be traced to theories on national innovation systems and the notion of the business ecosystem (Moore, 1993). In today's landscape, the development of IES relies on linking local capacities with global flows, embracing digital transformation, and promoting open innovation-recognized as key drivers of sustainable economic growth.

The IES refers to a dynamic web of interlinked participants, resources, and processes that collaborate to foster the creation and commercialization of new ideas. IES represent complex, geographically embedded entities where research institutions, entrepreneurs, business enterprises, investors, and the public sector engage in joint activities based on aligned interests and complementary resources. This inter-institutional connectivity contributes to the development of a resilient social infrastructure founded on mutual trust, thereby enabling accelerated knowledge exchange, efficient resource allocation, and the promotion of collective progress (Budden & Murray, 2025).

Drawing inspiration from the functioning of natural ecosystems, the central actors within the IES include entrepreneurs, academic researchers, early-stage ventures, universities, investors, established companies, public agencies, and market intermediaries. Within this constantly evolving framework, innovations emerge through intensive exchange and collaboration among these diverse stakeholders (Davis et al., 2023).

According to Adner (2017), the IES can be understood as an organized structural setting in which the coordination of activities and the management of interdependencies play a decisive role in achieving innovation outcomes. The performance of individual firms is only part of the equation; equally important is the quality of relationships and collaborative mechanisms that bind the ecosystem together. With the rise of digital technologies, the IES has been reshaped to enable novel forms of cooperation and value creation by integrating digital platforms with physical infrastructures (Nambisan et al., 2018). Jacobides et al. (2018) emphasize the evolutionary and network-driven nature of IES, highlighting the diversity of roles assumed by its actors and the importance of leadership in orchestrating collective action.

Unlike national or regional innovation systems, which are typically anchored in institutional frameworks and formalized collaboration at the policy level, IES tend to be more fluid and practice-driven. They bring together startups, accelerators, investors, and end users into interactive communities characterized by horizontal connections and informal knowledge-sharing mechanisms (Granstrand & Holgersson, 2020). Operating across multiple levels and often extending beyond national borders, IES connect local clusters with global networks, offering enhanced flexibility and adaptive capacity to address complex societal and technological challenges (OECD, 2019).

Contemporary innovation policies across the EU are increasingly embracing the concept of IES as dynamic constellations of actors, resources, and interlinked relationships. Since 2007, major international organizations-including the OECD and the World Bank-have integrated ecosystem-oriented perspectives into their innovation policy frameworks, highlighting the importance of connectivity, collaboration, and stakeholder interaction. Flagship EU initiatives such as *Horizon Europe* (2021–2027), with a budget surpassing €95 billion, and the *European Green Deal,* which envisions achieving climate neutrality by 2050, illustrate a decisive shift toward mission-driven innovation that prioritizes green and digital transitions. These strategies are primarily grounded in the 3TH model-linking universities, industry, and government-while increasingly incorporating elements of the 4QH by recognizing citizens and civil society as proactive participants in innovation processes. However, despite political discourse emphasizing inclusiveness and sustainability, implementation practices often reveal persistent gaps. Citizens are still too frequently positioned as passive beneficiaries rather than active co-creators, and sustainability tends to be interpreted narrowly through a technological lens, neglecting wider social dimensions. Bridging this gap requires reinforcing institutional capacities and developing participatory mechanisms that genuinely enable all stakeholders to contribute within the IES framework.

In the global context, growing scholarly attention has been directed toward China's innovation ecosystem, reflecting the country's exceptional achievements in international economic performance. China's IES is underpinned by a strong state-led policy framework, agile industrial structures, and rapidly expanding academic capabilities, with artificial intelligence technologies playing a pivotal role in shaping innovation outcomes (Zhu, 2024). Increasingly, Chinese enterprises are forming strategic alliances and partnerships aimed at accelerating the development of indigenous AI tools, illustrating a localized and adaptive manifestation of helix-based innovation dynamics (Reuters, 2025).

The strength of innovation IES lies in their ability to generate synergies through open innovation practices and self-regulating feedback loops. Physical proximity, as exemplified by innovation districts, accelerates knowledge transfer, while blended public and private funding supports the scaling of innovations and the integration of global resources (Pereira & Bittencourt, 2025). IES function as layered systems in which collaboration, institutional support, digital connectivity, and continuous adaptation form the pillars of long-term viability. In this context, success is defined by the ecosystem's collective performance rather than by individual achievements.

In the contemporary economy, IES are positioned as essential mechanisms for driving economic growth and securing competitive advantage. Their capacity to foster interfirm collaboration, facilitate knowledge exchange, and stimulate technological

development has made them a focal point of interest among scholars and practitioners. Within technology-driven markets, companies rely on product innovation as a strategic tool for accessing new markets and business opportunities, focusing their efforts on identifying and developing innovative solutions. Accordingly, industrial sectors are placing growing emphasis on the institutional promotion of ecosystems that enable cooperation and the creation of added value among key stakeholders (Sotirofski, 2024).

Discussion

Knowledge transfer within the 3TH model occurs through networks and collaborative channels that integrate both formal and informal information flows. The model enables two-way knowledge exchange between universities, industry, and government, thereby facilitating more rapid adaptation and practical application of innovations (Etzkowitz & Leydesdorff, 1996). Industry leverages scientific knowledge to develop products and services, while government provides the regulatory framework and financial support necessary for further development. Digital infrastructure and modern tools further reinforce this process, enabling global connectivity and interactive real-time communication (Carayannis & Campbell, 2009). In this way, knowledge is not only efficiently exchanged but also continuously refined and enriched through feedback loops and joint co-creation.

The functions of the 3TH model in innovation processes are reflected in its capacity to enhance synergy among diverse actors, eliminate barriers, and accelerate innovation cycles. By combining resources, expertise, and experience, the model creates conditions for innovations that arise spontaneously or through unexpected combinations of existing ideas and technologies-outcomes that would be unlikely within isolated sectors. The role of the state as mediator and regulator ensures the sustainability and inclusiveness of innovation processes. As a networked system, the 3TH model fosters rapid learning through collaboration and proximity among key actors. Participants are encouraged to approach knowledge creation and commercialization from their respective perspectives, representing three interconnected domains of equal importance within the national innovation network. Moreover, the model promotes active engagement in an open environment where knowledge and innovations circulate freely.

A fundamental novelty introduced by the 3TH model-which has made an undeniable contribution to the evolution of innovation ecosystems-is based on two key postulates: system openness and the balance between differentiation and integration (Xue & Gao, 2022). System openness introduces the principle of *equifinality*, which suggests that desired outcomes can be achieved regardless of initial conditions, provided that innovative approaches to problem definition and solution-seeking are adopted. This principle implies that developmental success is not exclusively determined by starting circumstances. In essence, it enables economically less developed environments to improve their performance by enhancing their capacity for innovation.

Maintaining the balance between differentiation and integration requires an open environment in which intentions and knowledge circulate freely, fostering the emergence of new ideas and their transformation into innovations, driven by principles of mutual support and collaborative engagement (Cai & Lattu, 2022). The 3TH framework

emphasizes the interaction among universities, industry, and government, leading to the affirmation of hybrid organizations and multi-layered innovation networks.

The 4QH model refers to civil society, whose core components include culture and media. Culture, as an element of civil society, encompasses shared value systems, prevailing attitudes, and foundational assumptions held by members of the community. By nature, culture is collective rather than individual, yet it is not universal-it reflects the norms and values accepted by the majority within a given society (Cao et al., 2025). Culture is internalized through socialization processes and expressed through behavior, manifesting in organizational routines, communication styles, and innovation practices. An organization's innovation culture is profoundly shaped by the environment in which it operates, including the broader socio-cultural context and dominant value systems (Boneto et al., 2022).

In any society, this culture must emerge from the ways in which its economic foundations-primarily enterprises-function. To remain competitive and advance, enterprises must be capable of offering new products, processes, technologies, organizational approaches, business models, and managerial practices aligned with contemporary realities. The 4QH model is closely linked to the rise of digitalization and the expansion of digital capital in contemporary society. The ubiquitous use of digital technologies has brought profound changes to human interaction. Advances in this domain have enabled entirely new modes of collaboration and communication among economic and social actors, reshaping social structures in ways reminiscent of the industrial and digital revolutions of the 19th and 20th centuries (Ochoa Pacheco & Coello-Montesel, 2023).

Research increasingly confirms that civil society plays a critical role in ensuring socially responsible innovation and promoting diverse participation in knowledge creation within IES. In this light, the 4QH framework becomes a vital instrument for inclusive innovation, incorporating not only universities, enterprises, and government but also the public as genuine agents of change. By doing so, the 4QH model fosters social legitimacy and cultural coherence through participatory collaboration and iterative feedback. However, the model is not without limitations. A notable weakness lies in its methodological foundations, particularly the lack of robust quantitative metrics. Critics argue that the inclusion of an additional helix without clearly defined theoretical justification may render the role of civil society conceptually ambiguous (Cai & Lattu, 2022).

By leveraging the synergistic potential of the 5QH model, a sustainable knowledge-based society is envisioned-one that operates in harmony with nature. Innovation has emerged as a central catalyst for advancing sustainable development, with collaboration among ecosystem participants recognized as a foundational condition for its realization. Within the 5QH framework, intermediary entities serve a strategic function by forging connections and enabling institutional partnerships. Through their integrative role, these actors support the dissemination of innovative practices and contribute meaningfully to the establishment of resilient innovation ecosystems aligned with the objectives of sustainable development (Turkina, 2023).

Achieving sustainability requires that each subsystem possess specific forms of capital necessary for networked functioning, knowledge generation, and innovation commercialization. The 5QH model not only links innovation with ecological factors

but also promotes the principles of the green economy and circular economy as central to sustainable development. The integration of ecological components ensures that innovations are socially and economically sustainable, emphasizing responsible natural resource management, environmental protection, and biodiversity (Meshram, 2024). In short, incorporating the logic of the 5QH model into IES reflects a deliberate consideration of environmental imperatives, underscoring the role of environmentally sustainable innovation, circular economy principles, and climate resilience as key dimensions for addressing global ecological challenges.

The model presupposes that each of the five segments possesses the resources necessary for generating scientifically and socially relevant knowledge. Knowledge functions as both input and output within interconnected subsystems, enabling continuous circulation that creates favorable conditions for its valorization through innovation (Carayannis et al., 2022). By linking economic activity with ecological management through the coordinated efforts of actors within the 5QH model, IES activities are aligned with the United Nations Sustainable Development Goals.

The integration of different helix models enables IES to evolve into globally connected networks of knowledge and innovation, capable of addressing the multifaceted demands of contemporary society. Table 1 presents the key actors, the main focus of the helix models, and their impact on the development of IES.

In the 3TH model, the existence of democracy is not inherently necessary for knowledge production and innovation; however, the 4QH model explicitly incorporates democratic principles. Its construction, design, and architecture clearly demonstrate that a 4QH innovation system cannot function without a democratic context. Media and culture-based public spheres provide a democratic lens through which knowledge creation and innovation are interpreted and legitimized. The 5QH model extends the 4QH by integrating elements of the natural environment, social ecology, and the socio-ecological transition, thereby deepening the systemic scope of innovation ecosystems.

Table 1: Key Actors, Main Focus of Helix Models, and Impact on IES

Model	Key Actors	Focus	Key Impact on IES
3TH	University, Industry, Government	Innovation through actor collaboration	Increasing innovation capacity through joint projects. Development of research centers and incubators. Government incentives accelerate market entry of innovations.
4QH	+ Civil society	Inclusiveness, social legitimacy	Innovations adapted to user needs. Greater social acceptance and reduced risk of failure. Media accelerates innovation diffusion. Increased transparency and social responsibility.
5QH	+ Natural environment	Sustainability	Steering innovations toward sustainable development. Development of green technologies and circular economy. Linking economic growth and resource conservation. Response to ecological and climate challenges.

Source: Authors

Although the 3TH, 4QH, and 5QH models provide a robust theoretical framework for the development of IES, their implementation is not universally successful. In contexts characterized by authoritarian regimes and weak institutions, the fundamental assumptions of these models are undermined, leading to limitations in their functionality and effectiveness. In authoritarian regimes, the state often assumes a dominant role in innovation processes, suppressing the autonomy of universities, industry, and civil society. Instead of horizontal collaboration and knowledge exchange, vertical control prevails, where innovations are directed toward political objectives rather than societal needs. Universities become instrumentalized, industry is subordinated to state interests, and civil society is often marginalized or repressed. Such a structure prevents the formation of synergies among actors, which is crucial for the successful functioning of helix models.

In addition to political constraints, weak institutions further complicate the application of the helix approach. In countries with low levels of institutional capacity, problems such as corruption, lack of transparency, inefficient administration, and legal insecurity are prevalent. These factors undermine trust among actors and hinder the coordination of innovation activities. Without stable and reliable institutions providing a framework for collaboration, helix models remain theoretical constructs with limited practical applicability. Similar findings are confirmed by recent research, which shows that the rationalist approach of the 3TH model often conflicts with local governance structures and cultural norms, particularly in contexts where state dominance suppresses the possibility of horizontal collaboration (Agbebia et al., 2024).

Within the 4QH framework, civil society emerges as the fourth dimension complementing academia, industry, and government. Civil society organizations play a vital role in empowering citizens to engage actively in public policy debates, innovation processes, and broader social transformation. They serve as watchdogs of institutional performance, advocate for transparency and accountability, and safeguard collective interests. By engaging a diversity of social groups, civil society ensures that innovation remains socially grounded, addressing real community needs and producing outcomes beneficial to society as a whole. This sphere also includes the media, arts, and cultural sectors, which influence public perception, stimulate critical dialogue, and foster creative approaches to societal challenges (Cvetanović et al., 2025).

The 4QH model has found growing application in the context of regional development, providing a platform for inclusive participation and multi-sectoral collaboration. Building upon this, the 5QH model extends the framework by recognizing the natural environment as an equal and active stakeholder. The inclusion of this ecological dimension strengthens the sustainability of innovation processes and enhances the overall capacity of IES to respond effectively to complex challenges facing contemporary societies.

Table 2: Comparative Framework for 4QH and 5QH Models: Scandinavian Countries vs. Southeast European Countries

Dimension	Scandinavian countries	Southeast European countries	Indicators
Institutional Collaboration	Stable clusters, PPP models, joint R&D programs	Project-based, weak institutionalization	Joint projects, clusters, co-patents
Civil Society (4QH)	Active, participatory, focused on sustainability	Limited involvement, top-down innovation	Platforms, engagement, co-creation
Environmental Sustainability (5QH)	Green innovation central to policy	Secondary priority, fragmented implementation	Green index, eco R&D, ecological footprint
Knowledge Transfer	Universities as innovation brokers	Weak absorption capacity in industry	Co-publications, spin-offs, patent citations
Innovation Governance	Stable, long-term, transparent policies	Unstable frameworks, reliant on EU funding	Policy continuity, R&D % of GDP
Social & Cultural Context	High trust, collaborative, egalitarian	Low trust, fragmented, weak coordination	Social capital, collaboration attitudes

Source: Authors

The degree to which these key attributes have been implemented is illustrated in Table 2, which presents a comparative analysis of two European regions: Scandinavia-where IES are highly advanced-and Southeast Europe, where significant developmental gaps remain. The comparative framework highlights both quantitative and qualitative indicators that help assess the maturity and effectiveness of IES in the observed regions.

A comparative examination of the 4QH and 5QH dimensions across Scandinavian and Southeast European regions reveals substantial disparities in the maturity of IES. Scandinavian countries display strong institutional cooperation, an active and engaged civil society, and well-integrated environmental policies-all of which contribute to sustainable and inclusive innovation development.

In contrast, Southeast European nations continue to grapple with challenges such as fragile institutional frameworks, limited civic engagement, and insufficiently developed mechanisms for knowledge transfer and ecological sustainability. These observations underscore that the effective implementation of helix models within modern IES requires more than the formal adoption of conceptual frameworks. It calls for a genuinely democratic environment, well-functioning institutions, and a societal openness that encourages participation from a diverse range of actors.

Absent these foundational conditions, helix models risk remaining largely declarative-symbolic rather than transformative-failing to exert tangible influence on social and economic progress. Future research should therefore focus on developing measurable indicators to assess the performance and impact of helix models in various contexts, as well as on identifying policy measures that advance inclusive and sustainable innovation practices.

Research Limitations

While this paper enriches the theoretical and conceptual understanding of helix models and their significance for the evolution of IES, several methodological constraints must be recognized. The study relies primarily on a qualitative approach and on secondary data analysis, without empirical testing to validate the underlying assumptions or to enable a quantitative evaluation of actor relationships. Although this method allows for an in-depth and interpretative exploration of the topic, it limits the generalizability of the conclusions.

Moreover, the reference materials, academic works, policy strategies, and institutional reports, reflect the particular standpoints of influential stakeholders such as the OECD and the European Commission. These perspectives may introduce certain biases in the portrayal of institutional realities. Additionally, while the comparative exploration of the 4QH and 5QHmodels in differing regional contexts (e.g., Scandinavia and Southeast Europe) provides valuable conceptual direction, it has not yet been empirically tested.

To address these gaps, future studies should adopt a mixed-methods approach that combines qualitative and quantitative techniques, incorporates comparative case studies, and applies empirical indicators to verify and operationalize the proposed conceptual framework. Such an approach would foster a more holistic understanding of both the practical applicability and the effectiveness of helix models in shaping and advancing innovation ecosystems.

Conclusion

The functioning of contemporary IES is predominantly based on the integration of the key characteristics of the 3TH, 4QH, and 5QH models. The 3TH model emphasizes synergistic collaboration among universities, industry, and government, enabling efficient knowledge exchange and accelerating innovation. The 4QH model extends this framework by incorporating civil society and users as active participants, directing innovations toward real societal needs and ensuring their social legitimacy. The 5QH model further integrates the natural environment and sustainability principles, highlighting the necessity for environmentally responsible innovations and contributions to the circular economy. Together, these models offer a holistic and evolutionary approach to understanding the “physiology” of contemporary IES.

Through the development of an integrated conceptual framework, this paper demonstrates that the contribution of the helix approach to the development of IES lies not only in expanding the number of actors but also in their interdependence, capacity to generate synergy, and ability to address challenges of inclusiveness and sustainability. By analyzing strategic documents of international organizations and existing theoretical approaches, key points of tension in institutional practices, as well as potentials for improving the quality of IES functioning, have been identified. The proposed framework provides not only a theoretical systematization but also practical guidelines for designing IES that incorporate a broader range of social and ecological requirements. The aim of the framework is to systematize existing helix approaches and offer a new perspective

that allows a deeper understanding of the role of various actors in the development of IES.

In future research, this model can serve as a basis for comparative analyses of IES at national and local levels, as well as for the development of new helix configurations that integrate digital technologies, cultural sectors, or the specificities of local communities as equal actors in the complex processes of knowledge creation, transfer, and commercialization.

Future research should aim to conduct comparative case studies examining the practical implementation of the 4QH and 5QH models within the contexts of Scandinavia and Southeast Europe. In addition, developing conceptual maps or correlation diagrams that visualize the interconnections among key actors within IES would provide valuable analytical insight. Such efforts would not only facilitate the empirical validation of the theoretical framework proposed in this study but also enhance its practical applicability in the formulation and refinement of innovation policy strategies.

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