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Triple and Quadruple Helix Models: Strategies of Saudi Universities to Foster Innovation, Entrepreneurship, and Technology Localization

Rana Abdullah Alghamdi [1,2]
[1] *Department of Chemistry, Faculty of Sciences,*
King Abdulaziz University, Rabigh, Saudi Arabia; raalghamdi3@kau.edu.sa.
[2] *Regenerative Medicine Unit, King Fahd Medical Research Centre,*
King Abdulaziz University, Jeddah, Saudi Arabia; raalghamdi3@kau.edu.sa.

Abstract. Innovation models such as the Triple Helix, Quadruple Helix, and emerging Quintuple Helix frameworks provide critical lenses for analyzing university–industry–government–society interactions. In Saudi Arabia, these frameworks align closely with the national Vision 2030 agenda to foster a knowledge-based economy. This study investigates the innovation and entrepreneurship strategies of eight Saudi universities, examining their institutional mechanisms such as investment arms, incubators, accelerators, and technology parks. A qualitative case study approach was employed, drawing on publicly available institutional documents and reports from 2022–2025. Key performance indicators, including patent activity, startup initiatives, and societal engagement, were coded and compared across institutions. The findings indicate that while most universities operate primarily within a Triple Helix (TH) framework, some, notably Princess Nourah bint Abdulrahman University, demonstrate elements of Quadruple Helix (QH) integration. Some universities, such as KAUST, have introduced sustainability-focused initiatives (e.g., water and energy research), which can be seen as preliminary steps toward Quintuple Helix (QNH) adoption. The study concludes with recommendations to strengthen civil society and sustainability dimensions. These findings highlight the need for stronger integration of civil society and environmental sustainability within Saudi universities' innovation strategies, with practical implications for policymakers and university leadership.
Keywords: Triple Helix; Quadruple Helix; Quintuple Helix; technology transfer; innovation ecosystem; entrepreneurship; Saudi universities; Vision 2030; artificial intelligence

1. Introduction

1.1. Contextualizing Knowledge Economies and Innovation Systems

Over the past three decades, the global economic paradigm has decisively shifted toward knowledge-based growth, where innovation, research and development (R&D), and entrepreneurship are

fundamental to national productivity and competitiveness [1]. Within this context, the Triple Helix Model (TH) has emerged as a foundational framework, reconceptualizing the role of universities from mere knowledge producers to active co-producers of innovation alongside industry and government. This model emphasizes the creation of hybrid interfaces—such as technology transfer offices (TTOs), incubators, and science parks—that blur traditional sectoral boundaries and foster dynamic interactions [1]. The structure of these interactions is illustrated in Figure 1.

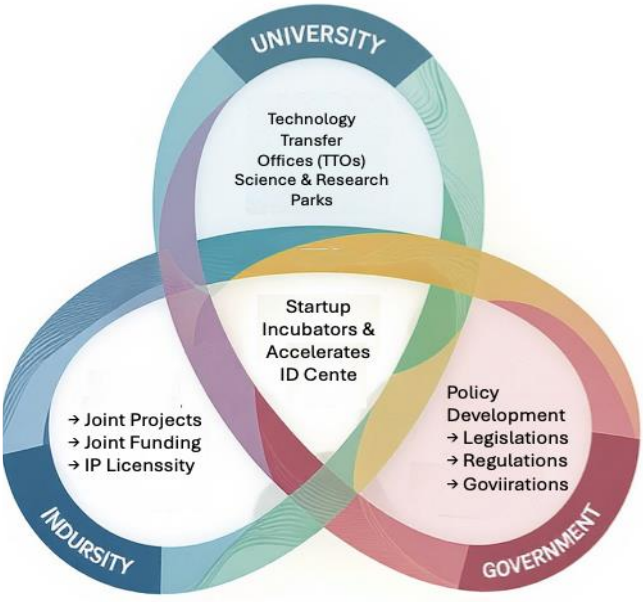

Figure 1: The Triple Helix Model (University-Industry-Government Interaction) driving the Saudi innovation ecosystem under Vision 2030.

While transformative, the TH model has faced critiques for underweighting the role of broader society. In response, the Quadruple Helix Model (QH) was developed, integrating civil society as a fourth, encompassing helix [2]. This expansion emphasizes that sustainable innovation requires more than institutional collaboration; it necessitates user co-creation, public engagement, and cultural and media ecosystems to accelerate the adoption and diffusion of new technologies. Mechanisms such as living labs, public challenge programs, and community partnerships are central to this approach, as shown in Figure 2.

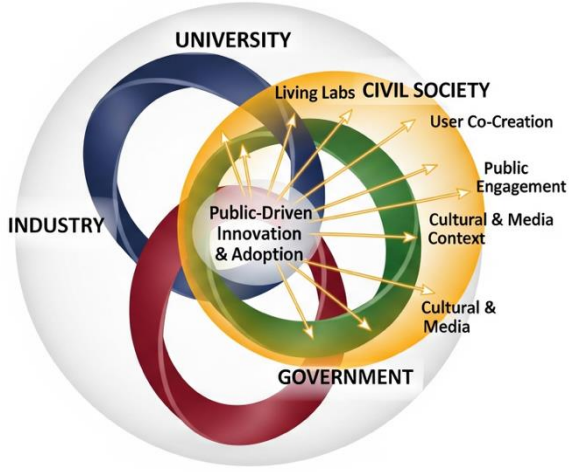

Figure 2: The Quadruple Helix Model, an evolution of the Triple Helix model, emphasizing the role of civil society as a fourth enabling co-creation and driving the adoption of innovation.

1.2. The Imperative of Vision 2030: Innovation, Diversification, and Technology Localization

In Saudi Arabia, this theoretical evolution finds its practical imperative in Vision 2030, which explicitly frames innovation and entrepreneurship as primary levers for economic diversification and Technology Localization [3]. The national strategy creates an urgent need for universities to move beyond traditional roles and actively deploy TH and QH strategies to build a vibrant innovation ecosystem.

This mandate requires institutions to maximize the benefits of modern technologies, facilitate active knowledge transfer, and support the domestic development of advanced technological industries within the Kingdom.

1.3. Research Gap, Contribution, and Structure

The existing literature on innovation ecosystems in the Gulf region largely describes the infrastructure built by universities (e.g., patent numbers, the existence of incubators). However, the current academic body lacks a robust, comparative, and explanatory analysis for the significant divergence in institutional strategies, mandates, and resulting innovation outputs among leading Saudi universities, particularly regarding their positioning within the helix evolution continuum. For example, why does one university achieve global IP volume dominance while another prioritizes venture capitalization or specialized social engagement?

This study moves decisively beyond institutional description by employing a structured analytical framework to explain why institutional differences exist and how the specific operationalization of

helix strategies drives these divergent outcomes. This approach provides necessary academic depth by translating institutional efforts into a comprehensive understanding of innovation ecosystem dynamics in a major emerging economy.

1.4. Theoretical Framework and Literature Review: Expanding Theoretical Grounding

1.4.1. The Foundational TH Model and Hybridization

The TH model, conceptualized by Etzkowitz and Leydesdorff (2000), describes the dynamic, non-linear interactions between three spheres: University, Industry, and Government [1]. Innovation arises from the reciprocal linkages and overlapping roles of these three actors, requiring the establishment of hybrid interfaces such as technology transfer offices and science parks to bridge the gap between academic research and market exploitation [1]. As Lawton Smith and Leydesdorff (2014) note, the effectiveness of the TH model must be assessed within the context of global change and regional dynamics, particularly in emerging economies where state influence is pronounced [4].

1.4.2 The Entrepreneurial University and Academic Entrepreneurship

The operational success of the TH is inextricably linked to the concept of the Entrepreneurial University. Etzkowitz defines this institution not just by its research output, but by its proactive role in economic development, characterized by the capitalization of knowledge, strong ties with industry and government, and permanent evolution of institutional relationships [1]. Becoming an entrepreneurial university provides regions with access to skilled graduates and can attract venture capital investment [5].

Academic entrepreneurship—the formation of spin-outs, licensing, and knowledge transfer—is the mechanism by which universities generate economic impact [6]. However, researcher argue that institutions prioritizing the entrepreneurial dimension of technology transfer must actively address skill deficiencies among TTO staff and academic researchers [7,8].

The integration of entrepreneurship education is essential for building entrepreneurial competency [9]. Universities are expanding their educational capabilities beyond educating individuals to ‘Universities are extending their role by supporting not only individual students but also start-ups and companies through incubator programs and specialized training [10]. These efforts, which focus on knowledge and cognitive learning, shifts in attitudes, and changes in behavior [11], are vital to professionalize the transfer process and ensure that the talent pipeline supports the localization mandate.

1.4.3. Evolution to Quadruple and Quintuple Helix Models

QH Model: Societal Inclusion and Normative Critique

The expansion to the QH, integrating Civil Society (the media- and culture-based public), emphasizes democratic knowledge production and human-centered innovation [2,12].

However, the academic literature highlights a persistent challenge: the normative claims of the QH model often remain highly theoretical, offering limited guidance on practical implementation or

defining the actual, measurable roles of the Fourth Helix actors [13,14]. Analyzing PNU's targeted approach provides a valuable empirical case study for overcoming this conceptual vagueness.

Quintuple Helix Model (QNH): The Sustainability Imperative

The Quintuple Helix Model (QNH) further expands the framework by incorporating the Natural Environment (or ecological subsystem) [2,15].

Carayannis and Campbell (2010) identified the environmental helix as the critical "missing link" for future innovation systems [2].

Recent bibliometric studies confirm a significant increase in publications focusing on the QH and QNH models, particularly since 2020, linking them directly to sustainability, policy, and territorial development [16,17].

The adoption of QNH is driven by the global requirement for sustainable development and eco-innovation, a necessity reinforced by national policies like the Saudi Green Initiative [5] and the national RDI priority area of 'Sustainable Environment and Supply of Essential Needs' [18].

1.5. Helix Models and the Localization Mandate in Emerging Economies

For nations like Saudi Arabia, innovation systems are characterized by strong governmental steering. Here, the helix models serve primarily as strategic tools for localization. The fundamental purpose of the university-industry-government exchange, facilitated by hybrid entities, is to accelerate the domestic adoption and production of technology. This strategic goal is directly reflected in the institutional mandates of investment arms like Wadi Jeddah [19] and Riyadh Valley Company [6,20], which are explicitly tasked with maximizing the benefits of modern technologies and supporting the localization of advanced technology industries within the Kingdom.

2. Methods

2.1. Research Design: Qualitative Multi-Case Study Approach

This study employs a qualitative, multi-case study research design to analyze the strategic application and operationalization of TH and QH models by eight leading Saudi universities. A purely quantitative approach is insufficient to understand the nuanced institutional strategies. The qualitative case study approach allows for an in-depth analysis of institutional documents, providing crucial context regarding strategic mandates, resource allocation, and the practical "mechanism" of helix interactions, which are essential for moving the analysis beyond mere description toward rigorous academic explanation.

Case Selection Rationale: The eight universities were selected based on three criteria: (1) demonstrable TH infrastructure (e.g., Wadi Jeddah [19], Riyadh Valley Company (RVC) [20], Dhahran Techno Valley (DTV) [21]) ; (2) institutional prominence and the availability of public data detailing their innovation activities (2022–2025); and (3) diversity in institutional mandate or sectoral focus (e.g., specialized technology institutions versus those with explicit QH approaches [21].

2.2. Data Collection and Sources

Institutional data was systematically collected from publicly available institutional documents, official university websites, and national policy reports spanning the academic years 2022–2025.

The primary data corpus included:

- Official university annual reports, highlighting R&D expenditure and technology transfer statistics.

- Strategic plans and innovation center reports detailing program structures (e.g., PNU's CODE Lab [22], KFUPM's DTV [23]).

- Publicly available information from hybrid entities, such as the mission statements of Wadi Jeddah [19] and Riyadh Valley Company [20].

- National policy documents, including Vision 2030 updates [23] and RDIA reports on national RDI priorities (Health, Sustainability, Energy, Future Economies) [18].

2.3. Analytical Framework Procedures

A thematic content analysis was applied to the documents to identify evidence of Triple, Quadruple, and Quintuple Helix application for explanatory analysis, a multi-stage thematic content analysis was applied to the collected institutional documents, based on the theoretical evolution of the helix models (TH → QH → QNH).

Analytical Framework: The framework posits that divergence in innovation performance is attributable to differences in (1) explicit institutional mandates and strategic prioritization and (2) the specific institutional mechanisms (hybrid interfaces) employed for helix interaction.

Analytical Strategy (Thematic Content Analysis): Document analysis proceeded through three levels:

Level 1 (Descriptive): Identifying explicit mentions of key institutional mechanisms, such as designated investment arms RVC [20], specialized research parks DTV [21], and centers dedicated to societal engagement (PNU's Innovation & Entrepreneurship Center [24]). This provided the baseline description of the infrastructure.

Level 2 (Axial/Categorical): Mapping the function and stated goals of these mechanisms to the theoretical Helix Categories:

TH Evidence: for elements relating to technology exploitation, industry partnerships, intellectual property protection, and joint venture grants (e.g., matching funds required for DTV collaborative grants [21]).

QH Evidence: for strategies explicitly addressing civil society, public engagement, specific demographic empowerment, or media/cultural interaction (e.g., PNU's empowerment of women innovators [24]).

QNH Evidence: for dedicated research in environmental conservation, water, renewable energy, and explicit strategic alignment with the national RDI priority pillar on Sustainable Environment and Essential Needs [18].

Quantitative Integration: Quantitative output data, specifically U.S. patent counts (as detailed in Table 1), was incorporated not as an end, but as a robust proxy metric of the success of the TH/Exploitation phase. The function of the analysis then became to provide a qualitative, explanatory narrative for the significant variation in this proxy metric across institutions.

3. Results

The analysis of eight leading Saudi universities demonstrates that while all have successfully built foundations for TH interaction, their strategies, infrastructure, and measurable outputs display marked institutional divergence, particularly in the realm of intellectual property (IP) intensity and the nascent adoption of higher-order helix models.

3.1. Core TH Infrastructure and Strategic Alignment

All major case study universities have operationalized the TH through the establishment of specialized hybrid entities, confirming the fundamental role of institutional hybridization in the Saudi ecosystem [25].

King Abdulaziz University (KAU) channels its strategy through Wadi Jeddah, an investment and innovation arm structured as a hybrid organization dedicated to supporting knowledge-based ventures and commercialization [19,26].

King Saud University (KSU) employs a similar strategy via the Riyadh Valley Company (RVC), its dedicated investment arm, whose core mandate is to contribute to the knowledge economy through commercial partnerships and investment in joint projects [6,20].

King Fahd University of Petroleum & Minerals (KFUPM) utilizes the Dhahran Techno Valley (DTV). DTV is a major, intensive TH interface, specializing specifically in energy, sustainability, and industrial innovation.[5]
It boasts significant outputs, including over 950 recorded technology transfer outcomes [21,27].

3.2. Patent Performance and Institutional Divergence

The data on measurable intellectual property output reveals significant, non-uniform growth across the sector, highlighting strategic institutional choices. Table 1 summarizes the patent metrics and strategic focus of the Saudi universities by the National Academy of Inventors (NAI) which has released the 2024 Top 100 Worldwide Universities Granted U.S. Utility Patents List [28]. The data shows that King Faisal University (KFU) secured 631 U.S. utility patents in 2024, achieving 1st place worldwide in the National Academy of Inventors (NAI) rankings. This dominance requires an

explanatory narrative linking strategic mandates to resource deployment, which is the focus of the Discussion section.

Table 1. Innovation Metrics and Infrastructure of Select Saudi Universities (2023-2024)

University	U.S. Patents (2024)	Global Rank (NAI*, 2024)	Key Infrastructure & Programs	Strategic Focus
KFU	631	1	KFUID [29]	Global IP leadership
KFUPM	265	5	DTV Startup Challenge [21]	Energy & IP intensity
IAU	141	15	Entrepreneurship programs [32].	Emerging IP contributor
KSU	56	64	RVC Entrepreneurship Institute [20]	Early investment & IP
PMU	40	93	University incubators [30]	Expanding capacity

* National Academy of Inventors

3.3. Early QH and QNH Integration

Targeted integration of higher-order helix models is visible in specific cases:

- **QH** Integration: PNU provides the clearest evidence of operationalizing the **QH**. PNU's institutional strategy explicitly engages civil society by focusing on a specific segment: empowering women innovators [24]. Mechanisms like the Innovation & Entrepreneurship Center and the CODE Lab [22] are designed to support female students and university affiliates in transforming ideas into projects, directly fulfilling the theoretical mandate of societal inclusion.

- Beyond PNU, other Saudi universities demonstrate civil society engagement through different mechanisms. KAU has articulated its commitment to "effective community initiatives" as part of its mission to build a competitive knowledge society [25]**.** The university aims to contribute to society through knowledge development, research, innovation, and leadership**.** KSU has engaged with civil society through initiatives such as its Deanship of Community Service and Continuing Education, established to facilitate community engagement and public education [31]**.** More recently, KSU partnered with the Saudi Data and AI Authority to launch a series of public scientific lectures on data and artificial intelligence technologies, demonstrating ongoing commitment to public knowledge dissemination [31]**.** Additionally, Saudi universities have embraced digital democratization of knowledge through Massive Open Online Courses (MOOCs). The Saudi Ministry of Labor partnered with edX to launch a MOOC portal designed to deliver vocational and employability skills to diverse audiences including women, youth, and rural communities [32]**.** Saudi universities including KSU, KFU of Petroleum and Minerals, Taibah University, and PNU offer free online courses accessible to the broader public, reflecting societal engagement beyond traditional academic boundaries [33]**.**

- QNH Signals: Early signs of QNH adoption, driven by the sustainability imperative, are emerging. KAUST has strategically re-focused its research to explicitly align with Vision 2030's RDI priorities, which include the critical areas of water, energy, and the environment [34–36]. The KAUST Research & Technology Park and the TAQADAM accelerator create a comprehensive support system that provides a pipeline from fundamental discovery to startups and industry partnerships [35,37].

This evolution is conceptually mapped in the Helix Evolution Ladder (Figure 3), where most universities remain at the TH stage, PNU has extended onto the QH rung, and institutions like KAUST show early QNH adoption.

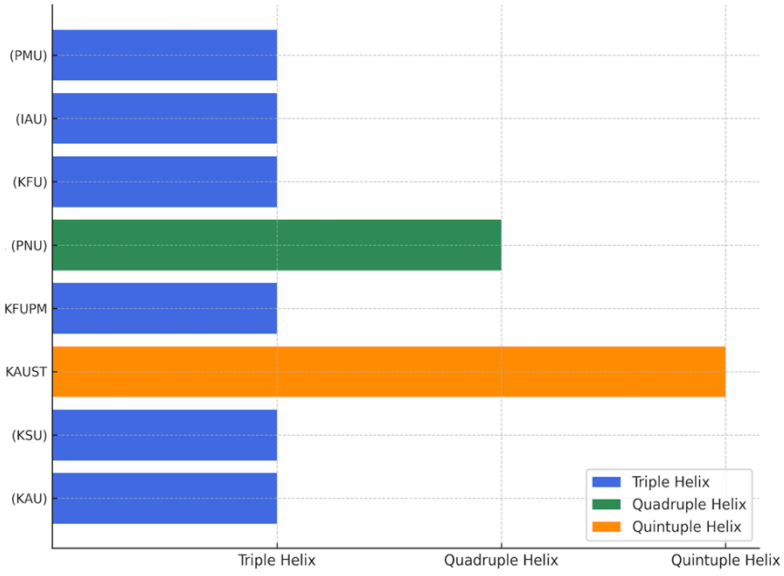

Figure 3. Helix Evolution Ladder showing positioning of Saudi universities within Triple, Quadruple, and Quintuple Helix frameworks.

4. Discussion

4.1. Explaining Institutional Divergence and Strategic Application

The primary objective of this study is to provide a rigorous explanation for the observable institutional divergence, particularly in output metrics like patent volume. and to elucidate the institutional mechanisms employed to operationalize the Quadruple and Quintuple Helix frameworks. This methodological approach transcends mere descriptive reporting by focusing on the underlying drivers of success and divergence in specific institutional contexts. The vast disparities in annual patent outputs (e.g., KFU's 631 patents versus KSU's 56) are not primarily attributable to fundamental research quality differences. Rather, they reflect deliberate and divergent institutional mandates regarding the purpose of intellectual property.

4.1.1. Strategic Divergence in TH Application (KFU vs. KSU/KAU)

The notable patent success of King Faisal University (KFU) is a reflection of an explicit institutional mandate to prioritize IP volume and global rankings [29]. KFU's strategy involved the deliberate development of "efficient legislation for scientific research" and dedicated resources specifically calibrated to encourage creative research that leads to international patents [38]. This constitutes a highly effective, yet specialized, TH *exploitation* strategy, focused on maximizing easily measurable global output metrics (IP registration).

In contrast, the universities whose TH efforts are channeled primarily through investment arms (KAU's Wadi Jeddah and KSU's Riyadh Valley Company) pursue a TH commercialization strategy. For these institutions, the end goal is not the patent count itself, but venture formation, investment in knowledge economy projects, and ultimately, technology localization outcomes. KFU's success, therefore, serves as an example of strategic institutional planning tailored to maximize IP registration, distinguishing it from peers that prioritize broader, qualitative economic development metrics like venture capital return or localization impact.

4.1.2. Sectoral Concentration and Focused TH (KFUPM)

King Fahd University of Petroleum & Minerals (KFUPM) exhibits a high patent count (265) and technology transfer rate (nearly 1,000 outcomes) [20] rooted in its historical and geographic legacy in the energy and industrials sector. The Dhahran Techno Valley (DTV) is a specialized TH physical cluster dedicated to energy, sustainability, and associated technologies [21].

The intensive nature of KFUPM's TH is structurally embedded in its collaboration models. For instance, the Dhahran Techno Valley Collaborative Research Grants require an equivalent amount of matching funding (cash or in-kind) from the DTV company partner [39]. This requirement enforces a deeply embedded, co-funded, and demand-driven TH relationship, ensuring that research outputs are directly aligned with industrial needs and market application, thus driving rapid and specialized technology transfer outcomes in fields critical to national energy and industrial leadership.

4.2. Operationalizing the Quadruple Helix: Targeted Societal Engagement

The theoretical definition of the Fourth Helix (civil society) has often been criticized for being abstract, lacking clear implementation guidance [12]. PNU provides a compelling model for overcoming this ambiguity through a pragmatic, targeted QH strategy.

Instead of engaging "civil society" generally, PNU defines its Fourth Helix engagement specifically as the empowerment of female students and entrepreneurs.[15] Through mechanisms like the Innovation & Entrepreneurship Center and dedicated CODE Labs [12], the university facilitates women-led innovation and digital entrepreneurship.

This targeted strategy directly addresses two major national policy objectives simultaneously: the theoretical mandate of democratic, human-centered knowledge creation (QH theory) and the practical Vision 2030 goal of increasing women's participation in the labor market and entrepreneurship [3,23].

4.3. The Quintuple Helix as a Policy Response: Alignment with Saudi RDI Priorities

The emerging institutional focus on Quintuple Helix (QNH) elements [15] (the Natural Environment/Sustainability) is not an organic evolution of academic interest alone. Rather it is a direct, top-down policy imperative flowing from the national Research, Development, and Innovation Authority (RDIA) strategy [18].

The RDIA framework mandates research in four national priority areas, including "Sustainable Environment and Supply of Essential Needs"[18]. This mandate is driven by critical national challenges, such as being one of the world's most water-stressed nations and experiencing temperature increases at twice the global average. Leading institutions like KAUST have strategically responded, evolving their research models to explicitly align with these RDI pillars, focusing on water, food, energy, and environmental conservation [34,35,37].

Chaaben et al. (2024) confirmed that the QNH model is an appropriate framework to assess Saudi Arabia's green economy performance [34,35,37] and progress toward the UN Sustainable Development Goals (SDGs)[40].

This institutional incorporation of environmental sustainability into the innovation ecosystem ensures that the universities' primary role moves beyond simple economic growth toward addressing fundamental national resilience challenges through eco-innovation and sustainable resource management. Table 2 synthesizes these findings, linking the observed strategies and performance outputs to their underlying explanatory institutional drivers.

4.4. Study Limitation

The primary limitation of this study is its reliance on secondary, publicly published institutional reports, which may introduce a positive reporting bias, potentially emphasizing successes over persistent challenges. Furthermore, the assessment of QH strategies is inherently challenging due to the difficulty of uniformly quantifying the success of intangible elements such as civic engagement and democratic knowledge production. [12,41].

Table 2. Explanatory Analysis: Linking Institutional Mandates to Helix Model Application

University Example	Core Helix Model Application	Observed Output/Strategy	Explanatory Rationale (Institutional Mandate/Legacy)	Broader Implication for KSA Ecosystem
KFU	Triple Helix (Exploitation Focus)	Global IP count leadership (631 utility patents)	Explicit, metric-driven mandate to develop efficient legislation and resources for high-volume patent generation	Specialized, quantitative metric driver for national IP ranking.

KFUPM	Triple Helix (Sectoral Intensity)	Dhahran Techno Valley (DTV) co-funding and high technology transfer rate (950+ outcomes)	Historical and geographic legacy in energy sector; mandate for high-impact, industry-matched collaboration	Deep sectoral alignment for localized industrial leadership (Energy & Industrials RDI pillar).
PNU	Quadruple Helix (Targeted Integration)	Dedicated centers supporting women-led innovation	Pragmatic operationalization of QH by defining civil society as a specific segment, fulfilling human capital goals of Vision 2030.[3]	Links social policy goals (women empowerment) directly to innovation output.
KAUST	Quintuple Helix (Policy Alignment)	Research re-focused on RDI pillars: Water, Energy, Environment	Top-down strategic alignment with national RDIA framework to solve critical resource challenges (e.g., water scarcity)	Shifts innovation focus toward national resilience and sustainable development (eco-innovation).

Additional limitations include the temporal scope of the data (2022-2025), which may not capture longer term trends or recent strategic shifts. The study also does not include primary interviews with university administrators, faculty, or industry partners, which would provide deeper insights into the operational challenges and informal mechanisms of helix interactions. The reliance on patent counts as a primary metric may not fully capture other valuable forms of knowledge transfer, such as consulting, informal collaborations, or capacity building activities.

Despite these limitations, the chosen case study design allows for rich contextualization and comparison of the stated strategic mandates, providing substantial academic rigor and a foundation for future longitudinal and mixed-methods research.

4.5. Practical Implications for Policy and Practice

The findings of this study offer several actionable implications for policymakers, university leaders, and innovation managers in Saudi Arabia and similar emerging economies:

For Policymakers:

• Develop differentiated policy frameworks that recognize and support diverse institutional strategies rather than imposing uniform innovation metrics. KFU's IP-focused strategy and KSU's venture focused approach both contribute valuable but different outcomes to the national innovation ecosystem.

• Establish funding mechanisms that explicitly incentivize QH and QNH activities, such as grants for community engagement projects, living labs, and sustainability-focused research that may not generate immediate patent outputs.

• Create national guidelines and benchmarks for measuring civic engagement and environmental impact in university innovation ecosystems, moving beyond traditional metrics like patent counts and licensing revenues.

For University Leaders:

• Strategically align institutional mandates with available resources and regional contexts. Universities should consciously choose between IP exploitation strategies (like KFU) or commercialization/ localization strategies (like KAU and KSU) based on their competitive advantages.

• Establish dedicated units for civil society engagement with clear mandates, resources, and accountability structures, learning from PNU's targeted approach to empowering specific demographic segments.

• Integrate sustainability and environmental considerations into all innovation activities, creating cross-functional teams that link research, technology transfer, and environmental goals.

For Innovation Managers and TTO Professionals:

• Invest in professional development programs that build competencies in entrepreneurship, industry collaboration, and community engagement, addressing the skill gaps identified in the literature.

• Develop hybrid funding models that combine university resources with industry matching funds (as demonstrated by KFUPM's DTV) to ensure market-relevant research outcomes.

• Create systematic processes for documenting and measuring civic engagement and environmental impact alongside traditional metrics, building evidence for the value of QH and QNH activities.

These recommendations are grounded in the empirical findings and theoretical frameworks presented in this study, offering a roadmap for advancing from TH toward more inclusive and sustainable innovation ecosystems.

5. Conclusion and Recommendations

The core analysis confirms that Saudi universities have successfully institutionalized the TH through hybrid entities, although resulting innovation outputs are strategically divergent, prioritizing either high IP exploitation volume (KFU) or deep commercial and sectoral integration (KFUPM, KAU). Crucially, the ecosystem demonstrates advancing maturity by pragmatically translating the abstract QH concept into targeted societal engagement (PNU). To realize the full potential of Vision 2030, the trajectory must embrace the Quintuple Helix as a mandated strategy for resilience and sustainability.

Accordingly, the study advocates for strengthening the system by mandating entrepreneurship education to professionalize technology transfer, formalizing QH mechanisms like "Urban Living Labs" for quantifiable societal impact and leveraging the QNH model for comprehensive alignment with national and global sustainable development objectives.

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R.A has the sole responsibility for the conception of the study, presented results and manuscript preparation. Authors has read and agreed to the published version of the manuscript.

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Appendix
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