

Designing a Technological Innovation Model for Sustainable Development

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ABSTRACT

The objective of this study is to design a comprehensive technological innovation model that supports sustainable development across organizational, environmental, and socio-economic dimensions. This study employed a qualitative research design composed of a systematic meta-synthesis of existing literature and in-depth expert interviews. The meta-synthesis analyzed a wide range of peer-reviewed studies focusing on technological innovation, sustainability, entrepreneurial ecosystems, and organizational capabilities. In the second phase, semi-structured interviews were conducted with eight experts selected through purposive and snowball sampling, continuing until theoretical saturation was reached. Data collection tools included a structured extraction protocol for literature analysis and an interview guide targeting innovation drivers, organizational strategies, socio-environmental considerations, and commercialization mechanisms. Data analysis followed grounded theory procedures, including open, axial, and selective coding, enabling the integration of extracted concepts into a coherent theoretical model. Constant comparative analysis ensured congruence between literature-derived constructs and expert insights. The analysis revealed that technological innovation emerges from the interaction of multiple systemic components, including organizational competence, technological capability, environmental factors, business models, and commercialization processes. Eight axial categories were identified: organizational competence, sustainable development, business model, organizational characteristics, technological innovation capability, environmental factors, commercialization, and infrastructure. These categories converged into four selective constructs: technological innovation input and regulatory indicators, supporting variables for technological innovation, the technological innovation model, and economic, social, and environmental effects. The inferential results indicate that sustainable innovation is dependent on the alignment of human capital, institutional structures, knowledge flows, socio-environmental values, and market mechanisms. The study concludes that technological innovation for sustainable development is inherently multidimensional, requiring integrated organizational structures, supportive governance frameworks, and dynamic interactions among technological, economic, and social factors. The resulting model offers a holistic framework that organizations and policymakers can adopt to facilitate innovation pathways leading to sustainable outcomes.

Keywords: Technological innovation; sustainable development; innovation capability; organizational competence; commercialization; innovation ecosystem; grounded theory.

Introduction

The rapid acceleration of technological change, coupled with intensifying global sustainability challenges, has positioned technological innovation as a critical mechanism for shaping economic competitiveness, social well-being, and environmental resilience in contemporary societies. Over the past decade, innovation ecosystems have



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expanded across sectors and regions, leading to new expectations for firms, universities, and policymakers to adopt strategies that integrate advanced technologies with long-term sustainable development. Scholars argue that the transition toward sustainability-oriented innovation requires more than isolated technological advancements; rather, it demands systemic transformation that aligns organizational capabilities, governance frameworks, knowledge infrastructures, entrepreneurial competencies, and societal priorities into coherent models capable of producing durable and equitable outcomes (1). Within this broader landscape, innovation is no longer conceptualized merely as product creation but as a multidimensional phenomenon influenced by social, institutional, ecological, and digital factors that shape its form and trajectory.

At the heart of these transformations is the recognition that sustainable development cannot be achieved without embedding technological innovation into broader governance mechanisms and urban systems. Contemporary debates in urban studies emphasize that ethical considerations, data governance, and the normative responsibilities of digital transformation are increasingly intertwined with innovation trajectories in cities, particularly in contexts where cultural and religious norms shape the adoption of technology (2). As global challenges become progressively interconnected, the need for models that integrate technological innovation with sustainability-driven governance becomes even more urgent. This complexity underscores the limitations of traditional linear innovation models and calls for new frameworks that account for social innovation, entrepreneurial ecosystems, and the co-production of value among multiple stakeholders.

The expansion of corporate innovation has also been shaped by ecological expectations and the evolution of environmental, social, and governance (ESG) performance standards. Recent research in China suggests that the emergence of the “energy internet” has enhanced organizational capacity to achieve ESG-related objectives by embedding green technological innovation within operational architectures (3). Similarly, studies examining sustainability-oriented technology entrepreneurship highlight the importance of innovation ecosystems in higher education, where universities serve as catalysts for technology-focused entrepreneurial activity by promoting digital literacy, interdisciplinary collaboration, and global innovation networks (4). Such findings point to the central role of institutional architectures in sustaining technology-driven development and demonstrate how innovation extends beyond firms to involve universities, investors, regulators, and civil society.

Social innovation and social entrepreneurship have concurrently emerged as parallel discourses that inform the broader debate on technological innovation for sustainable development. Analyses of global trends in social innovation reveal a growing emphasis on the capacity of communities and institutions to address societal challenges through collective intelligence, inclusive participation, and sustainable values (5). These developments closely align with technological innovation literature that conceptualizes innovation as a complex interplay of competencies, collaboration, and learning capabilities that evolve within dynamic entrepreneurial ecosystems. Indeed, recent systematic analyses show that technological innovation increasingly depends on how regulators, entrepreneurs, and innovators co-construct regulatory imaginaries that shape the pace, direction, and legitimacy of disruptive technologies (6). These imaginaries influence how societies perceive the risks and opportunities associated with emerging technologies, especially when innovation intersects with domain-level ethical concerns.

In corporate contexts, the strategic deployment of technological innovation has profound implications for competitive advantage, market share, and long-term value creation. Various scholars have investigated the internal mechanisms that determine how technological innovation translates into organizational performance. For example, an examination of manufacturing enterprises indicates that digital infrastructure and internet-based platforms play

a crucial role in accelerating innovation outcomes by reducing transaction costs and increasing access to knowledge resources (7). Complementary findings reveal that corporate adoption of green innovation practices helps clarify the broader disputes surrounding corporate social responsibility, demonstrating that environmental strategies can act as mediators between innovation performance and stakeholder expectations (8). These insights confirm that technological innovation is deeply entangled with corporate governance, stakeholder relations, and environmental consciousness.

In developing and emerging economies, however, innovation challenges differ significantly due to institutional gaps, resource limitations, and fragmented ecosystems. Studies on entrepreneurial ecosystems within universities show that several factors inhibit the development of innovation capacity, including regulatory constraints, lack of financial support, limited digital infrastructure, and insufficient linkages between academia and industry (9). Research in sustainable industrial leadership similarly reveals that inadequate competence development and misaligned incentives contribute to weak innovation performance, ultimately limiting firms' ability to contribute to sustainable development (10). These deficiencies underscore the need for innovation models tailored to contextual conditions in developing countries—models that go beyond generic prescriptions and respond to institutional, cultural, and economic realities.

Meanwhile, global discussions on high-technology entrepreneurship emphasize that entrepreneurial competencies, creativity, and innovation capabilities are decisive factors influencing enterprise performance. Studies show that entrepreneurial skills, personal competencies, and strategic thinking strongly enhance the capability to innovate within dynamic and competitive markets (11). Higher education institutions play a central role in cultivating such competencies, as demonstrated by research from Latin America that shows universities can significantly strengthen local innovation ecosystems by fostering entrepreneurial mindsets and nurturing knowledge networks among students and faculty (12). Building on this, investigations into sustainable engineering competencies highlight the growing need for education systems that prepare professionals capable of integrating technological, environmental, and managerial dimensions into innovation practices (13). These findings collectively illustrate the interconnectedness of educational systems, human capital development, and sustainable technological innovation.

On a conceptual level, technological innovation is increasingly seen as part of a dynamic process that integrates cost structures, organizational benefits, and core competencies. Models of the innovation process emphasize that innovation should be viewed not as a singular event but as an iterative cycle influenced by organizational resources, creativity, and strategic direction (14). Complementary research on high-technology SMEs shows that cluster structures and inter-firm cooperation significantly enhance innovation performance by improving knowledge flows, coordination, and collective problem-solving (15). As societies become more digitized, challenges in human-machine interaction further complicate the innovation landscape by introducing new complexities related to robotics, cyber-physical systems, and artificial intelligence, all of which demand new forms of digital competence and organizational adaptation (16).

Another strand of literature has approached technological innovation through the lens of sustainability transitions. Studies suggest that technological innovation systems (TIS) must be analyzed in relation to societal transformation processes, highlighting the role of governance, institutional stability, and systemic interdependencies in transitioning toward sustainable development (1). Related work demonstrates that financial development also interacts with technological innovation to determine environmental outcomes, especially in countries with advanced financial

systems, where investment capacity and technological capability jointly influence emissions and sustainability indicators (17). Similarly, evidence from energy-intensive industries suggests that digital energy systems can significantly improve environmental performance, thereby contributing to large-scale sustainability transitions (3). These results reinforce the idea that technological innovation operates within larger socio-technical systems shaped by regulatory, environmental, and financial constraints.

In the domain of entrepreneurship and social development, competencies for sustainability have emerged as critical enablers of innovation. Findings from developing economies emphasize that social entrepreneurial activities grounded in sustainability competencies can drive inclusive growth, community empowerment, and environmental protection (18). Entrepreneurs operating within innovation ecosystems often rely on resourcefulness, resilience, and community-oriented values to navigate institutional barriers and create sustainable solutions. These insights are complemented by tools designed to assess and develop technological innovation capability using maturity models, which offer structured approaches for evaluating innovation readiness and capability levels within organizations (19). Such tools demonstrate the potential to standardize innovation assessments and guide strategic capability-building.

Technological innovation research has also focused on the design of learning environments that support entrepreneurship and innovation education. Studies rooted in design thinking highlight how educational models can foster creativity, interdisciplinary collaboration, and practical problem-solving skills, which collectively enhance entrepreneurial readiness among learners (20). Parallel research on techno-startup courses in higher education suggests that innovative competence development requires experiential learning, iterative experimentation, and the integration of real-world startup practices into academic curricula (21). These insights underscore the importance of educational innovation as a foundational pillar for technological innovation systems.

Mapping the evolution of innovation processes in the global context has also been achieved through innovation mapping models designed to visualize technological trends, identify innovation clusters, and highlight emerging trajectories. Such models provide systematic approaches for tracking innovation dynamics and understanding how knowledge diffuses across sectors (22). Complementary international studies on technological and sustainable innovation emphasize that sustainable technology integration must align with managerial practices, market needs, environmental standards, and long-term competitiveness (23). Taken together, these insights highlight that technological innovation is deeply connected to both structural and behavioral dimensions of organizational practice.

Finally, scholarship on entrepreneurial competency frameworks demonstrates that innovation within universities and firms depends on the identification and enhancement of specific competency domains, including creativity, strategic awareness, communication skills, and opportunity recognition (24). These competencies play a vital role in shaping how individuals and organizations conceptualize technological innovation and apply it toward sustainable development goals. When combined with systemic models of innovation and sustainability, these perspectives illuminate the diverse mechanisms that underpin technology-driven development and provide a rich foundation for constructing integrative models.

Considering the complexity, diversity, and interconnectedness of the themes addressed in the literature, the present study seeks to design a comprehensive and context-sensitive model that links technological innovation with sustainable development outcomes. Accordingly, the aim of this study is to design a technological innovation model for sustainable development.

Methods and Materials

This research employed a qualitative design grounded in a meta-synthetic systematic review and complemented by expert interviews to ensure conceptual saturation and theoretical depth. The first phase of the study followed a meta-synthesis approach, systematically examining existing empirical and theoretical literature on technological innovation and sustainable development across reputable scientific databases. Inclusion criteria were established to identify peer-reviewed articles, conceptual models, and empirical studies published in English that directly addressed innovation dynamics, sustainability strategies, or model development in technology-driven organizations. This phase allowed the researchers to extract core concepts, consolidate thematic patterns, and identify gaps requiring exploration through primary qualitative inquiry.

The second phase involved semi-structured, in-depth interviews with experts selected through purposive sampling and later expanded using snowball sampling to ensure the inclusion of highly knowledgeable participants from academic, industrial, and policy-making backgrounds. A total of eight experts were interviewed, representing domains such as innovation management, sustainable development policy, technology-based enterprises, and organizational strategy. The number of participants was determined by theoretical saturation; interviews continued until no new themes, constructs, or relationships emerged from the data. All interviewees had at least ten years of professional or academic experience in relevant fields, ensuring the credibility and relevance of the insights gathered. Participation was voluntary, confidentiality was assured, and informed consent was obtained from all individuals prior to data collection.

Two primary tools were used for data collection: a systematic review extraction protocol and a semi-structured interview guide. In the meta-synthesis phase, a predefined extraction protocol was developed to record study characteristics, methodological approaches, conceptual frameworks, empirical findings, and reported innovation–sustainability linkages. This protocol ensured consistency and rigor in identifying comparable constructs across diverse sources. The extraction process included coding relevant segments of the reviewed studies, identifying first-order concepts, and transforming these into higher-order interpretive themes suitable for synthesis.

The semi-structured interview guide used in the second phase was designed to elicit rich, detailed narratives from experts regarding key determinants, mechanisms, and contextual influences shaping technological innovation for sustainable development. Questions focused on organizational capabilities, environmental drivers, technology adoption barriers, policy frameworks, and long-term sustainability strategies within innovation ecosystems. The guide was flexible, allowing the interviewer to probe emergent themes or clarify complex issues as needed. All interviews were conducted face-to-face or via online communication platforms depending on participant preference, lasted between 45 and 90 minutes, and were audio-recorded with permission. Transcriptions were prepared verbatim to maintain the accuracy and authenticity of the qualitative data.

The data analysis process consisted of two integrated stages: qualitative meta-synthesis of the literature and grounded-theory–based coding of interview transcripts. In the meta-synthesis stage, the researchers synthesized findings from the selected studies using reciprocal translation, comparative interpretation, and thematic integration techniques. First-order themes derived from individual studies were iteratively compared and merged into broader, theoretically coherent constructs representing various dimensions of technological innovation and sustainable development. This stage provided the conceptual baseline for developing the interview protocol and subsequent model-building procedures.

In the interview analysis stage, grounded theory procedures—including open, axial, and selective coding—were applied to the participants' narratives. Open coding involved identifying initial codes that captured meaningful statements, experiences, or interpretations shared by the experts. Axial coding was used to link these codes into categories, exploring relationships among causal conditions, intervening variables, contextual factors, action–interaction strategies, and resulting outcomes. Selective coding then integrated these categories into a core conceptual framework that described the structure and function of a technological innovation model aimed at achieving sustainable development. Throughout the analysis, constant comparison techniques were used to refine emerging categories, cross-validate findings with meta-synthesis results, and ensure conceptual coherence. Research rigor was supported through strategies such as member checking, audit trails, and peer debriefing, enhancing the credibility, dependability, and confirmability of the final model.

Findings and Results

The analysis of the meta-synthesis and expert interviews led to the extraction of a wide set of open codes that together form the foundational elements of the technological innovation model for sustainable development. These codes reflect the multidimensional nature of innovation drivers, organizational capabilities, environmental conditions, strategic processes, and sustainability-oriented outcomes. Through constant comparison and integration, the open codes were classified as primary conceptual indicators representing the operational, structural, contextual, strategic, and socio-environmental dimensions influencing the formation of a sustainable technological innovation ecosystem. The table below presents all open codes extracted during the qualitative analysis.

Table 1. Sources of Extracted Codes and Open Codes

Row	Open Codes	Source
1	Exploration of challenges; social entrepreneurship; future foresight; entrepreneurship; sustainable innovation; sustainability; social welfare; false market expectations	I1, I3, S2
2	Intellectual property rights; innovation network; investment; resource allocation; research and development; entrepreneurial vision	S1, S4, I2
3	Venture capital fund; human capital; technological development	S3, I4
4	Environmental factors; innovation engine; incubators; efficient structure; specialized innovation centers; training	S5, S7
5	Actor interactions; knowledge flow; cooperation facilitation	I2, S6
6	Emerging technology; innovation capacity; creativity; knowledge diffusion; innovation enablers	S3, S8, I5
7	Technology-based work environment; culture; adaptability; supplier capability; international regulations; technological intelligence	S9, I1, I6
8	Continuous organizational learning; trade openness; new technology adoption	S10, I3
9	Social equality; economic development	S11
10	Risk; product innovation; infrastructure; opportunity selection; specific market focus; opportunity identification; environmental protection	I4, S5, S12
11	Organizational innovation	S13, I2
12	Technological innovation; job creation; market share expansion; solving social problems; ethics; social responsibility; branding	I1, S3, S14
13	Environmental protection; transformative knowledge; systemic knowledge; scientific progress	S12, S15
14	Knowledge management; infrastructure; social entrepreneurship	S4, I3
15	Organizational strategy; performance evaluation; quality management; trademark protection; competitiveness; social characteristics; collaboration	S7, S9, I6
16	Ethics; social responsibility; branding; idea management	I1, S14
17	Customer services; security	S6, I4
18	Organizational characteristics; firm size; technological learning; misallocation of capital	S10, I5
19	Idea management; organizational strategy; demand; creativity and innovation	I1, S8
20	Performance evaluation; quality management; trademark protection	S7, S9
21	Strategic capability; competitive advantage; process innovation; technological regime; idea management; organizational strategy	S5, S13, I2
22	Identification of superior research; patent; customer services; security	S1, S6

23	Identification of superior research; patent; intellectual property; skill; general competencies; innovative thinking	S1, S8
24	Decision-making; business boundaries; commercial strategy; market needs; market structure; commercialization strategy; support from formal and informal institutions	S4, S11, I6
25	Policy-making and policy tools; specialization of technical activity	S15
26	Innovation performance; market innovation capability; marketing innovation capability	S6, S12
27	Capacity to use information resources; management innovation; production capability; organizational capability	S7, I3
28	Emotional intelligence; empathy; problem-solving; entrepreneurial resilience; effort for innovation; enthusiasm for innovation	I5, I7, I8
29	Science; innovation	S3
30	Economic bubble and artificial excitement; innovation ecosystem	I4, S12
31	Organizational characteristics; organizational competence; technological innovation capability; government facilitation; strategic thinking	S5, I6
32	Knowledge-based orientation; motivation; self-efficacy; economic bubble and artificial excitement	I7, S10
33	Resource management; uncertainty	S4, I8

The extracted codes presented in Table 1 reveal a highly diversified and interconnected set of factors shaping technological innovation for sustainable development. The codes highlight not only fundamental determinants such as intellectual property rights, investment, human capital, environmental conditions, and organizational strategy, but also emerging aspects such as emotional intelligence, resilience, social responsibility, innovation ecosystems, and transformative knowledge. Several clusters of codes point toward institutional and policy-level influences, including government facilitation, policy tools, and formal–informal institutional support. Other clusters emphasize organizational learning, creativity, technological capacity, and market-oriented innovation capabilities. The breadth and depth of these open codes demonstrate the complexity of designing an innovation model that integrates technological progress with economic, social, and environmental sustainability objectives, ultimately forming the backbone for the axial and selective coding stages of the model development process.

Table 2. Axial Codes and Their Related Open Codes

Axial Code	Related Open Codes
Organizational Competence	Organizational characteristics; organizational competence; human capital; strategic capability; firm size; idea management; technological learning; resource management; general competencies; misallocation of capital; problem-solving; adaptability; performance evaluation; quality management; competitiveness
Sustainable Development	Sustainability; social responsibility; ethics; environmental protection; social welfare; social equality; solving social problems; transformative knowledge; systemic knowledge; scientific progress; economic development
Business Model	Commercial strategy; business boundaries; opportunity selection; market needs; market structure; specific market focus; commercialization strategy; trademark protection; branding; customer services; security; demand
Organizational Characteristics	Culture; social characteristics; structure; efficient structure; strategic thinking; motivation; self-efficacy; enthusiasm for innovation; actor interactions; collaboration; continuous organizational learning
Technological Innovation Capability	Creativity; innovation capacity; product innovation; process innovation; technological development; emerging technology; knowledge diffusion; innovation enablers; technological regime; idea management; capacity to use information resources
Environmental Factors	Environmental conditions; international regulations; trade openness; government facilitation; formal and informal institutional support; policy tools; specialization of technical activity; false market expectations; economic bubble and artificial excitement; innovation ecosystem
Commercialization	Investment; resource allocation; risk; opportunity identification; entrepreneurial vision; decision-making; support institutions; superior research identification; patents; intellectual property; innovation network; venture capital; technology adoption; supplier capability
Infrastructure	Incubators; specialized innovation centers; technology-based work environments; infrastructure; production capability; organizational capability; training; knowledge management; research and development; information resource capacity

The axial coding process resulted in the integration of numerous open codes into eight broader conceptual categories that form the structural backbone of the emerging technological innovation model. The category of

organizational competence captured internal capabilities related to performance, strategic functioning, and human-resource strength, while sustainable development reflected the environmental, social, and ethical outcomes underlying the innovation model. Business model elements centered around the strategic, structural, and customer-oriented mechanisms necessary for creating and capturing value. Organizational characteristics encompassed cultural, structural, and behavioral attributes shaping internal dynamics and learning processes. Technological innovation capability emerged as a core category that integrated creativity, technological progression, and knowledge-based mechanisms. Environmental factors represented the external institutional, regulatory, and economic conditions influencing innovation trajectories. Commercialization encompassed resource allocation, investment, intellectual property, and opportunity exploitation mechanisms essential for turning innovation into marketable offerings. Finally, infrastructure reflected the foundational physical, technological, educational, and organizational components enabling the development and diffusion of innovation. Together, these axial categories provide a coherent and interconnected structure for understanding how technological innovation can be systematically directed toward sustainable development.

Table 3. Selective Codes and Their Related Axial Codes

Selective Code	Related Axial Codes
Technological Innovation Input and Regulatory Indicators	Environmental factors; infrastructure; organizational characteristics; organizational competence
Supporting Variables for Technological Innovation	Commercialization; technological innovation capability; business model
Technological Innovation Model	Organizational competence; technological innovation capability; business model; commercialization; infrastructure; environmental factors
Economic, Social, and Environmental Effects	Sustainable development; organizational characteristics; environmental factors

The selective coding stage synthesized the axial categories into four overarching theoretical constructs that articulate the core dimensions of the technological innovation model for sustainable development. The first selective category, technological innovation input and regulatory indicators, integrates environmental factors, infrastructure, organizational characteristics, and organizational competence, reflecting the foundational conditions and regulatory enablers required for innovation emergence. The second selective category, supporting variables for technological innovation, brings together commercialization mechanisms, technological innovation capabilities, and business model elements that act as enablers and accelerators in the innovation process. The third selective category, the technological innovation model itself, represents the integrative structure that links organizational capabilities, innovation processes, commercialization pathways, infrastructural foundations, and environmental dynamics into a coherent and functional system. Finally, the category capturing economic, social, and environmental effects shows how innovation outcomes extend beyond organizational boundaries to generate sustainable development impacts. Collectively, these selective codes illustrate a hierarchical and interconnected conceptual model, demonstrating how inputs and supporting drivers converge to form a comprehensive technological innovation framework that ultimately generates multi-dimensional sustainable development outcomes.

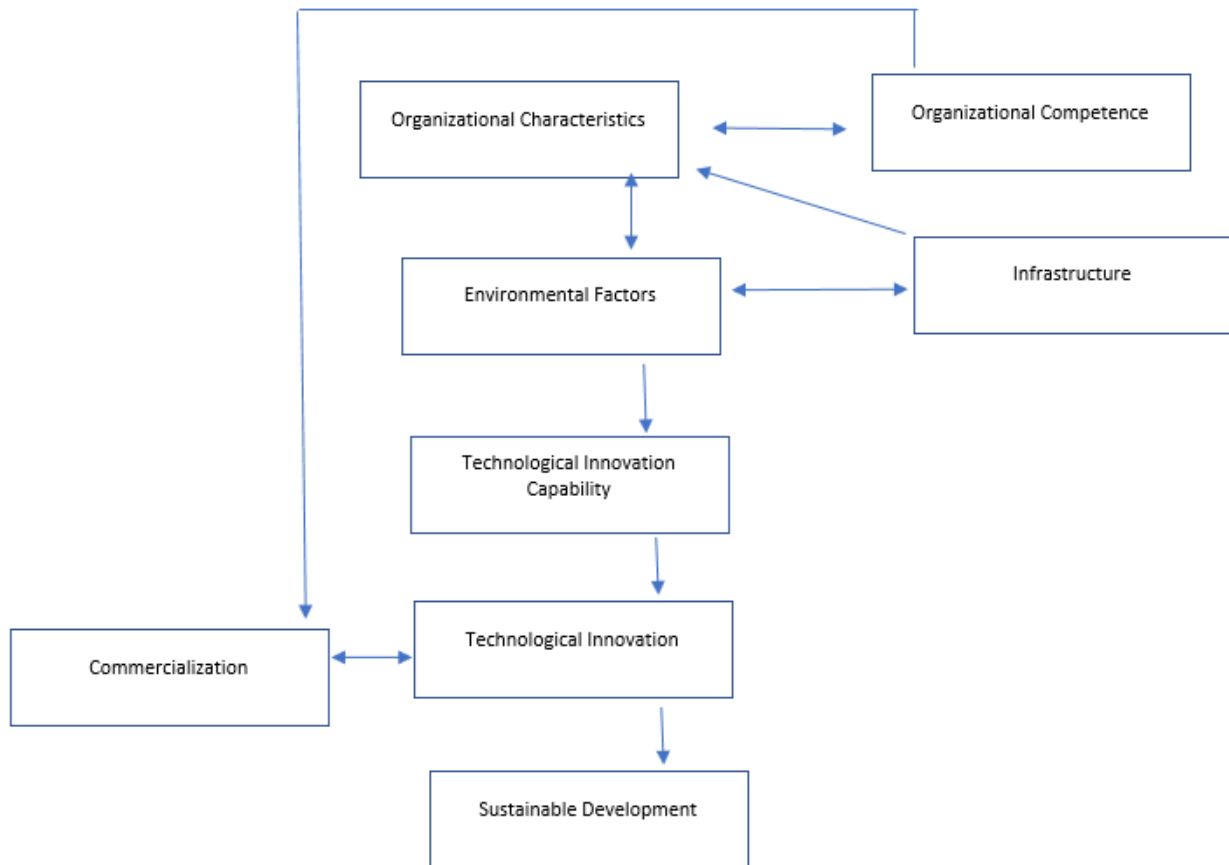


Figure 1. Conceptual Model

Discussion and Conclusion

The purpose of this study was to design a technological innovation model capable of contributing to sustainable development through a systematic synthesis of existing research and expert insights. The findings of the meta-synthesis and interviews revealed a multidimensional configuration in which organizational capabilities, environmental forces, technological competencies, commercialization mechanisms, and sustainability-oriented values collectively shape the innovation process. The integrated model emerging from selective coding illustrates how technological innovation is not a linear or isolated phenomenon but one deeply embedded in socio-technical, environmental, and institutional systems. This interpretation aligns with the growing consensus in innovation literature that sustainable innovation requires a holistic perspective encompassing governance structures, human capital development, knowledge systems, market readiness, and socio-ecological considerations.

The results indicate that technological innovation relies fundamentally on robust input indicators and regulatory frameworks that foster organizational readiness. Axial codes related to infrastructure, environmental factors, organizational characteristics, and internal competence converge into a selective category describing the foundational determinants of innovation. This finding corresponds with the observation that technological innovation systems depend on well-coordinated societal and institutional structures that mediate the interaction between technological change and sustainability transitions (1). Similarly, the emphasis on digital ethics, urban governance, and cultural legitimacy as part of innovation readiness resonates with studies showing that technological innovation in many cities, particularly in Islamic contexts, is shaped by ethical norms and regulatory expectations that influence

design, adoption, and governance dynamics (2). The alignment between the current findings and the literature suggests that innovation ecosystems cannot be understood independently of the sociopolitical and ethical structures within which they are embedded.

The identification of supporting variables—such as commercialization mechanisms, technological innovation capabilities, and business model elements—further reinforces the idea that innovation emerges through strategic orchestration of organizational resources. Prior research demonstrates that high-energy-consuming industries improve ESG performance and environmental outcomes when innovation strategies are embedded within digital infrastructures such as the energy internet (3). This supports the present finding that technological capabilities, when integrated with strategic and market-oriented functions, can generate sustainability benefits. Furthermore, the results coincide with studies describing how higher education institutions enhance technology entrepreneurship by implementing innovation models that encourage interdisciplinary collaboration and digital competence development (4). This parallel reinforces the centrality of learning, collaboration, and capability-building in innovation processes.

Social innovation and social entrepreneurship also emerged as relevant to the formation of a sustainable technological innovation model. The findings show that ethical sensibilities, social responsibility, and sustainability awareness play important roles in shaping organizational strategy and market engagement. This observation aligns with earlier work emphasizing that social innovation trends reflect institutional orientations toward community engagement, ethical governance, and socio-environmental improvement (5). In the same vein, studies examining regulatory imaginaries highlight that the trajectory of disruptive innovation is influenced not only by technological potential but also by institutional visions and collective expectations (6). The selective codes in the present study reveal similar dynamics: actors interpret and negotiate innovation possibilities based on regulatory, ethical, and social expectations.

The central position of business models within the innovation architecture highlights the strategic importance of market structures, customer demands, commercialization tools, and value-creation mechanisms. Studies have shown that innovation performance is strongly influenced by the clarity of business models and the degree to which firms integrate market needs into innovation processes (7). Moreover, research on corporate social responsibility demonstrates that green technological innovation can strengthen stakeholder trust and clarify organizational roles in sustainability debates (8), which is consistent with the current model's emphasis on aligning innovation with social and environmental outcomes. The findings also align with perspectives that consider entrepreneurial ecosystems as critical sites for innovation development, where institutional support, human capital, and social networks interact dynamically to catalyze innovation (9).

Human capital, competencies, and learning emerged as consistent themes across the meta-synthesis and interviews. Interviewees emphasized the importance of organizational learning, problem-solving, creativity, and technical proficiency. This corresponds with research noting that sustainable industry leadership and innovation depend heavily on competence development, organizational mindset, and strategic awareness (10). It is also consistent with systematic literature showing that entrepreneurial competencies—including creativity, strategic thinking, opportunity recognition, and communication skills—are vital drivers of innovation success (11). Findings from studies in higher education further reinforce this point, showing that universities play a central role in cultivating entrepreneurship and innovation through immersive learning environments (12). These insights validate the present model's emphasis on human capital as a cross-cutting enabler of technological innovation.

Technological innovation capability itself—one of the core axial categories—is strongly supported by prior research. Engineering education studies confirm that developing technological, managerial, and sustainability competencies is essential for preparing professionals to lead innovation initiatives (13). The innovation process model, which integrates competence, cost structures, and organizational benefits, also provides a conceptual foundation consistent with the multi-dimensional innovation capability observed in this study (14). Similarly, research on high-technology SMEs shows that industrial clusters enhance innovation outcomes by improving coordination and knowledge-sharing across firms (15). The model developed here reinforces these claims, illustrating that technological capability emerges from a combination of structural resources, organizational competencies, and external collaborative linkages.

Environmental and financial factors also appeared prominently in the findings. Studies indicate that technological innovation interacts with financial development to shape environmental sustainability, especially in advanced economies where investment capacity influences innovation adoption (17). Meanwhile, research on sustainability transitions highlights that innovation depends on broader systemic interdependencies linking governance, institutional structures, and societal priorities (1). The presence of environmental factors in the selective codes of the current model aligns with these insights. Moreover, energy-focused industrial research shows that digital infrastructures can substantially improve environmental performance (3), reinforcing the model's recognition of environmental protection as both a driver and outcome of innovation.

Social entrepreneurship competencies emerged as an important complement to technological capabilities. Research from developing economies indicates that sustainability competencies within social entrepreneurship can promote inclusive development and foster commitment to community and environmental stewardship (18). This aligns with the social responsibility and ethical dimensions present in the current model, suggesting that innovation must be accompanied by values-based governance. The same conclusion is supported by innovation capability maturity models that emphasize assessing and developing capabilities systematically to guide organizational innovation efforts (19).

The educational dimension of innovation also finds support in the literature. Design-thinking-based teaching models demonstrate that experiential learning and cross-disciplinary collaboration enhance innovation readiness (20). Meanwhile, techno-startup educational programs highlight the significance of competence development through iterative experimentation and hands-on activities (21). Innovation mapping studies similarly emphasize the need for structured knowledge monitoring to support innovation pathways (22). These findings mirror the current model's argument that digital literacy, creativity, systemic thinking, and entrepreneurial competencies form essential elements of sustainable technological innovation.

Finally, studies on technological and sustainable innovation argue that integrating technological advancements with sustainability objectives requires strategic alignment, managerial awareness, and institutional support (23). Research on entrepreneurial competencies within universities shows that innovation capabilities improve when individuals are equipped with the skills needed to navigate complex ecosystems (24). This perspective resonates strongly with the final selective category in the model, which emphasizes that economic, social, and environmental effects are integral outcomes of innovation—thus linking technological development with sustainable progress.

Taken together, the results of the present study are strongly supported by previous research, and the model produced aligns closely with contemporary discussions on sustainable technological innovation across organizational, educational, and policy contexts. By integrating insights from diverse academic domains, the study

highlights the multi-layered nature of innovation and its dependence on structural, human, technological, and environmental dimensions.

This study relied on qualitative methods, which, despite offering deep insight, may limit generalizability across industries and geographic contexts. The number of expert participants was intentionally small due to the theoretical saturation requirement, meaning that some sector-specific perspectives may remain underrepresented. Additionally, although the meta-synthesis covered a broad range of literature, publication bias may have influenced the availability and scope of the included studies.

Future research should apply mixed-methods or quantitative validation approaches to empirically test the proposed innovation model across industries and countries. Comparative studies between developed and developing contexts would help assess the model's adaptability. Longitudinal research could also track real-time organizational innovation processes to evaluate how capabilities evolve. Finally, future studies may explore technological innovation in specific sectors such as health, energy, or digital governance to refine domain-specific applications.

Practitioners should focus on strengthening organizational capabilities, particularly human capital and learning systems, to support technological innovation. Investing in infrastructure, digital tools, and knowledge systems will enhance readiness. Firms should prioritize integrating sustainability principles into innovation strategies, ensuring alignment with environmental and social objectives. Collaboration among universities, industry, and policymakers should be expanded to build innovation ecosystems that support long-term sustainability.

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Authors' Contributions

All authors equally contributed to this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

All ethical principles were adhered in conducting and writing this article.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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