IJMR | International Journal of Multidisciplinary Research
Международный институт управления и предпринимательства
Research Article Print ISSN 3105-8884 Online ISSN 3105-8892 October 2025, Vol. 1, No. 1
https://10.65231/ijmr.v1i1.34

Academic Progress and Trends in Technology Innovation Management under the Background of Sustainable Development

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KEYWORDS

Sustainable development;
Technology innovation management;
Trend analysis;
Green technology.

ABSTRACT

This paper comprehensively reviews the academic research progress in technology innovation management under the background of sustainable development, analyzes current global research hotspots and major achievements, and understands future research trends. Through bibliometrics and content analysis, it reveals that green technology innovation, digital empowerment mechanisms, and policy-coordinated governance have become research focuses. The study emphasizes that interdisciplinary integration and practice-oriented approaches are the core pathways to promoting the sustainable development of technology innovation management.

INTRODUCTION

Introduction 2025 marks the tenth anniversary of the United Nations Sustainable Development Goals (SDGs), placing the global sustainable development process at a critical turning point. According to the Sustainable Development Solutions Network (SDSN) Sustainability Report 2025, it is projected that less than 20% of the SDGs will be achieved by 2030. Insufficient fiscal space, inadequate multilateral cooperation mechanisms, and weakened support for multilateralism from major powers have become major obstacles to achieving the Sustainable Development Goals. While global averages mask significant regional disparities, China's SDG ranking has jumped from 68th out of 167 countries to 49th. China has successfully achieved SDG 1 (No Poverty) and SDG 4 (Quality Education) and has made significant progress in SDG 9 (Industry, Innovation and Infrastructure). Meanwhile, most developing countries in Asia still face severe challenges in addressing climate change[1].In this global context, technological innovation management, as a core driving force for sustainable development, is experiencing a multi-dimensional deepening trend in academic research and practical exploration. The academic community is beginning to pay more attention to how to overcome resource constraints and institutional bottlenecks in the process of achieving sustainable development goals through systematic innovation management mechanisms. On the one hand, considering the differences in development stages among different countries and regions, scholars are committed to constructing differentiated technology innovation path models, exploring how to improve the R&D and transformation capabilities of sustainable technologies by optimizing the efficiency of innovation resource allocation and strengthening the industry-academia-research collaborative innovation network, given limited fiscal investment. On the other hand, with the profound restructuring of global value chains, the research perspective of technology innovation management is gradually shifting from the internal innovation of individual enterprises to the collaborative governance of the global innovation ecosystem, exploring how to promote the widespread application of sustainable technologies in developing countries through transnational technology transfer, intellectual property sharing, and the unification of green technology standards, thereby narrowing the sustainable development gap between regions. Especially in the current context of the deep integration of the digital economy and the green economy, how to leverage emerging technologies such as big data and artificial intelligence to empower the green transformation of traditional industries and balance the environmental benefits and social costs brought about by technological innovation has become a key issue that urgently needs to be

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Received date:October 13, 2025; Revised manuscript received date: October 20, 2025; Accepted date: October 22, 2025; Online publication date: October 30, 2025.

addressed in the field of technology innovation management. Related research is accelerating from theoretical construction to empirical analysis and policy design.

Technological innovation is generally regarded as the core driving force for solving the above-mentioned problems. Since 2015, cutting-edge technologies such as digital technology and artificial intelligence have become the core forces driving progress towards the 17 Sustainable Development Goals (SDGs), showing the potential for systemic change in areas such as poverty eradication, ocean protection, and clean energy. By 2025, the synergistic effect of climate policy, technological innovation, and market demand will promote a comprehensive reshaping of production methods, consumption patterns, and value systems. This transformation requires the establishment of collaborative mechanisms from the enterprise and supply chain levels to the national level. Enterprises are facing a “perfect storm” of environmental, social, technological, and regulatory trends, and Sustainable Innovation Management (SIM) provides a theoretical framework for enterprises to cope with this complexity by balancing profitability and ecological responsibility[2].

1.Theoretical Foundation and Conceptual Framework

1.1.Definition of Core Concepts

Green technology innovation, as the core driving force for corporate sustainable development, is not limited to a single level of technological research and development. It is a multi-dimensional collaborative process encompassing comprehensive innovation from management models to market strategies. In this process, enterprises are committed to achieving efficient resource utilization and minimizing environmental impact through breakthroughs in key areas such as innovative energy technologies, resource recycling technologies, environmentally friendly materials technologies, and intelligent manufacturing technologies. The integration and application of these technologies not only help enterprises reduce their environmental burden but also drive them towards a greener, low-carbon development direction. The empowering role of digital technology is particularly crucial in this process. It not only highly relies on the integration of technology, data, and knowledge resources but also fundamentally changes the traditional innovation model through this integration. The application of digital technology enables enterprises to manage finances more effectively and alleviate financial pressure; at the same time, it breaks down information barriers, eliminates information asymmetry, and allows enterprises to respond to market changes more quickly and grasp consumer needs more accurately. In overcoming technical challenges, digital technology provides powerful computing and data analysis capabilities, helping enterprises overcome previously insurmountable technical obstacles. Furthermore, the core mechanism of digital technology lies in enhancing enterprises' dynamic knowledge capabilities, which includes the absorption, creation, application, and dissemination of knowledge. This enhanced capability allows enterprises to maintain continuous innovation vitality and competitiveness in the fierce market competition. Enterprises can internalize external knowledge into their own innovation resources through continuous learning and adaptation, thereby maintaining a leading position in the ever-changing market environment. The cultivation and enhancement of this capability is the inexhaustible driving force for enterprises to continuously move forward on the road of green technology innovation[3].Open innovation emphasizes the collaboration of multiple stakeholders in the innovation ecosystem, including interdisciplinary cooperation and industry-academia-research integration models involving enterprises, governments, research institutions, and the public[4].Open innovation theory emphasizes the synergistic effect of multiple stakeholders in the innovation ecosystem, with its core being the construction of a cross-organizational collaboration mechanism involving enterprises, governments, research institutions, and the public. This innovation paradigm breaks through the organizational boundary constraints of traditional innovation activities, achieving optimal allocation and efficient integration of innovation elements among heterogeneous stakeholders. Specifically, enterprises acquire complementary innovation resources by establishing strategic alliances, significantly reducing the uncertainty and technological risks of R&D investment; government departments provide regulatory frameworks and incentive structures for the innovation system through institutional design and policy tool combinations; research institutions, relying on their specialized knowledge production systems, provide basic research and key technology support for industrial innovation; and the public

promotes the marketization of innovative achievements through demand expression and innovation participation mechanisms. These innovation entities form functional complementarities within an open and collaborative networked innovation system, jointly constructing a dynamically evolving innovation community, driving the transformation of the innovation paradigm from a closed linear model to an open networked model, thereby accelerating the R&D cycle and industrialization process of green technologies.

1.2.Comparison of Theoretical Foundations

In the theoretical framework exploring the relationship between technological innovation and sustainable development, dynamic capability theory focuses on the adaptive analysis of organizations to environmental changes. This theory reveals the role of digital transformation leadership and decentralized structures in enhancing innovation responsiveness, as well as the interaction mechanism between supply chain learning capabilities and innovation. Meanwhile, the National Innovation Systems Theory, from a macro perspective, analyzes the interaction between institutional and technological change, emphasizing the impact of digital technology on the economic, social, and environmental dimensions of the Sustainable Development Goals (SDGs) through dynamic knowledge capabilities. Its core lies in the institutional mechanisms underlying the production and allocation of scientific and technological factors. The complementarity of these two theories lies in the fact that the dynamic capabilities theory focuses on building micro-level organizational capabilities, while the National Innovation Systems Theory focuses on the supporting role of the macro-level institutional environment. Together, they constitute the theoretical foundation for the management of technological innovation.

In addition to the above two theories, the Ecological Modernization Theory further elucidates the interaction between technological innovation and environmental governance from a sociological perspective. This theory advocates promoting the transformation of industrialization models towards eco-friendly models through the synergistic effect of technological progress and institutional change, emphasizing the integrated effect of market mechanisms, government regulation, and social participation in the diffusion of green technologies. The resource-based perspective focuses on the accumulation and allocation of heterogeneous resources within enterprises, arguing that scarce green resources and inimitable innovation capabilities are key sources of sustainable competitive advantage. Its core logic lies in improving the environmental performance of technological innovation through optimal resource allocation. Sustainable development economics, on the other hand, approaches the issue from a macroeconomic perspective, incorporating the internalization of environmental costs and green growth accounting into its analytical framework. It explores how technological innovation can achieve a win-win situation for economic development and ecological protection by improving resource utilization efficiency and reducing pollution emission intensity. Its theoretical focus is on constructing a comprehensive value assessment system that includes ecological capital. These theories, from different dimensions such as organizational dynamic adaptation, macro-institutional environment, social transformation mechanisms, enterprise resource allocation, and economic system optimization, provide diverse perspectives for understanding the complex interaction between technological innovation and sustainable development. Their cross-fertilization helps form a more comprehensive theoretical analytical framework, thus revealing more profoundly the inherent logic and practical path of green technology innovation management.

1.3.Integrated Analytical Framework

Based on an integrated framework constructed from micro-meta-macro dimensions, this framework incorporates enterprise practices, supply chain collaboration, and national strategies into a unified analytical system. At the micro level, the focus is on key elements of green technology innovation for enterprises, including R&D investment, green management systems, talent cultivation, and market demand [5]; at the meso level, the emphasis is on supply chain collaborative innovation mechanisms, such as interdisciplinary teamwork and stakeholder participation; at the macro level, the focus is on the path of national innovation systems to achieve SDGs through digital technology empowerment. The core of this framework lies in digital technology as an intermediary variable connecting innovation and sustainability goals. Through the dynamic capabilities of knowledge, it integrates micro-innovation

resources and macro-policy support to form a synergistic mechanism of "values-rules-knowledge," promoting the sustainable development effects of efficient resource utilization, green product production, and waste recycling [6].

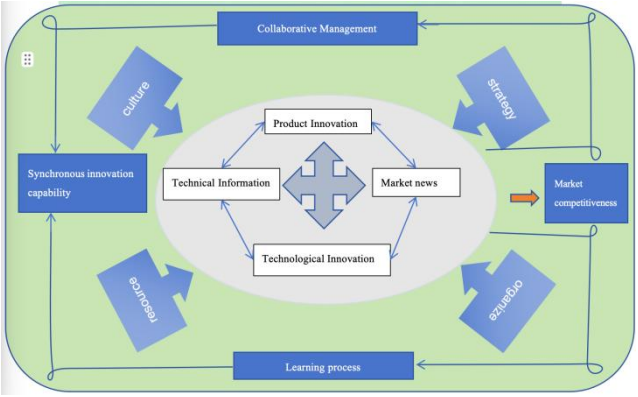

Fig.1. Audit Model of Collaborative Management of Technological Innovation

2.Multi-dimensional Practice Progress of Technological Innovation Management

2.1.Green Technology Innovation Management at the Enterprise Level

The practice of green technology innovation in enterprises needs to build a multi-dimensional collaborative system. Its core driving mechanism is reflected in the dynamic coupling of technology research and development, management model and market strategy. At the level of technology research and development, the core breakthrough focuses on pollution control and resource recycling technologies. For example, China Southwest Aluminum has achieved a win-win situation of annual emission reduction and 2 million yuan economic benefits through the cold rolling oil mist recovery system. China Coal Research Institute has developed a low-concentration coalbed methane enrichment technology that increases methane concentration from 20% to more than 90%, effectively curbing non-carbon dioxide greenhouse gas emissions[7]. Management model innovation emphasizes the construction of a green system. The Leonardo Group has optimized the production cycle through digital twin technology, reducing the resource consumption of prototype development by 30%, and has jointly built a laboratory with Solvay to develop recyclable composite materials, promoting the recycling of carbon fiber in the aerospace field. At the market strategy level, consumer environmental preferences and policy regulations create a dual driving force. For example, Google reduced the return rate by 40% through AI-driven virtual try-on technology, while strengthening the recommendation of durable products, thus achieving the unity of commercial value and environmental goals [8].

2.2.Technological Innovation Collaboration Mechanism at the Supply Chain Level

The construction of a technological innovation collaboration mechanism at the supply chain level needs to take the supply chain's learning ability as the core driving force. Its three-dimensional framework is: knowledge absorption (external technology introduction), knowledge creation (internal R&D transformation), and knowledge application (implementation of innovative achievements) [9]. Based on the dynamic organizational capability theory, these three dimensions together constitute the foundational capability system for collaborative technological innovation, directly impacting innovation performance at the product and process levels. To achieve efficient integration of these three dimensions in the supply chain's collaborative technological innovation mechanism, it is crucial to build a cooperative culture and trust mechanism system. In cross-organizational collaboration, cultural differences and heterogeneous management systems among different enterprises can easily lead to cognitive barriers and a lack of trust. Therefore, it is recommended to establish a regular joint training and exchange mechanism. This can be achieved by organizing supply chain member companies to participate in environmental technology seminars and visits to green production demonstration bases, promoting the integration of organizational values and creating a favorable organizational ecosystem for knowledge transfer, technological innovation, and commercialization of research results (commercialization of research results).

Building an incentive mechanism is a key element in ensuring collaborative effectiveness. It is recommended to establish a multi-dimensional incentive system: firstly, establish a special green technology innovation award fund to provide financial support to enterprises that excel in technology introduction, R&D breakthroughs, and technology transfer; secondly, enhance the reputation of enterprises within the industry by having authoritative industry associations recognize and award innovation honors,

thereby stimulating the motivation for collaborative innovation in the supply chain. Empirical research shows that such incentive measures can significantly improve the participation and innovation performance of member companies.

A sound risk management system is equally important. The main risks faced in collaborative technological innovation include: the risk of R&D failure, market adaptability risk, and intellectual property protection risk. It is recommended to construct a three-tiered risk response mechanism: establish a real-time monitoring and early warning system; for technological risks, a strategy of dynamically adjusting R&D direction can be adopted; for market risks, a rapid response mechanism needs to be established; finally, in terms of intellectual property protection, legal means such as improving contract design and establishing arbitration mechanisms should be used to ensure institutional guarantees for collaborative innovation.

A volatile technological environment, as a key moderating variable, will drive the supply chain to improve its dynamic responsiveness. The aerospace manufacturing industry case shows that cross-organizational collaborative networks that transform strategic suppliers into long-term partners effectively promote technology diffusion and the implementation of sustainable practices. Digital technologies further empower this process: AI-driven intelligent procurement systems optimize resource allocation; blockchain technology enhances collaborative trust by building transparent information-sharing mechanisms (such as carbon emission traceability in the peanut supply chain); and the application of the LightGBM algorithm in inventory management improves demand forecasting accuracy and resource utilization efficiency [10]. This dual-drive model of "technology tools-organizational collaboration" forms a dynamic capability closed loop to cope with uncertainty.

The practice of sustainable supply chain innovation exhibits significant regional differences. Enterprises in developed countries pay more attention to releasing collaborative advantages through organizational structure optimization and collaborative network design. In summary, the essence of supply chain technology innovation collaboration is a three-element coupling system of capability-network-technology. Enterprises need to build collaborative networks adapted to the technological environment based on their own learning capabilities, and achieve synergistic optimization of knowledge flow, material flow, and value flow through digital tools, ultimately achieving sustainable development goals.

2.3.Construction of Innovation Systems at the National and Global Levels

Sustainable energy transition at the national and global levels relies on the dual drivers of technological innovation and policy frameworks. The national innovation system, as a macro-coordination mechanism, has a systematic impact on the achievement of Sustainable Development Goals (SDGs) by integrating digital technologies and dynamic knowledge capabilities. Peng Shuhong et al. (2025), based on data from 51 countries along the Belt and Road Initiative from 2014 to 2019, constructed an integrated framework of "digital technology — dynamic knowledge capabilities — SDGs," showing that digital technologies, through the three stages of knowledge acquisition, integration, and application, have a significant positive impact on economic and social sustainable development, but a negative impact on environmental sustainable development. In this mechanism, knowledge absorption, creation, and application exhibit significant mediating effects, while knowledge dissemination, in some contexts, shows a masking effect, reflecting the complexity of knowledge flow within the innovation system [11]. National heterogeneity is significant in technological innovation strategies. Developed economies, leveraging their technological accumulation and market maturity, focus more on promoting economic growth through digital technologies, such as their leading positions in areas like AI-driven energy management and green cloud computing; while developing economies pay more attention to balancing social and environmental benefits. For example, major carbon-emitting countries in Asia set climate targets through Nationally Determined Contributions (NDCs) and are accelerating technological breakthroughs in areas such as advanced battery materials, bio-based biodegradable plastics, and carbon capture, utilization, and storage (CCUS). This difference is particularly evident in the implementation of the Belt and Road Initiative. Countries like China promote the diffusion of technological innovation through infrastructure connectivity, such as the practice of Multilingual Interoperation in Cross-Country Industry 4.0 System, providing technical standards and platform support for transnational industrial collaboration [1].

At the global level, sustainable development faces

significant fiscal gaps and collaboration challenges. While the $10 billion fund launched by the UN Technology Facilitation Mechanism (TPF) and the $580 billion global green bond issuance in 2023 have provided financial support for clean energy technologies, the Sustainable Development Report 2025 points out that the Global Financial Architecture (GFA) urgently needs reform to adapt to the funding needs of global public welfare. Against this backdrop, the importance of multilateral cooperation mechanisms is highlighted: on the one hand, the unification of global standards (such as the formulation of standards in the field of sustainable computing) becomes a prerequisite for the promotion of practice; on the other hand, regional collaborative models (such as China's "Belt and Road" Initiative) effectively reduce the risk of fragmentation of the innovation system through policy coordination, technology transfer, and capacity building. The spatial spillover effect of digital transformation on green innovation performance further confirms the key role of transnational technological cooperation in sustainable development.

3.Challenges

Technological innovation management faces multi-level systemic challenges in sustainable development practices, requiring collaborative solutions at the macro, meso, and micro levels. Significant systemic failures are evident at the macro level: a huge fiscal gap exists for global sustainable development. Data from the Fourth International Conference on Financing for Development (FFD 4) in 2025 shows that lagging reforms of the international financial architecture have led to insufficient climate finance supply, with Asian green bond issuance only meeting 35% of the expanding demand for renewable energy; the fragility of multilateral cooperation mechanisms is highlighted, and weakened support for multilateralism from major powers exacerbates the fragmentation of technical standards; the environmental cost paradox of digital technology is emerging, with data centers accounting for 3%-5% of global electricity consumption, while the energy consumption of each blockchain transaction is equivalent to a week's electricity consumption of an average household [1].

4. Conclusions

This study systematically reviews the academic progress and practical dynamics of technology innovation management under the background of sustainable development. The core conclusions are reflected in the synergistic evolution across three dimensions: At the enterprise level, green collaborative mechanisms have formed an integrated model of "open social innovation - multifunctional teams - collective knowledge management"; at the supply chain level, collaborative networks based on long-term partnerships have been established, and breakthroughs have been achieved in the development of resource recycling design tools driven by learning capabilities; at the national and global level, a systemic transformation path centered on a multi-level perspective (MLP) framework has been developed, with policy tools such as China's "Industrial Green Efficiency Code 2.0" promoting the transformation of industries towards low-carbon and intelligentization. The cutting-edge issues focus on a dual core contradiction: while digital technology improves resource utilization efficiency, its environmental negative effects governance mechanisms are still incomplete; open innovation accelerates sustainable transformation through value co-creation, but the risk prevention and control system in the knowledge flow of SMEs still needs to be built.

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