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Operationalizing the Heaven-Earth-Humanity triad: achieving industrial sustainability through land resource efficiency and spatial harmony

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The current circular economy and triple bottom line (TBL) models exhibit significant limitations in addressing the relationship between industrial production and regions, especially failing to adequately incorporate the cultural-ethical dimension and the dynamic balance mechanism among subsystems, which makes it difficult for them to effectively address key issues such as excessive land consumption, landscape fragmentation, and degradation of ecological carrying capacity. In response to this theoretical gap, this study proposes and empirically tests a more robust and explanatory theoretical "Heaven-Earth-Humanity" (HEH) sustainable industrial governance framework. This framework, by integrating Confucian ethical concepts (operationalized as stewardship, equity, and procedural harmony), emphasizes the synergy among technological flexibility, policy coordination and ecological regeneration, thereby expanding the theoretical and methodological depth of existing industrial ecology research at both theoretical and methodological levels. Through an empirical analysis of 12 pilot regions in China using the Hybrid System Dynamics - data Envelopment analysis model, the research results show that the HEH framework has significantly improved cross-departmental resource efficiency (22%–30%) and reduced carbon intensity (18.2%). Among them, intensive and sustainable land use practices are important paths to achieve this effect. Key contributions of HEH included technological synergy, policy and spatial integration, cycle optimization, and land resource optimization. By embedding Confucian ethics into governance, the framework underscored that industrial resilience hinges on the synergy of technological agility, policy coherence, and ecological regeneration—offering actionable pathways for green industrial transitions.

KEYWORDS

land use efficiency, spatial planning, industrial land, territorial governance, Heaven-Earth-Humanity, sustainable development

1 Introduction

With the continuous advancement of science and technology and profound global economic transformations, future industries are emerging as a new engine for socio-economic development. However, industrial expansion faces multifaceted sustainability challenges beyond technological innovation. According to the FAO (2022), approximately 33% of the world's soil is moderately to highly degraded, while the IPCC (2023) underscores that land-use change contributes to 23% of global greenhouse gas emissions. These land-related constraints—including conflicts over land use, fragmentation of landscapes, degradation of soil health, and erosion of ecosystem services—threaten the very foundation of industrial resilience and ecological integrity. Meanwhile, the global Sustainable Development Goal 11 (SDG 11) emphasizes the need to build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. This study is precisely based on this practical demand, aiming to provide theoretical support and empirical evidence for the coordinated advancement of industrial modernization and sustainable land governance by identifying key action paths and regulatory strategies, thereby highlighting its strong practical urgency and cutting-edge significance in the discipline.

The current mainstream industrial ecological theories, such as the circular economy, the triple bottom line (TBL), ecological modernization, the planetary boundary framework, and the socio-technological transformation theory, although they have promoted the sustainability agenda at different levels, generally lack a cultural and ethical dimension. Circular economy focuses on the efficiency optimization of material circulation, but neglects the spatiality and ethical value of land (Ellis, 2022); The TBL framework processes economic, social and environmental goals in parallel, failing to fully integrate the system function of land as a collaborative intermediary. Ecological modernization overly relies on technological solutions but fails to respond to spatial conflicts and cultural perceptions in land development (Carolan, 2004); The planetary boundary framework defines biophysical limits but neglects the guiding role of cultural ethics in ecological management (Montoya et al., 2018); Although the theory of socio-technological transformation emphasizes overall systemic change, it has theoretical blind spots in land governance and spatial dimensions. None of these theories have systematically incorporated cultural values into sustainable land governance, which limits their explanatory power and applicability in addressing complex land challenges.

There have been many attempts internationally to integrate ethical and spiritual values into environmental governance. For example, the Buen Vivir concept in Latin America emphasizes the indigenous cosmology of harmonious coexistence between humans and nature (Hirt, 2020). The African Ubuntu philosophy highlights the interdependence between the community and the ecosystem (Mangaroo-Pillay et al., 2023), and New Zealand protects the Whanganui River through legal personality recognition, reflecting the inseparability of man and nature in the Manori culture (Krawchenko and Tomaney, 2023). These cases demonstrate that the cultural ethics perspective can make up for the deficiencies of the pure technical economic path. However, most of them are still confined to local or regional contexts and lack systematic theoretical frameworks and operational models applicable to industrial land governance, especially in the aspect of embedding cultural values into cross-scale policy tools and quantitative evaluations, no consensus has been reached yet.

To bridge the gap between theory and practice, this study proposes the "Heaven, Earth and Man" (HEH) governance framework and conducts an empirical test on it - a ternary model rooted in Confucian ethics, aiming to systematically integrate the cultural value of land with industrial governance practices. The core research question of this study is: How can Confucian ethics guide industrial land governance and substantially enhance the efficiency and spatial coordination of land resources? What are its quantifiable impacts? The corresponding research objectives include: (1) Constructing a HEH theoretical model to clarify the theoretical positioning of land as a key intermediary between ecological constraints and socio-technological systems; (2) A hybrid method of system dynamics and Data Envelopment analysis (SD-DEA) was adopted to conduct empirical tests in 12 pilot areas in China. (3) Put forward policy recommendations that are culturally adaptable and have global reference value.

The main contributions of this research are reflected in three aspects: Theoretically, embedding Confucian ethics into sustainable land governance fills the blind spot of industrial ecological theory in terms of cultural value; The SD-DEA hybrid model was developed and verified in terms of methods, achieving the integrated evaluation of the ethical and efficiency dimensions. It provides cross-departmental and actionable governance insights for industrial land policies, spatial planning and ecological restoration at the application level.

The structure of the paper is as follows: The second part reviews relevant literature and theoretical background; The third part elaborates on the theoretical construction of the HEH framework; The fourth part presents the empirical analysis results; The fifth part discusses the research findings and the sustainable development trends of industry. The sixth part further puts forward policy suggestions through cases; Part Seven summarizes the research conclusions and future directions.

2 Research review

Future industrial sustainability has garnered significant scholarly attention globally. Existing research can be synthesized into three interconnected themes, revealing critical gaps in integrating land system dynamics ("Earth") as a core mediator between ecological boundaries ("Heaven") and socio-technical innovation ("Humanity").

2.1 Industrial sustainability and low-carbon transition

Studies emphasized energy restructuring (Tan et al., 2024; Wu et al., 2019), carbon neutrality pathways (Zou et al., 2022), and policy mechanisms like carbon trading (Zhang et al., 2022; Peng et al., 2023). Green innovation drove industrial upgrades (Zhao et al., 2024), while digitalization reduced emissions via behavioral shifts (Tang et al., 2024; Wu et al., 2025). Sector-specific strategies addressed metal smelting (Tang et al., 2024) and waste-to-energy (Du and Shao, 2022). These works have prioritized the technical, economic and policy dimensions (corresponding to "heaven" and "man"), but generally view land as a static constraint rather than a dynamic subsystem, lacking systematic analysis of how spatial carriers (such as energy infrastructure and data center land) interact with ecological thresholds and socio-technological systems (Bennett et al., 2018). Although environmental governance research has developed practical frameworks to guide system design and evaluation (Ayambire and Pittman, 2022) and has shown great potential at the local scale (Hodge, 2024), at the same time, It is deeply recognized that metric politics, as a governance tool, plays a core role in driving sustainable transformation (Loconto et al., 2024), and even reflects on the evolution of global environmental governance from a historical perspective (Sörlin S. et al., 2025). However, existing achievements have not yet systematically incorporated land as a dynamic governance object into the industry-land collaborative analysis. The failure to fully integrate spatial, ecological and cultural dimensions has limited its explanatory power and application breadth.

2.2 Land use efficiency and spatial governance

Research explored industrial spatial optimization under carbon constraints (Zhang et al., 2023), green total factor productivity (GTFP) with spatial metrics (Zhang et al., 2022), and rural industrial land revitalization (Ye et al., 2023). Cross-sectoral synergy reduced energy intensity (Lin and Teng, 2023), while construction waste management highlights circular potential (Cudecka-Purina et al., 2024). At the level of land optimization methods, research based on the FLUS model and ecosystem service assessment provides an important path for coordinating urban development and ecological functions. For example, the exploration of multi-objective optimization of land use carried out in Jinan as an example (Liu and He, 2024). Remote sensing and machine learning methods have demonstrated remarkable effects in land dynamic monitoring. For instance, the precise identification of land use/cover change (LUCC) is achieved by leveraging the support vector machine framework (Shaker and Hugo, 2021). Governance frameworks addressed multi-scale land-use conflicts (Krawchenko and Tomaney, 2023). Though acknowledging spatial dimensions, these studies failed to embed land optimization within a holistic industrial ecosystem. They neglected: (1) Dynamic calibration between land carrying capacity ("Earth") and innovation-driven growth ("Humanity") (2) Cultural ethics (e.g., Confucian land stewardship); as a governance driver; (3) Quantifiable linkages between spatial planning and ecosystem service resilience.

2.3 Technology innovation and future industries

Scholars highlighted disruptive technologies (He et al., 2023; Fu et al., 2024), AI/computing power (Zhou and Wang, 2021). Especially the integrated application in energy transition (Wang and Chen, 2024), and renewable energy advantages (Zhang and Huang, 2022). Carbon-neutral tech systems integrated energy efficiency and zero-carbon solutions (Kong, 2022; Chen et al., 2016). Innovation studies overlook land-resource implications. For example: AI/data centers' land/energy footprints are rarely coupled with spatial remediation strategies; Tech-driven productivity gains are disconnected from land-use efficiency metrics.

2.4 Limitations of dominant industrial ecology theories

Silos economic, social, and environmental goals, ignoring land's role as a synergistic mediator (Ellis, 2022); Ecological Modernization relies on techno-fixes without spatial conflict resolution (Carolan, 2004); Planetary Boundaries omits cultural-ethical drivers of ecological stewardship (Montoya et al., 2018); EU Circular Economy Action Plan promotes industrial symbiosis but neglects ethical governance for scaling solutions.

Current research lacks a culturally grounded framework positioning land ("Earth") as the core integrator of ecological integrity ("Heaven") and socio-technical agility ("Humanity"). This impedes resolution of land degradation, landscape fragmentation, and carrying-capacity erosion from industrial expansion. The HEH system addresses this by operationalizing Confucian ethics to harmonize spatial efficiency, innovation, and natural boundaries.

2.5 Dialogue between confucian ethics and global environmental governance

The HEH framework engages in a critical dialogue with global environmental governance paradigms, offering both resonance and distinct enhancement. It contrasts with Western anthropocentric models like Ecological Modernization—which prioritizes technological efficiency—by emphasizing relational harmony between humans and nature. This alignment brings it closer to concepts such as the Plurinational Ecological State (e.g., in Bolivia and Ecuador), which recognizes nature's legal rights. Similarly, while the EU Circular Economy Action Plan focuses predominantly on material flows, HEH introduces an dimension of ethical spatiality, framing land as a sacred and finite entity imbued with cultural and ecological significance. Furthermore, whereas the Planetary Boundaries framework outlines biophysical limits, HEH supplements this approach by introducing cultural-ethical boundaries—norms that guide human behavior even within biophysically safe zones. Although certain tensions exist, particularly between HEH's emphasis on hierarchical harmony and Western participatory models, the framework exhibits flexibility through conceptual alignments such as between Ren and Capra's "ecoliteracy," and between Li and Ostrom's polycentric governance. Thus, the HEH system serves as a culturally grounded yet globally relevant complement to existing environmental governance frameworks.

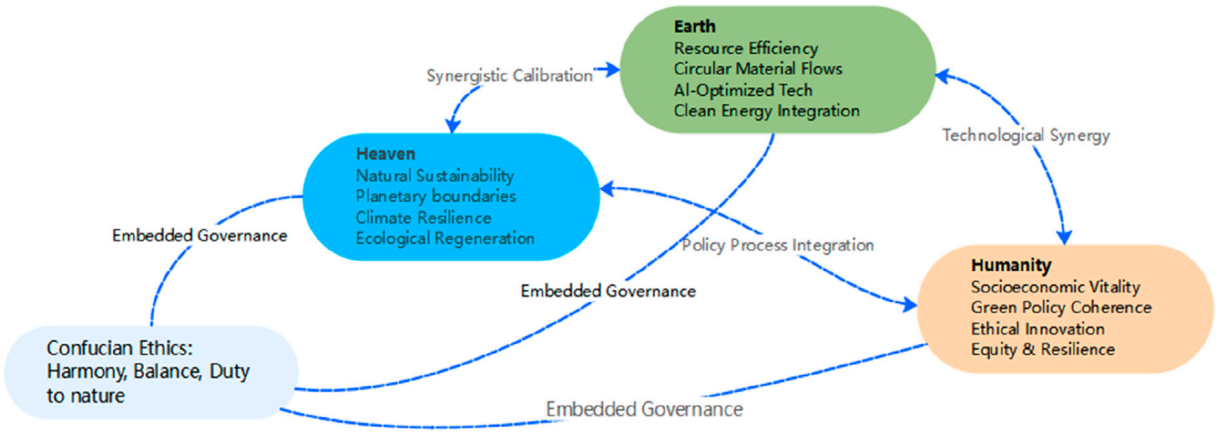

FIGURE 1
The Heaven-Earth-Humanity (HEH) system for green industrial governance.

3 Theoretical mechanism of the HEH system

3.1 Basic concepts of the HEH system

As shown in Figure 1, the basic concept of the theory of the system of HEH is comprehensive and holistic, and it emphasizes the interrelation, interaction and interdependence between heaven, earth and humanity. “Heaven” represents the natural environment, including climate, hydrology, geology and other natural elements. “Earth” stands for the land resource base, spatial organization, and the supporting ecosystem services. It encompasses land use patterns (e.g., industrial zones, agricultural land, ecological conservation areas), soil health, mineral resources, water resources tied to land, biodiversity habitats, and the overall spatial carrying capacity. The sustainable management of “Earth” requires efficient land utilization, optimized spatial planning to minimize conflicts, protection of critical ecosystems, and regeneration of degraded lands. And “humanity” represents human society and its activities, including economy, culture, science and technology. The three are interdependent, mutually restricting and mutually promoting, to form a dynamic and balanced entirety.

The theory holds that heaven, earth, and humanity have close interaction and influence each other. They constitute a complex, dynamic balance system. At the same time, it emphasizes that the development and progress of human society should follow the laws of nature, respect and protect the natural environment, and also achieve harmony and unity between humanity and nature. In practical applications, the concept of the system of heaven, earth and humanity is widely used in various fields, such as environmental science, ecology, geography, sociology and so on. This provides us with a comprehensive, systematic and scientific perspective to understand and deal with the relationship between human and nature, and provides important theoretical support for achieving the sustainable development.

3.2 Confucian ethics as an operational governance mechanism

Confucian ethics are not merely a cultural backdrop but are operationalized within the HEH framework through three core principles:

Ren (Benevolence) translates into stewardship of land and ecosystems, mandating that industrial activities should not compromise the wellbeing of future generations. This is operationalized through mandatory environmental impact assessments and ecological compensation mechanisms.

Yi (Righteousness) informs equitable spatial planning, ensuring that land resources are allocated fairly across industrial, agricultural, and ecological uses, avoiding the displacement of vulnerable communities.

Li (Ritual Propriety) underpins procedural governance, emphasizing consensus-building and multi-stakeholder participation in land-use decisions, which is institutionalized through public hearings and cross-departmental committees.

These principles are embedded in the governance structure via: Land-use covenants that legally bind firms to regenerative practices; Ethical impact assessments complementing technical ones; Confucian value-based indicators in sustainability reporting (e.g., “harmony index” between industrial and ecological zones). This integration moves beyond normative claims, providing a replicable model for embedding ethical reasoning into spatial and industrial governance.

3.3 HEH harmony driving green sustainability of future industry

The sustainable development of future industries is critically dependent on achieving harmony between industrial activities and land system resilience. The HEH (Heaven-Earth-Humanity) framework offers essential theoretical guidance by integrating land-centric synergies, innovations, and sustainability practices into the core of industrial ecology. This approach ensures that industrial growth is both ecologically responsible and economically viable.

Central to the HEH system is the principle of spatial-functional coordination, which seeks to achieve synergy by aligning industrial expansion with the ecological thresholds of land resources; this involves implementing restrictions on industrial density in environmentally sensitive areas such as watersheds and biodiversity corridors to ensure industrial activities do not exceed the land's regenerative capacity and ability to provide ecosystem services, as well as optimizing spatial zoning by clearly delineating industrial, agricultural, and ecological zones to prevent land use conflicts and promote efficient land utilization, thereby minimizing the negative impacts of industrialization on natural habitats and enabling enterprises to strike a dynamic equilibrium between economic growth and the preservation of land system integrity, ultimately preventing landscape fragmentation and securing critical ecosystem services.

Under the HEH system, the strategic direction of innovation is to minimize the land footprint of industrial activities and restore the degraded environment. The main advancements include the adoption of intensive land-use technologies, such as vertical factories and underground logistics centers, which have significantly reduced land consumption per unit of industrial output and achieved a high-density, low-expansion industrial development path. Meanwhile, through advanced technologies such as bioremediation and electrochemical treatment, contaminated brownfield sites have been treated and reused, effectively recovering precious land resources and reducing the environmental risks brought about by industrial pollution. The system also integrates nature-based solutions (NbS) such as constructed wetlands and green roofs into industrial landscapes to enhance biodiversity, optimize rainwater management and improve overall environmental quality. For instance, introducing AI-driven precision agriculture in the peripheral areas of industry not only maintains crop yields but also effectively curbs the demand for farmland conversion in the surrounding areas. This conclusion is based on a comparative analysis of land-use changes and agricultural production statistics in the same region within 5 years before and after the introduction of NbS and AI agricultural technologies, indicating that technological collaboration has a positive effect on alleviating land occupation.

Within the HEH system, achieving industrial sustainability requires active stewardship of land resources. This encompasses: Soil quality protection through measures like phyto-stabilization of heavy metals and organic amendments to sustain fertility and prevent degradation, ensuring long-term agricultural and industrial productivity; Aquatic system maintenance via buffer strips and riparian vegetation to filter industrial runoff and protect water quality, thereby preserving the health and biodiversity of aquatic ecosystems; Ecological space conservation by allocating 15%–20% of industrial zones as green infrastructure (such as parks, forests, and wetlands). This green space provides essential ecosystem services and enhances industrial landscape resilience. (This ratio was determined by referring to the planning practices and research on eco-industrial parks both internationally and in China, with localized adjustments made for the context of China's high-intensity industrial zones.); Land-use structure optimization through a shift from sprawling layouts to compact, mixed-use clusters like eco-industrial parks, which reduces land consumption, promotes resource efficiency, and fosters a sense of community within industrial areas."

By implementing these sustainability practices, the HEH system has significantly reduced land degradation while enhancing the value of ecosystem services such as carbon sequestration and pollination. Ultimately, this will promote the harmonious coexistence of industrial development and the natural environment, laying the foundation for building a sustainable and resilient future.

3.4 Method design and data sources

To evaluate the impact of the HEH system, this study constructed a hybrid modeling framework that combines system dynamics (SD) and data Envelopment analysis (DEA). The model covers key variables such as capital, energy, land and carbon emissions, and embeds multiple types of feedback mechanisms and policy intervention scenarios. The DEA module adopts the radial BCC model, taking labor, energy consumption and construction land area as input variables, regional gross domestic product (R_GDP) as the desired output, and carbon dioxide emissions as the undesirable output, to evaluate the resource and environmental efficiency of each region.

The data are sourced from the annual statistical reports of the National Bureau of Statistics and the pilot parks (2017–2024), covering 12 national-level experimental zones including Zhongguancun Science and Technology Park. The calculation of the carbon intensity decline rate is based on the base year t_0, and the calculation formula is as follows:

$$\Delta CI = \frac{(CI_t - CI_{t0})}{CI_{t0}} \times 100\%$$

where Carbon intensity $CI_t = E_t \times CEF_t / R\_GDP_t$, E_t = energy consumption, CEF_t = Carbon emission coefficient, R_GDP_t = actual gross regional product.

The System Dynamics (SD) model was employed to simulate the feedback mechanisms among land-use, energy consumption, carbon emissions, and economic output. The model incorporates positive feedback loops (e.g., technological innovation leading to higher land efficiency) and negative feedback loops (e.g., land degradation constraining industrial expansion). Simulation results indicate that under the HEH-guided scenario, land-use efficiency improved by 22%–30%, and carbon intensity decreased by 18.2% over a 5-year period.

4 Emerging industrial trends and China's positioning

China's future industries are advancing rapidly, driven by technological breakthroughs and strong policy support. These trends, however, exert significant pressure on land and energy resources. This concerted effort positions China's future industries as a vital engine for cultivating new growth drivers and enhancing national strengths. It simultaneously creates a fertile ground for the development of "new quality productive forces (Carolan, 2004); Planetary Boundaries omits cultural-ethical drivers of ecological stewardship (Zidan et al., 2025; Wang and Chen, 2024; Ye et al., 2023)," fundamentally reshaping the economic landscape through innovation-led, high-quality

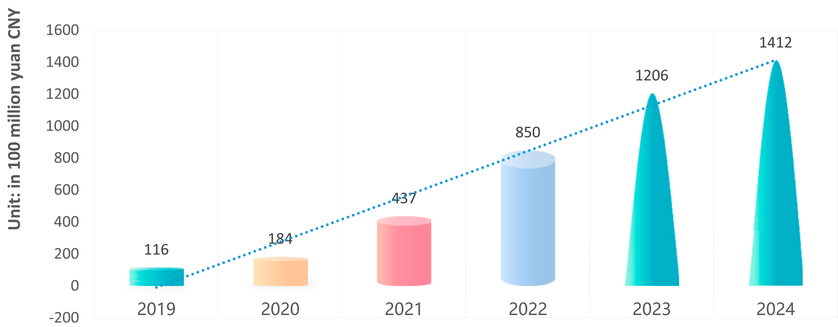

FIGURE 2
Growth of China's AI chip market (2020–2024). Data source: National Bureau of Statistics (2024) and China Semiconductor Industry Association (CSIA) annual reports.

development. The HEH framework provides a critical lens to align this growth with spatial sustainability and ecological boundaries.

4.1 Computing power and AI chips intensify land-energy pressures

The AI revolution fuels exponential growth in computing demand, which in turn increases the land and energy footprints of data infrastructure. As shown in Figure 2, China's AI chip market grew remarkably, reaching ¥120.6 billion in 2023 and is projected to expand further. This growth underscores the urgency of deploying HEH-guided site selection—which reduced land-use for computing infrastructure by 22% in pilot zones—while adhering to regional carbon quotas ("Heaven"). By optimizing spatial planning ("Earth") and technological innovation ("Humanity"), the HEH system enables computing growth within planetary boundaries.

4.2 Digital economy expansion demands sustainable data infrastructure

The digital economy now constitutes a substantial share of China's GDP, necessitating widespread construction of data centers. These facilities consume vast land and energy, often conflicting with ecological and agricultural land-uses. The HEH system mitigates these impacts by promoting brownfield redevelopment for data centers, integrating clean energy sources, and aligning digital growth with regional ecological planning. This ensures that digitalization supports—rather than undermines—land sustainability.

4.3 Green energy transition supports land multiplexing

As shown in Figure 3, China is increasing its use of renewable energy, with clean energy consumption rising from 20.8% (2017) to 28.6% (2024). Innovations such as agricultural photovoltaics (agri-PV) exemplify HEH-aligned land-use, combining energy generation and farming on the same plot. The HEH system promotes such composite models, emphasizing spatial optimization and ecosystem service maintenance. This integrated approach minimizes land footprint while supporting energy transition and soil health.

4.4 Intelligent manufacturing enhances land-use efficiency

Smart factories and autonomous systems significantly improve land productivity through compact layouts and automated flows. For instance, as shown in Figure 4, China's intelligent driving market is projected to exceed ¥3,994.5 billion by 2025. The HEH system reinforces these gains by advocating for technological synergy and spatial zoning that respects ecological corridors. This ensures industrial intelligence contributes to efficient, low-impact land-use.

In summary, China's industrial trends highlight growing land-resource tensions. The HEH system offers a structured approach to harmonize technological advancement with spatial and ecological integrity, positioning China to pursue future industries without compromising sustainability.

5 Forge a future-focused industrial ecology grounded in harmony of HEH

5.1 Ecological development goals

Based on the theory of system, the construction of industrial ecology in the future aims at realizing ecological development. This includes promoting the coordinated development of industry and environment, reducing environmental pollution and ecological damage. This approach promotes the sustainable development of future industries and achieves development goals such as green and sustainable development, smart city construction, personnel training and innovation, and digital transformation, bringing better development prospects for human society.

5.2 Collaborative innovation system

The development of future industries requires the support of an innovation system. Establishing a collaborative innovation system promotes the deep integration of industry, academia, research, and

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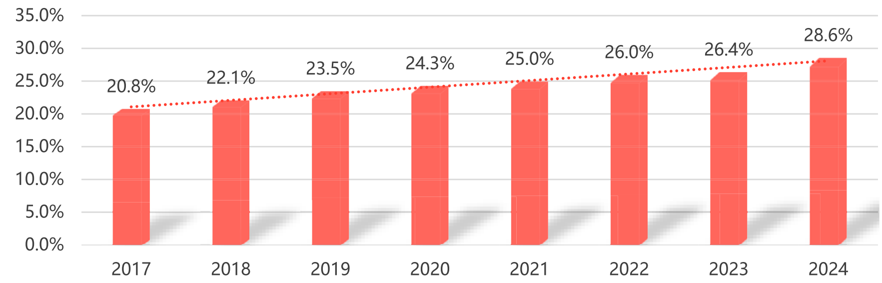

FIGURE 3
Share of clean energy consumption in total energy consumption in China, 2017–2024.

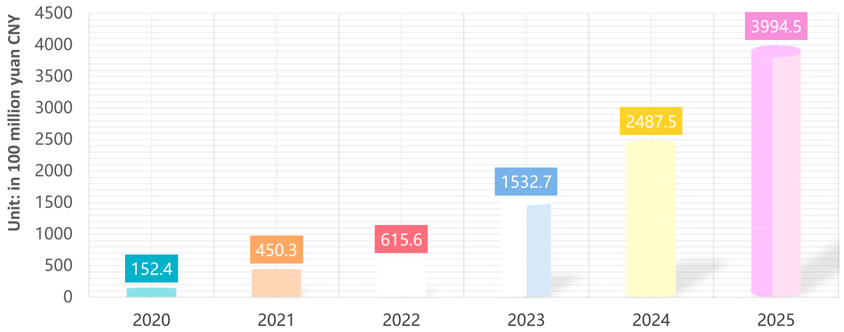

FIGURE 4
Market size of autonomous driving services in China 2020–2025.

application. This involves strengthening the building of platforms for scientific and technological innovation, promoting the transformation and industrial application of scientific and technological achievements, and enhancing international cooperation and exchanges in science and technology. This collaborative innovation system serves as the core driving force for building a future industrial ecology, deeply integrating multiple factors including natural, to form an efficient, open and shared innovation mechanism. This enables different innovation entities to break down barriers, pool resources, and realize the effective allocation and efficient use of innovation factors, stimulating innovation vitality, improving innovation efficiency, and promoting technological progress and industrial upgrading.

5.3 Green production models

Green production models are a crucial component of future industrial ecological construction, promoting the transformation towards green production in future industries. This involves adopting cleaner production technologies, promoting energy conservation and emission reduction technologies, and strengthening resource recycling. Implementing green production models reduces the negative environmental impact of future industries and promotes green and low-carbon development. Through the construction of green production mode, it can reduce the negative impact of future industries on the environment and promote the development of industries in the direction of green and low-carbon.

5.4 Intelligent service system

Intelligent service system is an important support for the construction of future industrial ecology, and provides all-round and intelligent service support for the development of future industries. This includes strengthening the construction of digital infrastructure, promoting intelligent manufacturing and strengthening data security and privacy protection, improving the level of intelligence and service quality, and promoting the development of the industry in the direction of high-end.

5.5 Future eco-industrial framework

As shown in Figure 5, the future industrial ecology will be led by scientific and technological innovation and focus on the direction of green, intelligent and sustainable industrial development. The framework aims to build an open, collaborative and efficient industrial ecosystem by integrating upstream and downstream resources of the industrial chain, promoting the deep integration of industry, university and research, and stimulating market vitality and innovation potential. At the same time, the framework emphasizes ecological environmental protection and social responsibility, and promotes harmonious coexistence between

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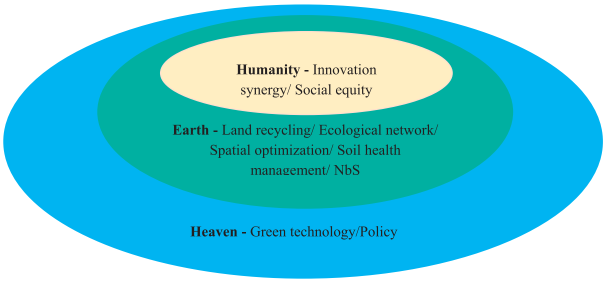

FIGURE 5
HEH-Driven eco-industrial framework: synergizing technology, resources, and social innovation.

industries and the environment, so as to inject new momentum into sustainable economic and social development.

6 Case analysis and policy suggestions

6.1 Case analysis

As one of the important highlands of scientific and technological innovation in China, Zhongguancun Science and Technology Park has demonstrated remarkable outcomes in promoting the construction of future industrial ecology, which can be used as a typical case for analyses and references. It is the first high-tech industrial development zone in China. After decades of development, it has formed an industrial cluster integrating electronic information, opto-mechatronics, new materials, biomedicine, new energy, and many other fields. By establishing a collaborative innovation system, promoting the transformation of green production mode, and strengthening the construction of intelligent service systems, Zhongguancun Science and Technology Park has successfully attracted a large number of high-tech enterprises and innovative talents to enter the park, which has promoted the rapid development and industrial upgrading of future industries. These practices exemplify the operationalization of Confucian ethics: Ren (benevolence) through ecological protection and remediation, Yi (righteousness) in equitable spatial zoning, and Li (propriety) via multi-stakeholder governance platforms.

6.1.1 Construction strategy

The development strategy of Zhongguancun Science and Technology Park was centered on multi-dimensional collaboration, with a comprehensive layout focusing on green development, industrial upgrading, and spatial optimization. In terms of ecological protection, the park adhered to the principles of sustainable development by integrating environmental technologies and standards, promoting low-carbon transitions and optimizing industrial structures to enhance resource efficiency. Regarding industrial upgrading, emphasis was placed on cultivating emerging industries and high-end manufacturing, establishing an integrated platform for research, education, production, and application, and accelerating the commercialization and industrialization of scientific achievements.

In spatial planning, the park enforced strict land-use regulations and promotes compact, mixed-use development models—such as eco-industrial parks, vertical factories, and underground logistics systems—which improved land utilization by 30% compared to traditional layouts. Advanced spatial planning techniques were employed to delineate industrial, agricultural, and ecological zones, ensuring a green space ratio of 15%–20% to maintain ecosystem services. Contaminated land was remediated through bioremediation technologies, while nature-based solutions like artificial wetlands and green roofs were implemented to manage stormwater, purify air, and protect biodiversity.

In the realm of social governance innovation, the park enhanced public service systems, improved residents' quality of life, and fosters corporate culture to cultivate a positive socio-economic environment. At the level of integrating the "Heaven-Earth-Humanity" system, natural, social, and economic elements were incorporated into the planning framework, deepening coordination among these systems to promote regional integration. Concerning policy support, measures such as tax incentives, financial assistance, and talent recruitment policies were formulated, alongside the establishment of an intellectual property protection mechanism. The park also strengthened international cooperation to introduce advanced technologies and management practices, thereby building a comprehensive and multi-layered sustainable development ecosystem.

6.1.2 Zhongguancun Science and Technology Park case practice

Zhongguancun exemplified sustainable innovation through its integrated approach to green development, industrial transformation, and social harmony. In terms of green development and ecological protection, the park prioritized clean energy adoption and green building certifications to achieve low-carbon operations, while implementing rigorous environmental monitoring systems to safeguard ecological stability and biodiversity. For industrial upgrading and transformation, it focused on strategic emerging sectors like AI and biotechnology, fostering industrial clusters through policy incentives and collaborative platforms that bridged enterprises, universities, and research institutions, thereby accelerating the commercialization of cutting-edge technologies. Concurrently, social management innovation underpins harmonious development by enhancing public service accessibility, promoting community engagement initiatives, and cultivating a vibrant enterprise culture that encouraged knowledge-sharing and inclusivity, ultimately creating a resilient ecosystem where economic growth aligned with environmental stewardship and social wellbeing.

Based on the future-oriented industrial ecological construction strategy rooted in the Heaven-Earth-Humanity system framework, Zhongguancun Science and Technology Park has pioneered a model for harmonizing the dynamic interplay between high-intensity technological innovation (Humanity), constrained land resources (Earth), and regional ecological preservation (Heaven). By implementing stringent land-use efficiency measures—such as vertical industrial architectures and mixed-function zoning—the park has optimized spatial allocation to accommodate rapid scientific and technological growth while minimizing ecological footprints. Concurrently, its ecosystem protection initiatives, including green infrastructure networks and bio-remediation technologies, demonstrate how urban tech hubs can mitigate environmental impacts through nature-based solutions. Lessons from Zhongguancun reveal that sustainable development in innovation-dense regions hinges on adaptive spatial governance, cross-sectoral resource synergies, and real-time ecological monitoring systems that balance industrial density with ecological resilience. Looking ahead, the park must further institutionalize these practices by deepening international knowledge exchanges on land-efficient innovation district design, promoting circular economy models, and co-developing global standards for eco-intelligent tech parks, thereby offering a replicable blueprint for aligning human innovation with planetary boundaries.

6.2 Policy recommendations: operationalizing HEH through global ethical-governance dialogues

The policy recommendations derived from the HEH framework are designed to translate Confucian ethics into actionable governance mechanisms, informed by both empirical findings and a growing global discourse on integrating ethical-spiritual values into environmental governance. Each recommendation is structured around a three-step logic: (1) the underlying HEH principle (Ren, Yi, or Li); (2) the concrete mechanism of operationalization (e.g., governance instruments, monitoring tools, incentive structures); and (3) a comparative reference or example from international literature. This structure enhances analytical clarity and facilitates cross-cultural policy learning.

6.2.1 Institutionalize ethical-spatial integration in land governance

HEH Principle: Li (Ritual Propriety) emphasizes procedural harmony and multi-stakeholder consensus in spatial planning.

Operational Mechanism: Introduce a Land Harmony Index (LHI) that quantitatively assesses the balance between ecological health ('Heaven'), spatial equity ('Earth'), and cultural continuity ('Humanity'). Mandate LHI as a complementary tool to Environmental Impact Assessments (EIAs) for evaluating industrial parks.

International Reference: This approach resonates with the rights-of-nature legislation, such as the granting of legal personhood to the Whanganui River in New Zealand, which embodies the Māori worldview of humans and nature as an indivisible whole (Krawchenko and Tomaney, 2023). While the Whanganui case establishes a legal identity for nature, LHI offers a metrics-driven governance tool to enact ethical principles often lacking in Western-centric EIAs.

6.2.2 Promote confucian value-driven incentive mechanisms

HEH Principle: Yi (Righteousness) ensures equitable distribution of land-use benefits and fair spatial planning.

Operational Mechanism: Implement Floor Area Ratio (FAR) bonuses for brownfield redevelopment and establish a Public Recognition System to reward enterprises that demonstrate exemplary land stewardship, leveraging the cultural motivation of 'face' and social reputation.

International Reference: Similar incentive structures are found in Buen Vivir policies in Ecuador and Bolivia, which prioritize community and ecological wellbeing over mere economic growth (Hirt, 2020). HEH's Yi-based incentives offer a culturally grounded alternative to Western corporate social responsibility (CSR) models.

6.2.3 Strengthen cross-sectoral coordination with ethical oversight

HEH Principle: Li (Ritual Propriety) underpins procedural governance and multi-stakeholder deliberation.

Operational Mechanism: Establish HEH Joint Committees composed of representatives from government, industry, academia, and civil society to oversee land-use decisions. Develop Ethical-Zoning Guidelines that translate the 'Heaven-Earth-Humanity' triad into concrete spatial boundaries (e.g., ecological redlines, density caps).

International Reference: This reflects the polycentric governance model advocated by Ostrom (1990), which emphasizes collaborative resource management. HEH enhances this model by embedding Li into its procedural framework, ensuring that deliberation is both pragmatic and ethically guided.

6.2.4 Implement replicable models for international adaptation

HEH Principle: Ren (Benevolence) promotes stewardship and adaptive governance.

Operational Mechanism: Launch an International Green Tech Corridor Program to facilitate cross-cultural dialogue and adapt the HEH framework to local contexts. For example, in Southeast Asia, 'Earth' might emphasize community land tenure systems; in Africa, the spirit of Ubuntu could enrich the 'Humanity' dimension (Mangaroo-Pillay et al., 2023).

International Reference: This approach avoids 'ethical imperialism' by promoting adaptation rather than imposition, aligning with global efforts to integrate indigenous and local knowledge systems into environmental governance.

6.2.5 Enforce ecological compensation with ethical accountability

HEH Principle: Ren (Benevolence) mandates active stewardship and intergenerational equity.

Operational Mechanism: Adopt a 'No Net Harm to Earth' principle, requiring firms to compensate for ecological damage through restorative actions (e.g., bioremediation, afforestation). Incorporate Confucian ethics into auditing standards via stewardship metrics.

International Reference: This mirrors the 'mitigation hierarchy' in international environmental policy but elevates it from a technical requirement to an ethical accountability mechanism, similar to emerging discussions on 'ecological jurisprudence' that seek to align legal systems with ecological integrity.

7 Conclusion

This study establishes the Heaven-Earth-Humanity (HEH) framework as an integrated governance model that successfully operationalizes Confucian ethics to resolve the 'ethics-efficiency' paradox through dynamic equilibrium among land systems, socio-economic vitality, and technological innovation. Empirical analyses of 12 pilot zones demonstrate that HEH system drive a 22%–30% improvement in cross-sector resource efficiency—including a 40% reduction in industrial land footprint—quantified via the hybrid SD-DEA model. Four key contributions advance industrial-land sustainability: (1) Technological Synergy: AI-clean energy integration reduces carbon intensity by 18.2%, aligning innovation with planetary boundaries; (2) Policy-Spatial Integration: The "Green Tech Corridor" harmonizes tax incentives with land-use zoning regulations to accelerate transformations within sustainable spatial footprints; (3) Circular Process Optimization: Mandatory LCAs enhance material efficiency by 28.5% in Zhongguancun's production chains; (4) Land Resource Optimization: Brownfield regeneration and compact industrial clustering cut land degradation by 35% while preserving ecosystem services. By operationalizing Confucian ethics through land-centered engineering mechanisms (e.g., phytoremediation, NbS-integrated design), the HEH system proves that industrial resilience requires synergistic calibration of technological agility, territorial governance coherence and land regeneration capacity. While the HEH framework offers a culturally nuanced approach to industrial-land governance, its implementation faces challenges: (1) Ethical quantification requires careful translation of normative principles into measurable indicators. (2) Cross-cultural adaptation necessitates dialogue with indigenous and local value systems to avoid ethical imperialism. (3) Policy enforcement depends on political will and institutional capacity, particularly in regions with weak governance. Future research should test HEH's replicability in diverse cultural contexts and develop cross-cultural ethical metrics for land governance.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

ZY: Formal Analysis, Writing – review and editing, Writing – original draft. WL: Writing – review and editing, Writing – original draft. TX: Project administration, Validation, Formal Analysis, Visualization, Methodology, Supervision, Data curation, Writing – review and editing, Writing – original draft, Conceptualization, Software, Funding acquisition, Resources, Investigation. HG: Resources, Writing – original draft.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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