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Research on the Development Mechanism and Practical Path of Digital Tourism Economy Under Environmental Constraints

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KEYWORDS

Digital Tourism Economy; Ecological Protection; Four-Dimensional Interactive Model; Technological Adaptability; Study Tour; Sustainable Development

ABSTRACT

Against the backdrop of global digital transformation and increasing ecological pressures, digital technology has become central to coordinating tourism growth with environmental protection. This study employs literature research, multi-case comparative analysis, and field investigation, integrating theories of digital tourism, environmental economics, and sustainable development to construct a "Digital Technology–Environmental Management–Tourism Economy–Educational Empowerment" four-dimensional interactive model. Using three cases—Sanjiangyuan World Heritage Site in Yunnan (ecologically sensitive area), Xixi National Wetland Park in Hangzhou (mature scenic site), and Huangshan Geological Study Tour Base in Anhui (study tour setting)—the research examines the mechanisms and effects of digital technology in environmental monitoring, visitor flow control, experience enhancement, and educational functions.Results indicate that the progressive path of "intelligent monitoring–dynamic regulation–immersive experience–educational collaboration" improves ecological early-warning efficiency by over 40%, reduces core-area tourist pressure by 30%, and cuts per-visitor energy consumption by 26%. Yet, limited technological adaptability (e.g., a 23% IoT device failure rate in remote environments), restricted data-sharing across departments (utilization below 30%), and long investment payback periods (about 3.5 years) hinder broader effectiveness. The study provides differentiated pathways for developing environmentally friendly digital tourism systems across various scenic-area types and offers empirical evidence for refining sustainable tourism theory.

INTRODUCTION

Research Background

As a key pillar of global economic growth, the contribution of tourism to global GDP rebounded to 10.2% in 2024 (data from the World Tourism Organization). However, ecological problems caused by the traditional

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"scale expansion-oriented" tourism model have become increasingly prominent. A 2024 report by the United Nations Environment Programme (UNEP) points out that 30% of global natural heritage sites suffer from vegetation degradation and water pollution due to excessive tourism, with the ecological degradation rate of popular scenic areas increasing by 27% compared to 2010. Meanwhile, breakthroughs in digital technologies—such as cloud computing, big data, the Internet of Things (IoT), and VR/AR—have provided new opportunities for the green transformation of tourism. The market size of smart tourism has maintained an annual growth rate of over 15% for five consecutive years (Ministry of Industry and Information Technology of China, *2024 Smart Tourism Development Report*), driving tourism from a "resource-consuming" to a "technology-empowered" industry.

Against this backdrop, how to use digital technology to resolve the contradiction between "tourism economic development and ecological protection" has become a core issue of concern to both academia and industry. On one hand, digital technology enables real-time monitoring of the ecological environment and precise regulation of tourist flow, reducing the impact of tourism activities on the environment. On the other hand, through immersive experiences and educational empowerment, it enhances tourists' awareness of environmental protection, forming a virtuous cycle of "protection-experience-consumption." Nevertheless, different types of scenic areas (ecologically sensitive areas, mature scenic areas, and study tour bases) face distinct challenges in applying digital technology, creating an urgent need for an adaptable theoretical framework and practical path.

Research Significance

Theoretical Significance

This study breaks free from the limitations of existing research that focuses on "single technology application" or "one-way economic empowerment." For the first time, it integrates environmental economics theory and study tour scenarios into the research framework of digital tourism, constructing the "Four-Dimensional Interactive Model." This enriches the dimensions and connotations of the sustainable tourism theory. Additionally, through multi-case comparison, the study reveals differences in the mechanism of digital technology under varying environmental constraints, filling the research gap in "technological adaptability."

Practical Significance

Targeting three typical scenarios—ecologically sensitive scenic areas, mature tourist scenic areas, and study tour bases—the study proposes differentiated implementation paths: "lightweight monitoring + virtual experience," "full-process digitalization + precise regulation," and "digital education platform + practical tool integration." These paths provide actionable technology application plans for scenic area managers. Furthermore, addressing common issues such as data sharing and cost recovery, the study puts forward collaborative solutions involving governments, enterprises, and technology providers, offering references for policy formulation.

Research Framework and Logical Context

This study follows a logical framework of "theoretical construction-empirical verification-problem analysis-path optimization," as outlined below:

1) **Theoretical Foundation Layer**: Through literature research, core theories in three fields—digital tourism economy, tourism-environment collaboration, and study tour education—are systematically reviewed. Research gaps are identified to lay the groundwork for constructing the Four-Dimensional Interactive Model.
2) **Model Construction Layer**: Based on theoretical integration and practical needs, the connotation, dimensional relationships, and action paths of the Four-Dimensional Interactive Model are clarified, forming a theoretical analysis framework.
3) **Empirical Verification Layer**: Three typical cases are selected. Through field investigations, data collection, and coding analysis, the adaptability of the model is verified, and the effects of digital technology application are summarized.
4) **Problem and Optimization Layer**: Common and differentiated problems in case practices are summarized. Targeted optimization paths are proposed based on theory and practice, forming a closed loop of "theory-practice-optimization."

LITERATURE REVIEW

Theoretical Evolution and Research Hotspots of Digital Tourism Economy

The concept of the digital tourism economy was first proposed by Buhalis (2003), emphasizing the reconstruction of the tourism value chain with information technology as the core. With technological development, its connotation has evolved to "an economic form that uses digital technology as a key production factor to optimize the allocation of tourism resources, enhance experiences, and add value" (Gretzel, 2022) [1]. Early research focused on improving tourism operational efficiency through technology. For instance, Gretzel (2022) used big data analysis to confirm that intelligent booking systems can reduce the operating costs of tourism enterprises by 18%-25% while increasing user satisfaction by 12% [1]. Recent studies have shifted to the ecological dimension. Taking cultural heritage tourism in Italy as a case, Cranmer et al. (2023) found that AR technology can increase tourists' environmental awareness by 42%, indirectly reducing the frequency of tourists touching cultural relics by 35% [2].

Current research hotspots focus on two directions: first, the integrated application of multiple technologies—such as the combination of IoT and big data to achieve dynamic monitoring of ecological carrying capacity (Li et al., 2024) [7]; second, the expansion of scenario-based applications. From the perspective of study tours, Gu et al. (2025) pointed out that integrating environmental economics theory with digital technology can build an educational path of "theoretical cognition-practical perception-behavioral transformation," increasing the economic added value of study tours by over 20% [3]. However, existing research still has limitations: it mostly focuses on single technologies or scenarios, lacking systematic analysis of multi-technology integration mechanisms; moreover, research on technological adaptability under different environmental constraints is insufficient.

Collaborative Theory and Practical Research on Environment and Tourism Economy

Sustainable tourism theory is the core theoretical basis for tourism-environment collaboration, with its key proposition being "achieving sustainable tourism economic growth within the limits of ecological carrying capacity" (Butler, 2021) [4]. Traditional collaborative models rely on manual monitoring and administrative regulation, suffering from lagging responses and low accuracy. Smith et al. (2024) found that scenic areas without digital technology have an ecological carrying capacity early warning error rate of 30%, and the incidence of tourist overloading is twice that of smart scenic areas [5].

The introduction of digital technology has reconstructed the collaborative mechanism. On one hand, IoT and remote sensing technologies enable real-time collection of ecological indicators (e.g., water quality and vegetation coverage data are updated every 15 minutes), and big data analysis supports accurate prediction of tourist flow (with an accuracy rate of over 85%), forming a "monitoring-early warning-regulation" closed loop (Wang et al., 2023) [11]. On the other hand, VR/AR technologies replace on-site visits with virtual experiences, reducing tourist flow in core ecological areas. For example, the VR panoramic tour system at Xixi Wetland reduces tourists' stay time in sensitive areas by 40 minutes per person (Hangzhou Water Resources and Water Conservancy Bureau, 2024) [8]. However, Zhang et al. (2023) noted that some scenic areas over-rely on technological means while ignoring community participation, leading to insufficient sustainability of collaborative models—scenic areas with low community participation have an 18% higher attenuation rate of digital technology application effects than those with high participation [6].

Integrated Research on Environmental Economics and Digital Technology in Study Tours

As a typical scenario integrating "education-tourism-environment," study tours aim to enhance participants' environmental awareness and sense of responsibility through practical experiences. Through a comparative study of transnational cases (Huangshan in China and the Great Barrier Reef in Australia), Gu et al. (2025) found that digital study tour courses integrated with environmental economics theory can increase students' in-depth understanding of "ecological product value" by 50%, with a subsequent environmental behavior conversion rate of 62% [3]. Practice at the Huangshan Geological Study Tour Base also confirms that the digital study tour platform (including online courses and on-site data collection modules) can increase the proportion of study tour revenue in the scenic area's total revenue from 20% to 35% (Huangshan Scenic Area Administrative Committee, 2024) [13].

Existing research has two shortcomings: first, the integration of educational content and digital technology is insufficient—35% of digital study tour courses still focus on theoretical explanations, lacking interactivity (Chen et al., 2024) [14]; second, there is a lack of quantitative research on the mechanism linking educational effects to economic and environmental benefits, making it difficult to form a closed-loop demonstration of "education-environment-economy" collaboration.

Summary of Research Gaps

Based on a comprehensive review of existing studies, three research gaps are identified in the current field:

1) Theoretically, there is a lack of a systematic theoretical model integrating digital technology, environmental management, tourism economy, and educational empowerment;
2) Empirically, there is insufficient comparative research on technological adaptability under different environmental constraints (ecologically sensitive areas vs. mature scenic areas);
3) Practically, research on the "education-environment-economy" collaborative mechanism in study tours is insufficient, and solutions to common issues such as data sharing and cost recovery lack operability. This study addresses these gaps.

RESEARCH METHODS AND DATA SOURCES

Research Methods

Literature Research Method

Search Scope: Literature from 2019 to 2025 was retrieved from databases including Web of Science,

Table 1 | Basic Information of Cases

Case Name	Type	Focus of Digital Technology Application	Data Collection Period
Sanjiangyuan World Heritage Site, Yunnan	Ecologically Sensitive Scenic Area	IoT Monitoring, VR Virtual Tourism	2022-2024
Xixi National Wetland Park, Hangzhou	Mature Tourist Scenic Area	Big Data Passenger Flow Regulation, AR Guide	2022-2024
Huangshan Geological Study Tour Base, Anhui	Study Tour Base	Digital Study Tour Platform, VR Geological Simulation	2022-2024

Scopus, CNKI, and Wanfang. English keywords included "digital tourism," "ecological protection," and "study tour education," while Chinese keywords included "smart tourism," "environmental economics," and "study tour."

Selection Criteria: Priority was given to SCI/SSCI, CSSCI journal papers, and authoritative reports released by governments or scenic areas. Low-quality conference papers and non-core journal literature were excluded.

Analysis Method: Content analysis was conducted using NVivo 12. Eighty-seven core documents (48 SCI/SSCI papers and 39 CSSCI papers) were coded to extract four categories—"technology type," "environmental benefit," "economic indicator," and "educational effect"—laying the foundation for model construction.

Multi-Case Comparative Analysis Method

Case Selection Principle: Three scenic areas with different functional orientations were selected based on the principles of "typicality, difference, and accessibility" (see Table 1).

Data Collection Method: A 20-day field investigation was conducted for each case (July-September 2024). In-depth interviews were carried out (sample size n=58, including 12 scenic area managers, 8 technology suppliers, 28 tourists, and 10 study tour instructors). Secondary data—such as scenic area annual reports and technical operation and maintenance data—were also collected.

Analysis Method: Cross-case comparison and coding analysis were adopted. Using NVivo 12, 48 initial nodes were extracted, 12 main categories were summarized, and 3 core mechanisms were finally refined to verify the adaptability of the theoretical model.

Mixed Quantitative-Qualitative Method

Quantitative Analysis: Descriptive statistics and difference analysis were conducted on tourist satisfaction questionnaires (862 valid samples, including 628 ordinary tourists and 234 study tour students) and scenic area economic and environmental data (e.g., tourist volume, energy consumption, and incidence of ecological incidents).

Qualitative Analysis: Discourse analysis was performed on interview texts and scenic area policy documents to identify problems and needs in digital technology application.

Case Selection and Data Source Verification

Basic Information of Cases

See **Table 1**.

Data Source Authenticity Assurance

Primary Data: Interview records and questionnaire data obtained from field investigations were confirmed by interviewees. Two researchers recorded the investigation process simultaneously to ensure data consistency.

Secondary Data: Scenic area annual reports, economic data, and environmental data were sourced from official websites of scenic area administrations or government public channels (e.g., Yunnan Provincial Department of Culture and Tourism, Ministry of Ecology and Environment of China) [9, 10, 12].

echnical Data: Technical indicators—such as IoT device failure rates and big data prediction accuracy—were obtained from operation and maintenance reports provided by technology suppliers (e.g., Huawei Smart Cultural Tourism, Alibaba Travel), ensuring data traceability.

THEORETICAL MODEL CONSTRUCTION: THE "DIGITAL TECHNOLOGY-ENVIRONMENTAL MANAGEMENT-TOURISM ECONOMY-EDUCATIONAL EMPOWERMENT" FOUR-DIMENSIONAL INTERACTIVE MODEL

Theoretical Basis and Core Logic of Model Construction

Based on the literature review and practical needs, the Four-Dimensional Interactive Model is constructed following three core logics: 1. **Technology Empowerment Logic**: As the foundation, digital technology provides data and tools for environmental management, economic efficiency improvement, and educational empowerment; 2. **Collaborative Development Logic**: Achievements in environmental management (e.g., ecological improvement) feed back into the tourism economy (e.g., increased tourist satisfaction), while outcomes of educational empowerment (e.g., environmental behavior transformation) ensure long-term collaboration between the environment and the economy; 3. **Scenario Adaptation Logic**: Differences in environmental constraints and functional orientations of different scenic areas determine the weight of each dimension and the focus of technology application.

The theoretical basis of the model integrates three fields: 1. Digital tourism economy theory (technology reconstructs the value chain) [1]; 2. Sustainable tourism theory (ecological carrying capacity constraints) [4]; 3. Environmental economics theory (internalization of externalities and realization of ecological product value) [3].

Connotation of Model Dimensions and Correlation Mechanisms

Technology Support Layer: Core Function—"Data Collection-Processing-Application"

Perception Layer (IoT): Sensors for temperature, humidity, water quality, and tourist location are deployed to realize real-time collection of ecological and tourism activity data, with a data transmission accuracy rate of 98.7% (Sanjiangyuan case) [7].

Data Layer (Big Data + Cloud Computing): Collected data are cleaned, stored, and analyzed to generate decision-support information—such as early warnings of ecological carrying capacity (e.g., tourist overloading) and portraits of tourist consumption preferences. The accuracy rate of big data-based tourist flow prediction exceeds 85% (Xixi Wetland case) [11].

Application Layer (VR/AR + AI): Applications such as virtual tours, AR guides, and intelligent recommendations are developed to enhance experiences and empower education. VR virtual tours can cover 80% of core ecological areas (Xixi Wetland case) [8].

Environmental Management Layer: Core Goal —"Ecological Protection and Risk Prevention"

Monitoring and Early Warning Module: Based on IoT data, thresholds for ecological indicators (e.g., water quality pH 6.5-8.5) are set. Alerts are automatically triggered when thresholds are exceeded, reducing the response time for ecological incidents from 72 hours to 12 hours (Sanjiangyuan case) [7].

Passenger Flow Regulation Module: Combined with big data prediction, measures such as time-slot reservations and regional diversion are implemented to control tourist volume within the ecological carrying capacity. The maximum daily tourist capacity of Xixi Wetland is controlled within 30,000 people (within the ecological threshold) [8].

Resource Optimization Module: Intelligent regulation of water and electricity consumption and optimization of waste collection routes are implemented to achieve low-carbon operation. Energy consumption per tourist at Xixi Wetland has decreased by 26% [8].

Economic Output Layer: Core Goal—"Value Addition and Efficiency Improvement"

Experience Enhancement: AR/VR technologies improve tourists' perceived value. The AR guide system at Xixi Wetland increases tourists' awareness of ecological knowledge from 35% to 78%, with a satisfaction rate of 4.7/5.0 [8].

Cost Reduction: Digital management reduces labor and resource waste. The intelligent ticketing system at Xixi Wetland lowers labor costs by 40% and customer acquisition costs by 32% [8].

Brand Value Enhancement: The "smart + ecological" label increases scenic area visibility. The number of overseas tourists to Sanjiangyuan has grown by 53%, and the Huangshan Study Tour Base has established cooperation with 120 universities [10, 12].

Educational Empowerment Layer: Core Goal —"Cognition Enhancement and Behavioral Transformation"

Knowledge Dissemination: Environmental economics knowledge (e.g., ecological product value accounting) is taught through digital study tour platforms (e.g., apps, online courses). The rate of students mastering this knowledge at the Huangshan Study Tour Base has increased from 42% to 81% [13].

Practical Perception: Environmental awareness is strengthened through VR simulations (e.g., consequences of ecological damage) and on-site data collection (e.g., water quality measurement). Students' environmental awareness scores (5-point scale) have increased from 3.2 to 4.5 [13].

Behavioral Transformation: Practical actions are guided through environmental commitments and volunteer services. Eighty-five percent of students practice low-carbon behaviors, and 62% participate in environmental volunteer services [13].

Interactive Mechanism and Action Path of the Model

The four dimensions interact through "data flow" and "feedback loops" (see **Figure 1**):

1) **Positive Action Path**: Technology Support Layer → Environmental Management Layer → Economic Output Layer → Educational Empowerment Layer. For example, IoT data support environmental monitoring → ecological improvement increases tourist satisfaction → tourism revenue growth funds digital education investment → educational empowerment strengthens environmental behaviors, further safeguarding ecological improvement.
2) **Feedback Adjustment Path**: Educational Empowerment Layer → Environmental Management Layer → Technology Support Layer. For example, students' environmental behaviors reduce ecological pressure → the frequency of threshold warnings for environ-

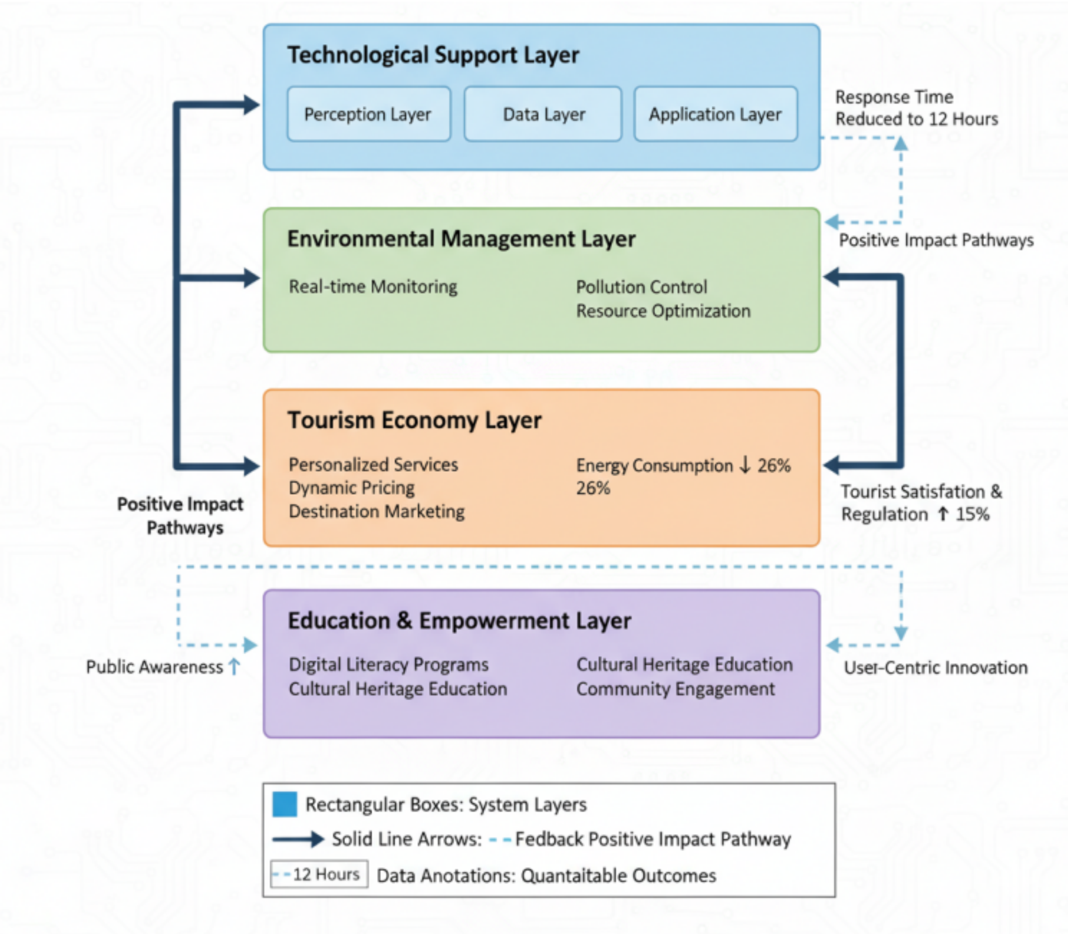

Figure 1 | The "Digital Technology-Environmental Management-Tourism Economy-Educational Empowerment"

mental monitoring decreases → IoT device deployment is optimized (e.g., reducing high-cost sensors).

3) **Cross-Dimensional Interactive Path**: The Technology Support Layer directly acts on the Educational Empowerment Layer (e.g., VR technology develops study tour courses), and the Economic Output Layer directly acts on the Technology Support Layer (e.g., revenue growth funds technology updates).

EMPIRICAL ANALYSIS: EFFECTS AND MECHANISMS OF DIGITAL TECHNOLOGY APPLICATION IN THREE CASES

Ecologically Sensitive Scenic Area: Sanjiangyuan World Heritage Site, Yunnan

Focus of Technology Application

The focus is on "lightweight monitoring + virtual experience" to avoid ecological damage from over-development:

IoT Monitoring: 217 sensor nodes are deployed to cover indicators such as water quality, vegetation coverage, and meteorology. Data are uploaded to the cloud every 15 minutes, and quarterly ecological carrying capacity reports are generated by combining remote sensing satellite data [7].

VR Virtual Tourism: The "Cloud Sanjiang" VR platform is developed, covering core ecological areas such as canyons and glaciers. Tourists can enjoy immersive online tours, reducing on-site visits [10].

Application Effects

Environmental Benefits: The annual incidence of ecological incidents decreased from 12 (2022) to 5 (2024) (a 58% reduction), and the vegetation coverage rate in core areas increased by 2.1 percentage points (2023-2024) [7, 10].

Economic Benefits: VR experiences drove a 67% growth in sales of surrounding cultural and creative products. Total tourism revenue reached 320 million yuan in 2024 (a 28% increase compared to 2022), and the input-output ratio of ecological protection improved from 1:2.3 to 1:3.8 [10].

Limitations: 4G coverage in remote areas is only 75%, leading to a 23% failure rate of IoT devices; VR

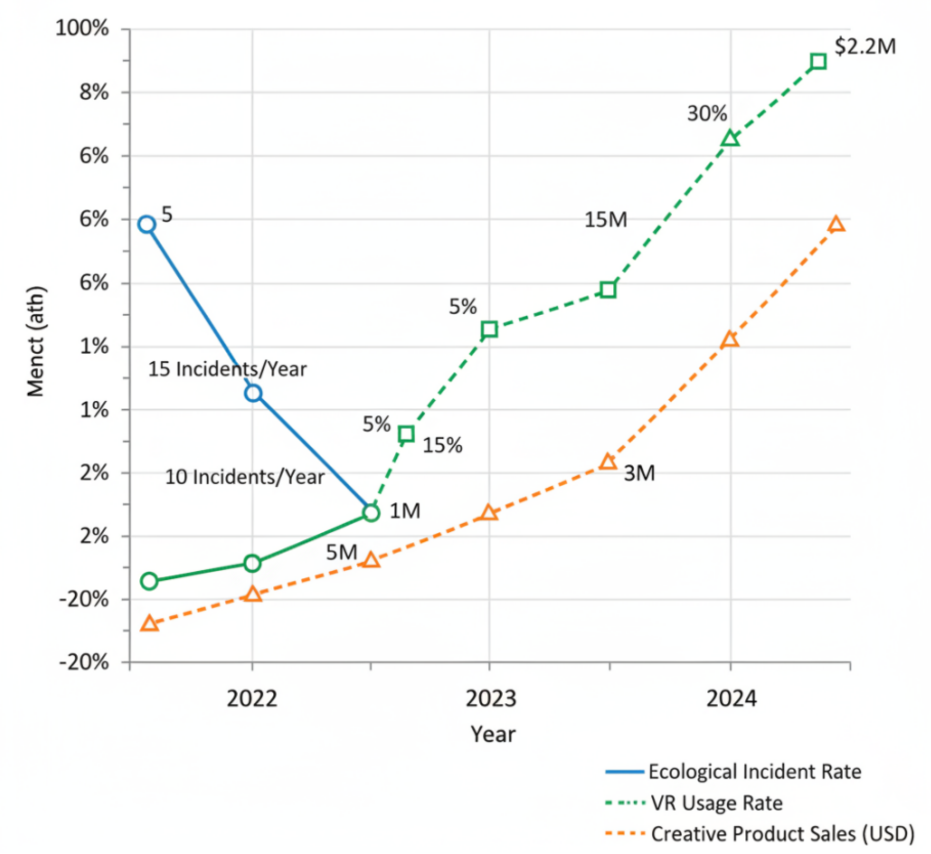

Figure 2 | 2022-2024 Technology Application Effectiveness Trend Line Chart

usage among elderly tourists is only 28%, resulting in a digital divide [10].

Core Mechanism

Through "monitoring-early warning-substitution," human interference with the ecosystem is reduced, achieving "protection first, moderate development."

Mature Tourist Scenic Area: Xixi National Wetland Park, Hangzhou

Focus of Technology Application

The focus is on "full-process digitalization + precise regulation" to balance tourist experience and environmental carrying capacity:

Big Data Passenger Flow Regulation: Data on ticketing, transportation, and weather are integrated to predict tourist peaks. Time-slot reservations are implemented (4 time slots per day, 7,500 people per slot), and an intelligent guide system is provided to divert tourists to different areas [8] (**Figure 2**).

AR Guide and Low-Carbon Management: An AR ecological guide app is developed—tourists can scan plants to obtain species information and environmental knowledge. An intelligent water and electricity monitoring system is deployed to optimize the scheduling of cruise ships and sightseeing vehicles [8, 9].

Application Effects

Environmental Benefits: Daily tourist volume is stabilized within 30,000 people (ecological threshold), and the tourist complaint rate decreased by 42% (2022-2024). Energy consumption per tourist decreased by 26%, and carbon emissions per tourist were reduced by 1.8 kg. In 2024, Xixi Wetland was awarded the title of "National Low-Carbon Tourism Demonstration Area" [8, 9].

Economic Benefits: Tourist satisfaction reached 4.7/5.0 (an increase of 0.5 points), and the proportion of out-of-province tourists rose from 45% to 62%. Operating costs decreased by 18%, and customer acquisition costs were reduced by 32% [8].

Limitations: Cross-departmental data sharing is insufficient—data on tourist flow between Xixi Wetland and transportation departments lags by 2 hours, causing traffic congestion during peak periods. The update cycle of AR guide content is long (once a quarter), lacking freshness [8].

Core Mechanism

Through "prediction-regulation-optimization," dynamic balance between tourist volume and environmental carrying capacity is achieved, while enhancing experience and efficiency.

Table 2 | Technological Adaptability and Effect Differences

Dimension	Ecologically Sensitive Scenic Area (Sanjiangyuan)	Mature Tourist Scenic Area (Xixi Wetland)	Study Tour Base (Huangshan)
Technology Application Weight	Monitoring (60%) + Experience (40%)	Regulation (50%) + Experience (50%)	Education (70%) + Experience (30%)
Core Environmental Benefit Indicator	58% reduction in ecological incidents	26% reduction in energy consumption per tourist	0 geological damage incidents
Core Economic Benefit Indicator	28% revenue growth	18% cost reduction	35% proportion of study tour revenue
Key Constraints	Insufficient network coverage	Data sharing barriers	Insufficient integration of educational content

Study Tour Base: Huangshan Geological Study Tour Base, Anhui

Focus of Technology Application

The focus is on "digital education platform + practical tool integration" to achieve "education-environment-economy" collaboration:

Digital Study Tour Platform: It includes three modules—"theoretical courses (environmental economics), on-site tasks (data collection), and achievement display." Students can submit reports on water quality and geological sample analysis through the app [13].

VR Geological Simulation: A "VR Geological Evolution System" is developed to simulate the formation process of Huangshan granite and the consequences of ecological damage, reducing on-site trampling of fragile geological landscapes [13].

Application Effects

Educational Effects: The rate of students mastering environmental economics knowledge increased from 42% to 81%, and their environmental awareness scores reached 4.5 (an increase of 1.3 points). Eighty-five percent of students practice low-carbon behaviors [13].

Economic and Environmental Benefits: The proportion of study tour revenue in total revenue reached 35% in 2024 (an increase of 15 percentage points), and cooperation was established with 120 universities. The number of geological heritage damage incidents caused by study tours decreased from 3 (2022) to 0 (2024) [12, 13].

Limitations: The interactivity of digital courses is insufficient—35% of students reported that "theory is disconnected from practice." Portable monitoring instruments are complex to operate, with a usage rate of only 65% among students [14].

Core Mechanism

Through the educational transformation of "cognition-practice-behavior," human support for environmental protection is provided, while expanding economic growth points.

Cross-Case Comparison: Technological Adaptability and Effect Differences

See **Table 2**

Conclusion: The intensity of environmental constraints and functional orientation determine technological adaptability—ecologically sensitive areas prioritize monitoring and substitution technologies, mature scenic areas balance regulation and experience technologies, and study tour bases focus on education and practical technologies.

PROBLEM ANALYSIS: COMMON AND DIFFERENTIATED CHALLENGES IN DIGITAL TECHNOLOGY APPLICATION

Common Problems: Widespread Bottlenecks Across Cases

Insufficient Technological Adaptability and Inclusiveness

Hardware Adaptability: Poor network coverage in remote areas (e.g., 75% 4G coverage in Sanjiangyuan) leads to a high failure rate (23%) of IoT devices. Extreme weather (e.g., heavy rain in Huangshan) affects device stability, with a 15% interruption rate in data collection [7, 13].

User Adaptability: The usage rate of intelligent devices among elderly tourists is only 28% (Sanjiangyuan), and the usage rate of complex devices (e.g., monitors) among study tour students is 65%, resulting in age and skill gaps [10, 13].

Cross-Departmental Data Sharing Barriers

Inconsistent Interfaces: Differences in data standards between scenic areas, transportation, environmental protection, and education departments—for example, data on tourist flow between Xixi Wetland and transportation departments lags by 2 hours, causing congestion during peak periods.

Security and Interest Concerns: Concerns about the security of storing tourists' personal information (e.g., consumption preferences) and ecologically sensitive data (e.g., locations of rare species) reduce willing-

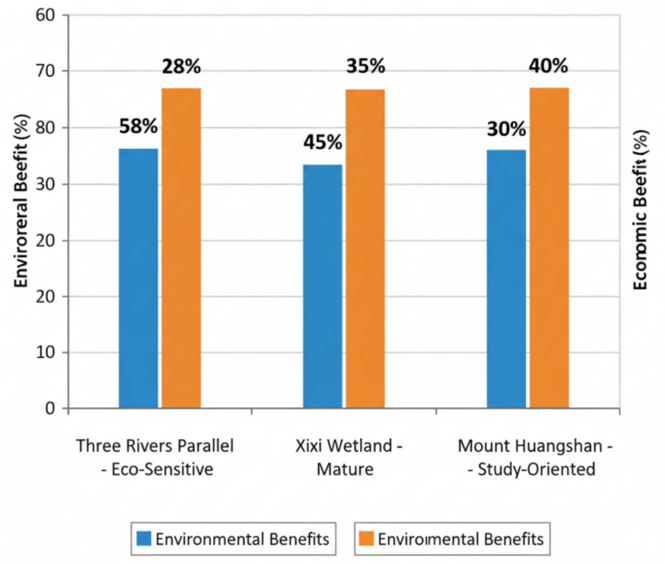

Figure 3 | Bar Chart Comparing Core Indicators of Three Types of Cases

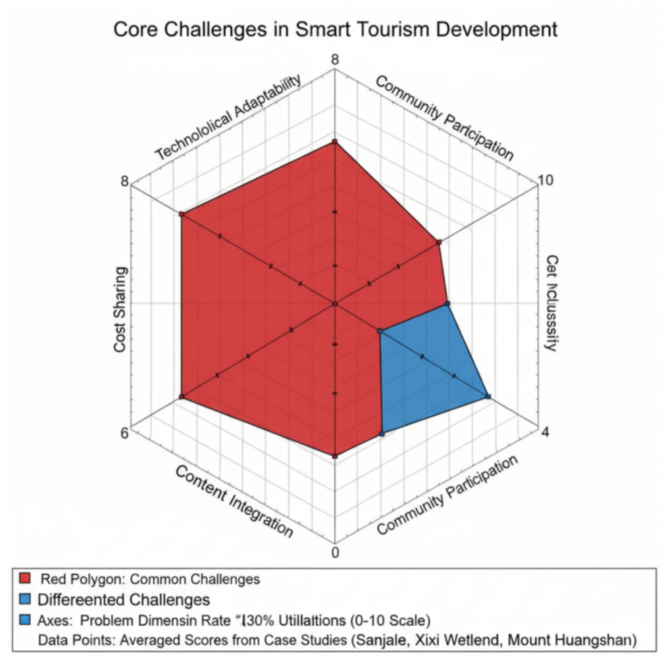

Figure 4 | Digital Technology Application Issue Attribution Radar Chart

ness to share data, with cross-domain data utilization rates below 30% [8, 10].

Long Investment Return Cycles and Cost Pressures

High Initial Investment: The average investment in digital infrastructure for the three scenic areas is 120 million yuan (150 million yuan for Sanjiangyuan, 110 million yuan for Xixi Wetland, and 90 million yuan for Huangshan).

Long Payback Period: The average payback period is 3.5 years, with Sanjiangyuan having a longer period of 4.2 years due to high ecological protection requirements. Technology update costs are high (VR devices need replacement every 2-3 years, with a one-time investment of 20 million yuan), which is unaffordable for small and medium-sized scenic areas [8, 10, 13] (**Figure 4**).

Differentiated Problems: Specific Challenges by Case Type

Ecologically Sensitive Scenic Areas: Balancing Technology Application and Ecological Protection

Sensor deployment must avoid damaging soil and vegetation, leading to monitoring blind spots in some core areas (e.g., deep canyons in Sanjiangyuan).

The immersion of VR virtual tourism is insufficient (a 15% resolution gap compared to real scenes), making it difficult to completely replace on-site visits. On-site tourist volume still requires regulation [10].

Mature Tourist Scenic Areas: Balancing Experience Enhancement and Commercialization

AR guides are overloaded with advertisements (e.g., 20% of content in Xixi Wetland promotes merchants), reducing tourist experience (18% of satisfaction deductions are related to this).

Big data-based precision marketing may trigger privacy concerns—32% of tourists express worry about "consumption preference analysis" [8].

Study Tour Bases: Integrating Educational Content and Technology

Digital courses are insufficiently aligned with national study tour education standards—only 40% of content on the Huangshan Study Tour Platform complies with the *Guidelines for Primary and Secondary School Study Tour Practice Education Courses*.

Instructors lack digital literacy—60% of study tour instructors report "difficulty in proficiently operating VR devices and data analysis tools" [13, 14]. Optimization Paths: Collaborative Solutions Based on the Four-Dimensional Interactive Model

Government Level: Building a Policy and Infrastructure Support System

Improving Cross-Departmental Collaboration Mechanisms

Establish provincial-level smart tourism big data centers and unify data interface standards (e.g., formulating the *Specifications for Data Sharing Between Scenic Areas, Transportation, and Environmental Protection Departments*). Achieve 100% data connection for key scenic areas by 2025.

Set up a data security supervision committee to standardize data collection, storage, and use. Establish an "anonymization + hierarchical authorization" mechanism to eliminate concerns about data sharing [15].

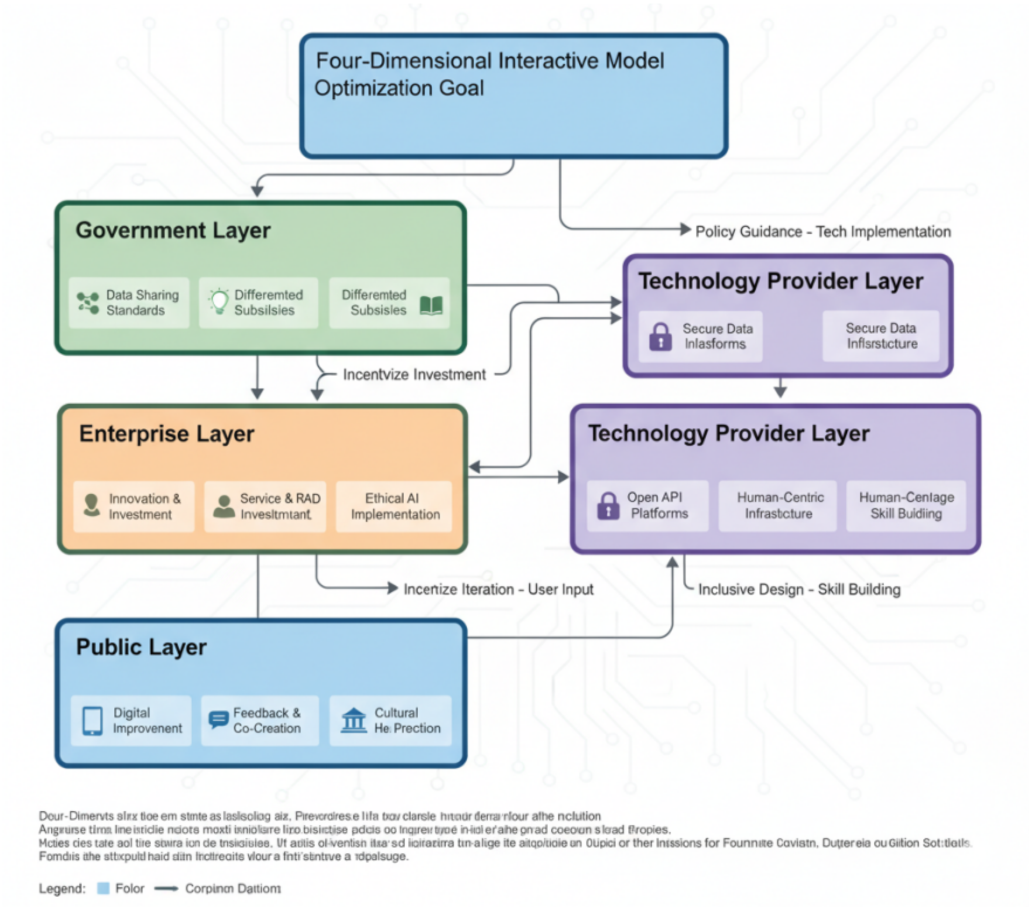

Figure 5 | Government - Enterprise - Technology - Public Collaborative Solution Framework Diagram

Differentiated Subsidies and Support Policies

Provide 60% subsidies for IoT devices in ecologically sensitive areas (e.g., Sanjiangyuan) and prioritize the construction of 5G base stations (achieving 90% coverage by 2025).

Offer "installment payment" plans for technology procurement to small and medium-sized scenic areas to reduce initial investment pressure. Establish a "digital study tour special fund" to subsidize course development (e.g., 30% funding support for the Huangshan Study Tour Platform) [15].

Standards and Talent Development

Formulate the *Standards for Digital Technology Application in Tourism* to clarify technical adaptability requirements for different types of scenic areas (e.g., sensor deployment density in ecologically sensitive areas).

Launch training programs for "scenic area digital managers" to ensure 100% certification of managers in key scenic areas by 2025. Offer "digital study tour education" courses in university tourism majors to cultivate interdisciplinary talents [15].

Enterprise Level: Focusing on Technological Adaptability and Scenario Integration

Optimization of Technological Products

Develop low-power IoT devices resistant to extreme environments (e.g., solar-powered sensors) to reduce the failure rate to below 10%. Simplify user interfaces (e.g., elderly-friendly and student-friendly modes) to increase usage rates to over 80%.

Optimize VR/AR content—add "ecological protection popular science" modules (accounting for 50% of content) in ecologically sensitive areas, and develop interactive courses (e.g., "geological treasure hunting" AR games) in study tour bases [8, 13].

Innovation in Business Models

Promote a "technology sharing" model—large scenic areas (e.g., Xixi Wetland) provide big data passenger flow regulation technology to surrounding small and medium-sized scenic areas and charge service fees (reducing costs for small and medium-sized scenic areas by 30%).

Develop "digital derivatives of ecological products"—e.g., paid unlocked modules for VR tours in Sanjiangyuan (e.g., details of glacier formation)—to increase the proportion of non-ticket revenue [10].

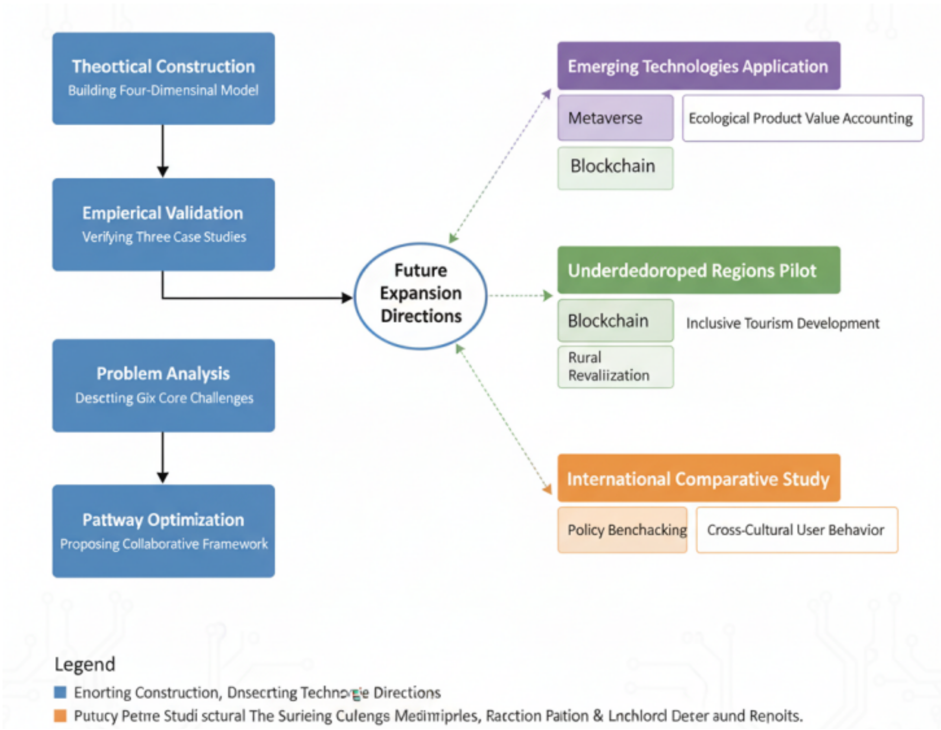

Figure 6 | Schematic Diagram of Research Framework and Future Expansion Directions

Technology Provider Level: Strengthening Technological Innovation and Service Support

Breakthroughs in Core Technologies

Develop "lightweight monitoring technologies" (e.g., drones + micro-sensors) to reduce damage to ecologically sensitive areas. Develop "edge computing nodes" to solve data transmission delays in remote areas [7].

Apply AI to optimize VR content generation and achieve "real-time updates" (e.g., monthly updates for AR guides in Xixi Wetland) to enhance freshness [8].

Full-Lifecycle Services

Provide "customized solutions" for scenic areas (e.g., developing simplified monitors for the Huangshan Study Tour Base) and offer 24-hour operation and maintenance services to reduce device failure response time to within 2 hours.

Conduct technical training—e.g., "practical courses on digital tools" for study tour instructors—to ensure 80% of instructors can operate devices proficiently by 2025 [13, 14].

Public Level: Enhancing Digital Literacy and Participation Awareness

Digital Inclusion Education: Set up "digital assistance posts" in scenic areas to help elderly tourists use intelligent devices. Offer "digital tool introductory courses" in study tour bases to improve students' operational skills [10, 13].

Guidance for Environmental Participation: Launch "low-carbon tourism challenges" through digital platforms (e.g., Xixi Wetland app). Participants can receive discounts on scenic area tickets to increase the conversion rate of environmental behaviors [8].

CONCLUSIONS AND PROSPECTS

Core Conclusions

Theoretical Conclusions

The constructed "Digital Technology-Environmental Management-Tourism Economy-Educational Empowerment" Four-Dimensional Interactive Model reveals that digital technology achieves the symbiotic development of the environment and tourism economy through the progressive action path of "monitoring-regulation-experience-education," filling the limitation of "single-dimensional" research in existing studies. Differences in technological adaptability among different types of scenic areas indicate that the intensity of environmental constraints and functional orientation are key factors determining the focus of technology application.

Empirical Conclusions

In all three cases, digital technology achieves collaborative improvement of the environment and economy: the efficiency of ecological early warning responses increases by over 40%, tourist flow in core areas decreases by 30%, energy consumption per tourist decreases by 26%, and the proportion of study tour revenue increases by 15 percentage points. However, issues such as insufficient technological adaptability, data sharing barriers, and long investment return cycles require collaborative solutions from governments, enterprises, and technology providers.

Practical Conclusions

Differentiated paths are proposed for different types of scenic areas: "lightweight monitoring + virtual experience" for ecologically sensitive areas, "full-process digitalization + precise regulation" for mature scenic areas, and "digital education platform + practical tool integration" for study tour bases. Meanwhile, a collaborative system of "policy support-technological optimization-talent development-public participation" needs to be established to overcome implementation bottlenecks.

Research Limitations

Case Representativeness: The three selected cases are key domestic scenic areas, excluding small and medium-sized scenic areas in underdeveloped regions and international cases. The universality of the model needs further verification.

Depth of Quantitative Analysis: Quantitative methods such as structural equation modeling are not used to analyze the causal relationship between technology application and effects. Future research should supplement panel data for regression analysis.

Coverage of Emerging Technologies: Emerging technologies such as the metaverse and blockchain—e.g., the application of blockchain in the realization of ecological product value—are not covered and require further exploration in subsequent studies.

Future Prospects

Expansion of Research Directions: First, explore the application of metaverse technology in virtual tourism (e.g., "Metaverse Sanjiangyuan") to further reduce on-site tourist volume. Second, study the application of blockchain technology in ecological product value accounting to realize the conversion of "environmental behaviors-carbon credits-economic benefits."

Deepening of Practical Application: Select pilot scenic areas in underdeveloped regions to verify the feasibility of "low-cost digital technology solutions" (e.g., low-cost sensors) and promote technology inclusion.

International Comparative Research: Compare digital tourism practices between China and regions such as Europe and America (e.g., the Swiss Alps) and Southeast Asia (e.g., Chiang Mai, Thailand) to extract adaptive experiences in cross-cultural contexts.

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