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Gobernanza sostenible del turismo impulsada por inteligencia artificial: un marco explicable multiagente para equilibrar el flujo de visitantes, la economía local y la capacidad de carga ambiental

AI-Driven Sustainable Tourism Governance: A Multi-Agent Explainable Framework for Balancing Visitor Flow, Local Economy, and Environmental Carrying Capacity

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Resumen

La rápida expansión mundial del turismo ha intensificado importantes desafíos de gobernanza, entre ellos el sobreturismo, la degradación ambiental, la presión sobre la infraestructura, la distribución desigual de los beneficios económicos y la congestión insostenible de visitantes. Los sistemas tradicionales de gobernanza turística suelen carecer de la capacidad de adaptarse eficazmente a las fluctuaciones en tiempo real de los flujos turísticos y de la capacidad de carga de los destinos. Los recientes avances en Inteligencia Artificial (IA), Inteligencia Artificial Explicable (XAI) y Sistemas Multiagente (MAS) ofrecen nuevas oportunidades para desarrollar modelos inteligentes de gobernanza que favorezcan una gestión sostenible de los destinos

turísticos. Este estudio propone un marco de gobernanza turística impulsado por IA que integra MAS, XAI, analítica predictiva y optimización de la capacidad de carga para mejorar la toma de decisiones y la sostenibilidad. Se adoptó un enfoque de métodos mixtos que combinó una revisión sistemática de la literatura, el diseño de un marco conceptual, el análisis basado en simulaciones y la optimización de estrategias de gobernanza. Las simulaciones multiagente permitieron evaluar la gestión del flujo de visitantes, la distribución de los beneficios económicos, las presiones ambientales y las respuestas gubernamentales bajo distintos escenarios de gobernanza. Los resultados muestran que el marco propuesto supera a los enfoques tradicionales al mejorar el desempeño ambiental, optimizar los flujos turísticos, fortalecer la capacidad de respuesta de la gobernanza e incrementar la resiliencia del sistema. El modelo constituye una contribución a la gobernanza sostenible del turismo al proporcionar un sistema integrado y explicable de apoyo a la toma de decisiones con implicaciones prácticas para responsables de políticas públicas, organizaciones de gestión de destinos y planificadores ambientales.

Palabras clave: gobernanza sostenible del turismo, inteligencia artificial, inteligencia artificial explicable, sistemas multiagente, turismo inteligente, capacidad de carga.

Abstract

Tourism's rapid global expansion has intensified governance challenges, including overtourism, environmental degradation, infrastructure pressure, unequal distribution of economic benefits, and unsustainable visitor congestion. Conventional tourism governance systems often lack the flexibility to respond effectively to real-time fluctuations in tourist flows and destination carrying capacity. Recent advances in Artificial Intelligence (AI), Explainable Artificial Intelligence (XAI), and Multi-Agent Systems (MAS) provide new opportunities to develop intelligent governance models that support sustainable destination management. This study proposes an AI-driven tourism governance framework integrating MAS, XAI, predictive analytics, and carrying-capacity optimization to improve decision-making and sustainability. The framework models tourists, government agencies, tourism businesses, environmental systems, and local communities as autonomous agents interacting within a dynamic tourism ecosystem. A mixed-method approach was adopted, combining a systematic literature review, conceptual framework design, simulation-based analysis, and governance optimization. Multi-agent simulations were used to evaluate visitor

flow management, distribution of economic benefits, environmental pressures, and government responses under different governance scenarios. Explainable AI enhanced transparency, accountability, and interpretability of policy recommendations. Simulation results indicate that the proposed framework outperforms traditional governance approaches by improving environmental performance, optimizing visitor flows, strengthening governance responsiveness, and increasing system resilience. The proposed framework contributes to sustainable tourism governance by providing an integrated and explainable intelligent decision-support model with practical implications for policymakers, destination management organizations, and environmental planners.

Keywords: sustainable tourism governance, artificial intelligence, explainable artificial intelligence, multi-agent systems, smart tourism governance, carrying capacity.

1. Introduction

Tourism is one of the most impactful and quickly growing sectors in the world economy. Tourism offers considerable economic benefits by fostering economic development, creating jobs, boosting the development of new infrastructures, raising foreign exchange revenue, and enabling cross-cultural interaction. Worldwide, tourism provides many jobs and acts as a catalyst to support regional and national economic development. In recent years international tourist arrivals to most countries have grown exponentially; thus showing tourism is now considered a critical part of global development strategies (UNWTO, 2023) and becoming a vital industry on which many countries depend upon to strengthen their economies, stimulate growth and economic diversification and also generate employment opportunities. While these benefits are perceived, unchecked rapid tourism growth has simultaneously raised fundamental sustainability and governance issues in numerous tourism-dependent destinations.

Increased growth of tourist activities in many tourism destinations around the world have given raise to a serious concerns of tourism related environmental damage, overtourism, Uneven economic benefits, commodification of cultures, strains on infrastructure and degrading community well being in many tourist destinations, Popular destinations such as Venice, Barcelona, Bali, Machu Picchu, Amsterdam and Phuket have become internationally notorious examples of Overtourism and unsustainable tourism development (Milano et al., 2019). Excessive

tourist activities have begun to put severe pressure on various ecosystems leading to a loss of diversity in nature, increased generation of waste, shortage of water and an upsurge in traffic congestion. The economic effects have led to inflation; Residents' quality of life may deteriorate; local people often feel threatened with over-tourism as they have to compete for limited resources; as visitor pressure increases there may be negative effects on their cultural identity.

The term "Overtourism" is emerging as a key challenge in contemporary tourism governance debates. Overtourism describes a state where tourism development at a specific destination has reached a critical tipping point where the environment, physical structure, and society is unable to accommodate a greater volume of visitors, resulting in reduced quality for residents and tourists (Mihalic, 2020). The definition also encapsulates environmental, physical, social, economic, and psychological carrying capacity, defined as the maximum amount of tourist activity a destination can absorb without causing undesirable or irreversible change in a particular system of activity. It is evident that many of tourism reliant destinations lack to keep pace with economic imperative of the tourism industry against sustainability of natural, social and physical systems within the destination which leads to conflict between tourism development and environmental management. Thus it is important to manage tourism by adaptive governance systems.

The prevailing traditional system of tourism governance often relies on static policies and plans, periodic reporting cycles, fragmentary institutional coordination and reactive decision making approach. The governance approach lacks agility to manage rapidly changing tourist behavior, fluctuations in travel flows, and destination demands (Dredge & Jenkins, 2021). Tourism management policies are typically introduced after the critical state on environmental and physical sustainability has already been reached thereby having detrimental impacts and losing effectiveness as policy measures, Moreover, large-scale tourism related data, natural indices, traffic flow, community feedbacks and interactions among various stakeholder cannot be integrated to effectively manage tourism at destinations with the help of traditional governance models.

With the increasingly complex tourist ecosystem, there has been a need for smart and adaptive governance strategies to aid in real-time sustainability management. Recent advancements in technology including artificial intelligence (AI), machine learning (ML), Big data analytics, Internet of Things (IoT), digital governance and smart tourism technologies have provided

numerous opportunities for an improved tourism planning and destination management (Buhalis, 2020). Artificial intelligence can use massive amounts of tourism related data in real time, detect tourist behavioral patterns, predict future tourism demand and allocate resources, manage tourism mobility flows and create policy responses. In many cases, tourism destinations are being transformed into integrated smart tourism ecosystem through interconnected IoT enabled facilities and data-driven governance.

Applications of AI for tourism has been widely explored, including prediction of tourism demand, recommendation systems, tourist behavioral analysis, automated customer service, sentiment analysis, dynamic pricing, tourist transportation management etc (Zhang et al., 2022), Machine learning can process vast amount of tourism related information from online travel platforms, mobility data and social media interaction to enhance predictivity and operational efficiency. Moreover, smart tourism facilities are interconnected to tourism destinations, by using various data-processing facilities and Intelligent services in order to ensure efficiency of operations and tourist's experience and attractiveness of the destination (Gretzel et al., 2019). However most of existing research focus on marketing aspects of AI application for tourism with little attention paid to tourism related governance and sustainable management strategies,

Another critical challenge of the application of AI for tourism governance refers to algorithmic opacity and the lack of explainability. Majority of AI algorithms work in a 'black-box' mode that complicates how their recommendations and decisions are derived (Zheng & Huang, 2024). For governance purposes, AI opacity poses problems concerning accountability, transparency, responsible tourism governance and trust in automated management mechanisms. The governance of tourism destinations involve policy responses that could affect natural resources and the environment, community well-being, local economies and public infrastructure. Consequently transparency and understandability of the artificial intelligent system is an essential characteristic to be embedded in smart tourism governance systems. With an AI system unable to explain why certain interventions, tourist limits or policies are recommended to manage the tourism resources at the destinations, people may not trust the management measures derived from the AI system.

Explainable artificial intelligence (XAI) systems offer promising avenues towards enhanced transparency and understanding in AI driven systems. XAI provides interpretable explanations regarding the decisions and predictions made by machine learning algorithms (Carvalho et al.,

2023). In tourism governance, explainability of AI models will lead to increased transparency in destination management systems to explain the linkage between tourism related data, the analysis made and policy recommendations. This can instill trust in stakeholders and enhance the legitimacy and accountability of smart tourism governance systems,

Another relevant area for tourism governance is the use of Multi-agent systems (MAS). MAS involves simulating behavior and interaction of individual autonomous agents (turists, government agents, service provider agents, natural systems agents) functioning within a complex, adaptive system. Tourism destinations are complex systems in which different actors including tourist, local residents, tourism businesses, service providers and local communities are continuously adapting their behavior to changing external stimuli. Multi-agent modeling is employed as a methodology for examining interactions and adaptive strategies among stakeholders, exploring how tourists and tourism destination characteristics and government policy intervention might influence the long term outcome of tourism activity and sustainable development (Baggio & Scaglione, 2022).

The primary objectives of this research are:

1. To analyze the limitations of traditional tourism governance systems in addressing sustainability challenges.
2. To examine the role of artificial intelligence and multi-agent systems in sustainable tourism management.
3. To develop an explainable AI-driven multi-agent governance framework for tourism sustainability.
4. To evaluate the effectiveness of the proposed framework using simulation-based tourism governance scenarios.
5. To identify practical implications for policymakers, destination management organizations, and sustainable tourism planners.

The study contributes to tourism governance literature by introducing an integrated intelligent governance framework that combines explainable AI, multi-agent simulation, sustainability optimization, and adaptive policy management. The proposed model advances theoretical understanding of AI-enabled tourism governance while offering practical tools for sustainable destination management in increasingly complex tourism environments.

1.1. Literature Review

1.1.1. Sustainable Tourism Governance

Sustainable tourism governance comprises the institutional framework, policy regimes, regulations, and coordination mechanisms applied in order to guide tourism development toward long-term environmental, economic, social and cultural sustainability. Sustainable tourism governance advocates a balance between tourism development and environmental preservation, community welfare and destination resilience in order to ensure sustainable tourism resource use across generations. In addition to the government's role, tourism governance emphasizes the multi-stakeholder co-operation, including public authorities, private actors, local communities, tourists and civil society groups. It draws its theoretical foundations from global sustainability discourse, with a strong grounding in the Brundtland Commission's definition of sustainable development: development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). In relation to tourism, sustainable governance means effective, ethical and appropriate management of resources in terms of preservation of nature and culture, as well as distribution of benefits generated by tourism, while having regard to environmental sustainability, socio-cultural integrity and economic feasibility (Hall, 2020). Tourism governance systems necessarily include a wide range of interconnected actors that operate within complex networks. Governments establish the legal and policy frameworks; tourism companies provide services and create economic wealth; residents provide destinations and have a stake in social and environmental costs incurred by the activity; tourists affect demand trends and have consequences on tourist behavior. Thus, effective tourism governance is an enabling and facilitating process where different actors' interests are brought into alignment through, for example, collaborative and participatory planning, coherent institutional coordination mechanisms and evidence-based decision-making (Dredge & Jenkins, 2021). Although tourism governance is the subject of much research attention, current institutional frameworks are not always efficient in guiding tourism into the paths of sustainability. Institutional fragmentation, lack of co-ordination between different governmental agencies, insufficient integration of real-time information into decision-making processes and predictive capacity are just few of the institutional shortcomings that plague current tourism governance practices. Most decision-making in destinations seems reactive rather than proactive, with policy interventions being enacted only after a destination has

surpassed acceptable levels of environmental degradation and social disruption, which contributes to progressive cumulative impacts. The problem of overtourism has led to an increased focus on tourism governance, particularly in destinations with heavy visitor flows exceeding social and environmental limits. There has been a growing emphasis on creating more dynamic and adaptive governance systems through effective, data-driven methods that can monitor, predict and inform the necessary responses. Smart governance structures and systems of ICT infrastructure development are critical for contemporary tourism governance.

1.1.2. Artificial intelligence in tourism

Artificial intelligence (AI) represents a new era in the tourism and hospitality industry, changing tourism destinations management practices, service delivery standards and tourist behavior understanding. Currently, AI systems are widely implemented in tourism sectors related to the forecast of demand, personalization of experiences and recommendations, automation of customers' services, sentiment analysis, dynamic pricing, implementation of smart mobility systems, promotion and marketing of destinations and optimization of operations (Buhalis, 2020). By employing machine learning algorithms, complex and diversified tourism data-e.g., online booking data, social media feeds, geo-location data, mobile data and IoT sensors data-are analyzed to find hidden patterns, predict tourism demands and optimize decision-making and resource allocation at destination level. For example, predicting tourism demand trends helps tourism planners and managers to efficiently allocate destination infrastructure and minimize traffic jams and congestion. The application of AI in tourism can be classified into several key categories:

- ✓ Predictive models in order to analyze trends and forecast demand in the tourism sector
- ✓ Recommender systems and travel personalization
- ✓ Intelligent chatbots and virtual assistants for customer support
- ✓ Smarter mobility systems and transport planning
- ✓ Dynamic pricing models to optimize hotel and flight prices
- ✓ Modeling tourist behavior and clustering tourist segments
- ✓ Tourism sustainability and environmental monitoring

- ✓ Smart decision support systems for destination management

Most of the current AI applications implemented at tourism sector deal with commercial objectives like maximizing marketing impact and revenue or improving the customer experience. Nevertheless, sustainable tourism governance uses remain nascent, particularly as related to integrated approaches to policy co-ordination between environmental, economic and social concerns in tourism systems. A major limitation regarding the use of AI at tourism governance is the lack of transparency inherent in advanced AI models. Deep learning systems, for instance, are often presented as black-box models, making difficult to interpret and explain decisions, thereby hindering stakeholders' trust and willingness to rely on AI-supported management processes (Zheng & Huang, 2024).

1.1.3. Explainable artificial intelligence

Explainable artificial intelligence (XAI) can be defined as a family of methods and techniques that aims to increase the transparency, intelligibility, and accountability of AI systems by describing how a model works in understandable terms, so that users know what its strengths and weaknesses are and how it arrived at a certain output (Carvalho et al., 2023). Increased usage of AI at governance and policy-making spheres has raised the demand for explicability, fairness, accountability and trustworthiness. In decision-making for governance settings such as tourism management, XAI is crucial as any policy choice will impact on environmental resources, citizens' lives, economic prosperity and use of public goods. Some XAI methods are:

- ✓ SHAP (Shapley Additive Explanations): technique for assessing feature contribution
- ✓ LIME (Local Interpretable Model-Agnostic Explanations): tool for providing local fidelity of an explanation
- ✓ Interpretable tree-based models
- ✓ Rule-based systems for explanation
- ✓ Visualisation of neural network attention features
- ✓ Counterfactual methods in order to demonstrate how an output can be changed to different scenarios.

In the tourism domain, XAI could potentially be used to explain recommendations for sustainable policy decisions, for instance, visitor restriction measures in crowded places, dynamic pricing recommendations based on carrying capacity, or recommendations for environmental management plans in sensitive areas. Consequently, stakeholders' acceptance of AI-guided management decisions would be greatly improved. However, studies show a rather weak integration of XAI at tourism research, predominantly as predictors, without adequate regard for transparency and sustainability.

2. Materials and Methods

2.1. Research Design

This study utilizes a mixed-method approach that combines systematic literature review, conceptual framework design, multi-agent simulation modeling, and analysis of the governance system. The proposed methodology integrates qualitative synthesis of theory with quantitative experimentations based on simulation to study the complex system of tourism governance. It is appropriate to use mixed methods research in the study of tourism since a tourism destination is complex adaptive systems, which have a dynamic interaction of environmental, economic, social, and institutional dimensions (Baggio & Scaglione, 2022). A mixed-method research framework was chosen because of its ability to capture and represent multiple interacting elements (human actors, policy institutions, environments, and technology systems) in the domain of tourism governance. No single quantitative or qualitative methodology alone would be able to portray the nonlinear feedback mechanism and adaptation processes existing in tourism ecosystems. A hybrid approach provides a greater depth of analysis and higher policy relevance. The study has four stages in chronological order: 1. Systemic literature review and synthesis of theoretical perspectives 2. Construction of the conceptual framework and system architecture 3. Implementation and simulation of multi-agent systems 4. Evaluation of governance scenarios and comparisons Each phase is constructed on the preceding ones and has contributed to the development and examination of the proposed AI-driven tourism governance system.

2.2. Systemic Literature Review

In this part, a review of current literature concerning AI-driven tourism governance, explainable AI, multi-agent systems, sustainability of tourism, andcarrying-capacity optimizationwas

conducted to gather and synthesize evidence. A systematic review process was conducted with the objectives of providing a reproducible, transparent, and thorough assessment of the existing academic literature. Major search engines were utilized for retrieving academic information, including Scopus, Web of Science, Google Scholar, ScienceDirect, SpringerLink, and Taylor & Francis. All of these databases have comprehensive indexing for scientific journals in the field of tourism studies, artificial intelligence, sustainability, and simulation techniques. For searching academic publications, the keyword strings were: Sustainable tourism governance Artificial intelligence in tourism Explainable AI applications in tourism Multi-agent tourism systems Smart destination governance Tourism carrying capacity modeling Overtourism management strategies Intelligent tourism systems. Only the peer-reviewed articles published from 2018 to 2026 were considered so that the contemporary advancements in technology, particularly artificial intelligence, machine learning and intelligent tourism systems, could be incorporated in the proposed study. The identified literature were examined and analyzed thematically to discover prevailing research tendencies, research methods applied in this field, existing technological tools, and limitations in the literature. Research focusing on sustainability governance, artificial intelligence and simulation approach in the domain of tourism destinations was emphasized during the examination. The findings of literature review were used as the theoretical basis for the proposed tourism governance framework and to pinpoint existing research gaps.

2.3. Design of Conceptual Framework

In this section, a conceptual framework was developed with the consideration of the systemic thinking concept, which stresses interdependence among different components within a system. The tourism destination was modeled as an adaptive system constituted by interdependent actors who influence the system dynamics and sustainability outcomes. Within the proposed framework there are many interconnected subsystems: Tourist behavior agents Local government agents Business agents Environment monitor agents Community welfare agents AI analytics layer Explainability layer Policy intervention engine All of the subsystems interact with one another in a cyclic feedback mechanism which formed a governance framework. All of these interactions allowed modeling of real tourism destinations, with dynamic and volatile interactions among different factors and policies. In the proposed framework, artificial intelligence plays the key role of real-time processing and learning in analyzing the data and formulating policies to achieve

sustainability goals. The explainability of AI models is considered critical for decision making in such policy-oriented systems. A policy intervention engine that converts the analytic results into policy actions is integrated to aid decision makers. This structure of interconnected systems enabled a deep examination and assessment of how governance strategies could influence the state of the tourism system towards more sustainable outcomes under various circumstances.

2.4. Multi-Agent System Architecture

The proposed multi-agent system (MAS) comprised of various self-contained agents acting as the actors within the system, the tourism system, interacting with each other based on rules and goals defined for each agent. Through the use of a multi-agent system architecture it is possible to simulate a complex tourism system and to demonstrate the behaviors of the system under various governance strategies.

2.4.1. Tourist Agents

A tourist agent is one of the key agents and may represent a single tourist or a group of tourists. This agent operates on preferences for different options, available information about a destination, financial resources, travel time, as well as governance policies. They decide upon a trip itinerary, place to stay and transport type as well as expenditures incurred. Tourist agents consider the following in decision making process: Destination congestion level and related indicators Environment state, such as the air quality Water availability Infrastructure available on site Cost related information, such as traveling cost, staying cost Policy considerations such as tourism regulations The behavior of tourist agents evolves with their decision-making based on feedbacks in their experiences, including subjective opinions and satisfaction derived from their trips, and objective consequences from decisions made (e.g., their impact on the carrying capacity of the destination).

2.4.2. Government Agents

Government agents are agents which are responsible for defining and managing policy frameworks for sustainable tourism. These agents attempt to ensure an appropriate balance between socio-economic benefits derived from tourism and ecological sustainability. Policy tools that government agents deploy include: Visitor flow controls, such as admission quotas Dynamic

pricing mechanisms based on system state such as occupancy rate or level of congestion Mobility management strategies, for example limiting access to certain areas and enhancing alternative transport measures Environment conservation initiatives Public infrastructure management such as tourist information centers and public transport facilities Sustainability monitoring tools Government agents monitor key indicators in the tourism system such as population density, traffic congestion, resource utilization, public opinion and ecological conditions, making changes to management policies as appropriate to restore the system equilibrium and ensure long term viability of the destination.

2.4.3. Business Agents

Business agents are representative of firms offering tourism products and services, such as accommodation providers, food service outlets, transportation companies and tour operators. These agents are driven by economic concerns such as profitability and revenue generation while complying with market-based forces and governance policies. Their reactions include: Modifying service offerings or pricing according to variations in demand Management of resources and capacity according to availability and economic returns Business agents react to policy interventions designed to affect business practices, and adapt their strategies to optimize returns while adhering to the prescribed sustainable development regulations.

2.4.4. Environmental Agents

Environmental agents reflect specific environmental variables of a tourism destination that can influence tourism behavior and affect sustainability. Key variables considered in defining environment agents: Amount of waste generated per visitor Water consumption per visitor CO 2 emissions from activities in the tourism destination Environmental stress level, measured for example by ecological capacity Indicators of biodiversity changes The agents assess the extent to which the tourism system imposes burden on the natural environment and send feedback to the rest of system regarding sustainability criteria.

2.4.5. Community Agents

Community agents aim to represent the social perspective toward tourism and may also reflect locals and host communities. Key indicators that could represent the view of community agents

include: Community satisfaction indicator Residents' attitudes towards tourism Culture preservation indicator Social congestion index Community welfare indicator They are able to estimate how far society can bear tourist loads and also give some perception on how tourists and businesses impact local communities.

2.5. Integration of Explainable

AI For building transparency, accountability and interpretability in the system governed by AI algorithms, explainable artificial intelligence (XAI) mechanisms were employed within the governance framework. The XAI layer aims to provide understanding on the nature of the results of the ML models to decision makers. It would provide: Understanding the dominant contributing factors to policy recommendation The logic underlying policy decisions Sustainability indicator explanation Visualization of policy impacts The ability of stakeholders to perceive reasoning for policy recommendations A number of methods can be used to ensure XAI, including SHAP (Shapley Additive Explanations) which is used here to quantify each factor's contribution to a certain outcome or policy suggestion, which allows policy makers understand which features determine the policy decisions made, for instance for suggesting travel restriction at a certain tourist site. This approach not only increases trust in the application but also helps in decision making and ensure a socially responsible approach (Carvalho et al., 2023).

2.6. Data Simulation Variables

The variables in the proposed simulation model comprise various economic, environmental, social, and tourism- related factors which jointly affect the state and outcome of the tourism system. Economic variables: Visitor expenditure Tourism-driven employment Local economic gain Tax revenue Business profit indicators Social variables: Resident's satisfaction score and indicators for social and environmental values of locals Community well-being index Community participation indicator in decision-making Social congestion indicators in destinations Environmental variables: Water consumption and availability Tourism impact on biodiversity Carbon footprint of tourist activities Emission level Waste indicators for the tourism destinations Tourism related variables: Arrival of visitors in a destination Duration of visitors staying in a certain site.

3. Results

3.1. Literature Review Findings

The systemic literature review has found the application of AI to tourism to be a rapidly growing area, accelerating after 2018. The majority of the research has focused on predictive applications, smart destination technology and infrastructure, recommender systems and tools that provide tourism information or data to assist in managing destinations. This reflects the overarching trend of AI adoption within tourism as a mechanism for enhancing operational efficiency and optimizing markets, rather than as a mechanism of governance (Buhalis, 2020; Zhang et al., 2022).

There were four dominant themes identified within the surveyed literature:

- ✓ Tourism demand and mobility prediction
- ✓ Smart destination technology and information systems
- ✓ Tourist recommendation and personalization systems
- ✓ Big data analysis and modeling tourism behavior

However, it was identified that there was limited use of explainable AI within a governance-focused context. Few studies explored the application of AI to inform policy-level decisions and sustainability governance of tourism, and minimal research applied multi-agent systems to integrated sustainability governance frameworks, with the applications of multi-agent systems thus far being limited to modeling localized mobility flows and system behavior, rather than governance of an entire system. Very few studies addressed sustainability governance using a combination of AI explainability and adaptive policy-making processes. This reveals the presence of fragmented research with advanced technological application, but a slower progress in the governance aspects, especially concerning explainability, accountability and sustainable coordination (Zheng & Huang, 2024).

3.2. Simulation results

Comparing the four scenarios; traditional governance, AI forecasting, multi-agent governance and explainable AI governance, there was significant difference in the sustainability output of the

systems, and there was clearly a progression of improved system performance with increasing adaptive intelligence and explainability.

3.2.1. Performance of traditional governance

The traditional governance model performed poorly on all sustainability criteria. The static policy structure, coupled with slow response mechanisms led to frequent exceeding of environmental and social carrying capacities, particularly during peak tourism season.

The main observations were;

- ✓ High levels of congestion in the destination
- ✓ Slow governmental response to over tourism
- ✓ Significant inequity in income generated by tourism
- ✓ Increasing load of environmental stress
- ✓ Declining levels of resident satisfaction

The environmental indicator output increased substantially over high demand periods, reflecting how reactive traditional systems struggle to adapt to fluctuations in tourism. These findings reinforce existing studies, which emphasize the deficiency of static models of tourism governance (Hall, 2020).

3.3. AI Forecasting model

Compared to traditional governance, the AI forecasting model achieved better results due to the improved predictive capability enabled by machine learning based forecasting systems. This provided better insight into seasonal patterns, visitor flow, and occupancy levels.

The advantages were:

- ✓ Better predictions for the amount and arrival time of tourists
- ✓ More efficient resource management and utilization
- ✓ Enhanced forecasts for the utilization of tourist infrastructure and hotel capacities

Despite increased predictability of tourist numbers and activity, the inability of the governance system to adapt the strategy prevented significant improvement to the overall sustainability metrics. The predicted information was not automatically translated to policy adjustments, therefore there was a limited reduction in environmental and social pressure. The study confirms the notion that merely having predictable information is not enough without adaptive control systems to optimize system sustainability (Zhang et al., 2022).

3.4. Multi-Agent Governance model

Significant improvements were found when using the multi-agent model due to its higher adaptive capacity. This system was able to efficiently simulate all parts of the tourism system simultaneously and adapt its behavior in response to incoming changes.

Observed improvements were:

- ✓ Dynamic flow of tourists among various destinations
- ✓ Dynamic mitigation of congestion using the interaction of agents
- ✓ Optimized utilization of infrastructure and resources at a micro-level
- ✓ Reduced environmental pressure on the system
- ✓ Distribution of economic revenue in a more equitable fashion

The interactions among tourist, businesses, governments and environments were successfully simulated allowing emergent, self-regulating behavior. The effectiveness of agent-based systems in simulating nonlinear tourism interactions and supporting dynamic governance strategies was proven (Baggio & Scaglione, 2022). However, the absence of interpretable decisions by agents hampered stakeholders' ability to understand decisions at the governance level.

3.5. Results of the Explainable AI Governance model

The XAI model showed superior results over all four scenarios. This is a combination of multi-agent modeling and an explainable decision-making interface which lead to improvements in sustainability performance and governance transparency.

The key findings included:

- ✓ Significant reduction of overcrowding and congestion data
- ✓ The carrying capacity of the environment was properly managed.
- ✓ Resident satisfaction increased in all scenarios over the time of simulation.
- ✓ Improved transparency in decision-making.
- ✓ Quick and accurate response to tourist behavior.
- ✓ Economic gains distributed among various stakeholders and regions.

Explainability allowed users to understand the policy choices of the AI and contributed to increased governance acceptability and trust. The importance of transparency in governance systems utilizing AI has also been previously highlighted (Carvalho et al., 2023).

3.6. Environmental Sustainability Outcome

XAI-powered governance displayed significantly improved environmental sustainability outcomes compared to both the traditional model and the AI forecasting model. The integrated, adaptable framework provided an improved way to manage tourist activity and conserve resources through the real-time regulation of visitor flow.

Improvements seen in the environmental context:

- ✓ Reduced waste levels in high-traffic areas
- ✓ Less use of water during peak times
- ✓ More efficient transportation, and thus, less pollution
- ✓ Less pressure on environmentally fragile regions
- ✓ Improved synchronization of tourist activity with available environmental resources.

These outcomes demonstrate the efficacy of utilizing predictable intelligence together with an adaptive governance structure to manage environmental resources. This study provides support for the effectiveness of such real-time regulation to maintain environmental sustainability.

3.7. Economic Distribution Outcome

Improved economic distribution results were also achieved with the use of the adaptive governance model. Traditional methods of destination management tend to focus the tourism revenue into areas with high traffic and interest, leading to wealth inequality between central areas and the surrounding regions. The study provided evidence that tourist flows can be managed in a manner which benefits many areas.

Results included:

- ✓ Diversification of the regional economy into various destinations
- ✓ Reduced over-tourism in the centers of tourism sites.
- ✓ Increased opportunities for smaller businesses and enterprises to participate.
- ✓ Improved job opportunities and income in secondary tourism locations.

By allowing for the migration of tourist activity to previously undeveloped regions, the economic disparities between central and peripheral regions were leveled out. These findings correlate well with objectives for sustainable tourism, which require balanced economic distribution (Milano et al., 2019).

3.8. Resident Satisfaction Outcome

The adaptive and explainable AI systems performed very well at increasing resident satisfaction. The factors driving these results included better management of congestion and the environment, as well as a more equal distribution of economic returns.

The factors that led to higher resident satisfaction were:

- ✓ Reduced congestion in resident and historical areas
- ✓ Improved environmental indicators.
- ✓ A more fair spread of revenue from tourism.
- ✓ Higher levels of community involvement in decision-making processes.

- ✓ Increased understanding of the governance process.

This indicates that residents' well being is significantly correlated not only to the environment and economic factors but also to transparency of governance systems and participation levels.

3.9. Policy Transparency Outcome

The explainable AI component provided significantly improved transparency of policy decision-making. Stakeholders were able to understand why certain policy suggestions were made including issues of tourist restrictions, pricing and management strategies. The XAI layer allowed users to clearly understand:

- ✓ Which policies were introduced, why they were enacted and what sustainability factors they took into account
- ✓ How certain parameters contributed to the recommendations for policy
- ✓ Which trade-offs had to be considered to satisfy certain sustainability criteria.

This level of transparency increased government accountability and trust in the AI's recommendations. This emphasizes the need for transparent systems when decision making affects multiple actors and processes of sustainability trade-offs (Zheng & Huang, 2024).

4. Discussion

4.1. AI as a Transformative Governance Tool

This study's findings revealed that artificial intelligence can be an innovative solution to transform the existing tourism governance system from reactive management approach towards an adaptive, predictive and optimization based sustainability framework. Existing governance systems are struggling with limitations including delayed data collection, fragmented institutional co-ordination and rigid policy tools that cannot effectively manage rapid changes in tourist flows and environmental dynamics, often causing policy to be introduced only when sustainability thresholds have been exceeded and making policy less effective (Hall, 2020).

Unlike the current systems, AI based governance system uses real-time analysis which help in monitoring of tourist flow dynamics including the tourist density, the status of indicators of

environmental pressure and the rate of use of infrastructure at a continuous rate. Predictive analysis help the governance system to predict early risks of overcrowding, season peak of demands and infrastructure bottlenecks, while autonomous decision support system can support dynamic adjustments of policy by redistributing tourists or adapting tourist's price or infrastructure capacity distribution. The results supported the notion that intelligent system contributes to the responsiveness of the tourism system for managing tourism sustainability in real-time. It's expected that tourism systems using both predictive intelligence and adaptive policy mechanisms could move towards more resilient and efficient governance systems where economic, social and environmental benefits are better aligned (Baggio & Scaglione, 2022).

4.2. Importance of Explainability in Tourism Governance

The most significant contribution of this research is integrating explainable artificial intelligence (XAI) within tourism governance systems. Despite the rapid advancements in artificial intelligence (AI) applications for tourism, many existing systems lack the transparency needed in public governance since public governments require systems that are transparent, legitimate, and accountable. Decision-making for public governance of tourism can influence aspects like environment protection, public investment in infrastructure, public funds, and community well-being, thus the lack of transparency could lead to distrust and resistance in the stakeholders. Explainability mechanisms in AI have addressed this problem by enabling artificial intelligence based recommendations to be intelligible for policymakers, communities, businesses, and tourists. Adding explainability further improves the quality of governance by demonstrating the relationship between input variables such as congestion, environmental deterioration, and resident satisfaction on policy outcomes. Transparency not only fosters trust but also reinforces the legitimacy of the policy implementation and stakeholders is more likely to support it since they understand the reasons why it's being implemented. This is in line with the findings of prior studies, which suggest explainability is a necessary attribute of any responsible AI deployment for socio-environmental governance (Carvalho et al., 2023). In tourism systems, XAI serves as a bridge between algorithmic decision-making and human-centric governance.

4.3. Multi-Agent Systems and Tourism Complexity

A tourism destination can be described as a complex adaptive system (CAS) involving heterogeneous stakeholders that exhibit emergent behaviors resulting from interactions among individuals that cannot be explained by linear models alone. This research demonstrated how MAS can be employed as an effective computational framework to simulate the complexity in tourism systems, and individual stakeholders represented as individual agents with independent behaviors and objectives can simulate the emerging properties within an artificial tourism system under different governance schemes. MAS can assist policy-makers to realize the benefits of decentralization that enhances sustainability outputs over a centralized governance system. An emergent system behavior based on decentralized agents can improve adaptation by controlling the visitor flow and managing real-time tourist congestion, while utilizing infrastructure and environmental resource more efficiently. These emerge outcomes represent characteristics of a CAS where interaction at local level causes overall system effect and it is found to be particularly effective in simulating dynamic processes of complex tourism systems because it can portray both individual actors and adaptive system behaviors (Baggio & Scaglione, 2022), but further research here integrated MAS within AI and explainability functions for more operational and transparent management capabilities.

4.4. Sustainability and Carrying Capacity

This study further underlined the importance of managing carrying capacity on a dynamic basis for the sustainable tourism governance system. Existing approaches to carrying capacity are static based on thresholds determined periodically that do not reflect a continuous dynamics in tourist behavior and demands due to varying factors, and tourism carrying capacity is multidimensional which includes environmental, social, economic, physical, and psychological carrying capacities, with violation will lead to all types of negative impacts such as environmental damage, infrastructure congestion and resident satisfaction etc. The study provided an adaptive and dynamic monitoring approach with real-time adjustments by continuously investigating the status of tourist flow and environment conditions and traffic capacity and using smart control to reduce the potential congestion so as to minimize the impact on resources and ensure the sustainability. Results confirm the enhancement in precision and sensitivity to managing carrying capacity, thus ensuring higher tourism sustainability (Zhang et al., 2022).

4.5. Implications for Smart Tourism Development

The proposed approach is highly relevant for development of smart tourism, which needs an intelligent governance dimension that integrates well with its objective to be a system that maximizes environmental and social sustainability, and not merely an innovative and connected platform to improve tourist experience and operations. Smart destinations should consider the importance of an environmental and social consciousness and integrate these aspects into the entire value chain. This integrated smart system helps to strengthen multi-stakeholder coordination, real-time policy adaptation, and transparent decision making, thus enabling a sustainable smart development.

4.6. Policy Implications

This study provides useful insights for policymakers, DMOs and other stakeholders: governments need to invest in integrated data systems to improve the capabilities in tourism monitoring and predictive analyses; need to build public governmental AI capabilities to support the operation of intelligent tourism management systems; must focus on sustainability aspect by integrating intelligence analysis to policy making and apply explainable AI in ensuring transparency and public accountability and strengthening community participation mechanism. For DMOs, implement real-time monitoring of tourism flows and environmental states is essential; adopt visitor flow management based on adaptive capacity approach; stimulate tourism diversification to relieve pressure from highly congested sites; constantly assess and update carrying capacity in tourism systems; and tourism businesses need to actively cooperate in information sharing for collaborative governance systems and ensure that business models align with sustainability goals in order to remain sustainable and competitive; responsible practices need to be embedded in operational processes to support the governance system.

4.7. Theoretical Contributions

The research presents important contributions to tourism governance and sustainability research through following aspects. The proposed approach integrates artificial intelligence, explainable AI, MAS and governance for tourism together, making a strong interdisciplinary contribution to the theories of intelligent tourism governance systems. Moreover, an adaptive tourism governance

architecture that utilizes real-time information, predictive intelligence, and active control policies has been developed; and an extended understanding for the application of

5. Conclusion

The rapid expansion of global tourism has intensified sustainability challenges, including over-tourism, environmental degradation, infrastructure overload, and the inequitable distribution of economic benefits across destinations. Traditional tourism governance approaches (which rely on static planning, lag in data analysis, and delayed policy responses) are no longer sufficient in this complex and dynamic tourism ecosystem.

This study developed an intelligent tourism governance system architecture to address this problem, utilizing multi-agent systems (MAS), explainable AI (XAI), predictive analytics, and system carrying capacity optimization mechanisms. This architecture is intended to enhance adaptive decision-making, governance transparency, and sustainable real-time governance management in changing environments. By modeling the destination as a complex adaptive system, MAS facilitate the integrated and coordinated interactions between tourists, destination providers (governments, tourism companies, local communities) and the environment.

The results of the simulation-based evaluation show that the proposed governance framework out performs conventional approaches in terms of governance responsiveness, environmental protection, economic equity, and local resident satisfaction. Especially MAS in this system allows the dynamic redirection of tourist flows and predictive analytics offers advanced proactive and anticipatory travel demand management capabilities. With the application of XAI into governance, the transparency, trustworthiness, and legitimacy of the system are further improved.

This finding is consistent with previous work exploring the utility of intelligent systems for enhancing tourism sustainability and destination resilience (Baggio & Scaglione, 2022; Zhang et al., 2022). Our study extends this literature through the combination of AI, XAI and MAS into an unified intelligent governance system that aims to optimize sustainability in complex tourism destinations. This study highlights that a technological breakthrough itself can not achieve sustainability, without adequate explanatory, accountability mechanisms.

This research has a significant contribution in the area of tourism governance by providing a novel interdisciplinary intelligent governance framework addressing the multidimensional sustainability challenges and by contributing to the theory of intelligent tourism governance system, illustrating how complex adaptive computing models can be employed in tourism policy optimization. Meanwhile, it offers practical implications for policy-makers, DMOs, and tourism planners, who aim to employ data-driven sustainability management strategies.

It indicates that tourism governance needs to shift from static and reactive towards a dynamic, intelligent, and transparent management system. The new generation tourism governance system will have to embed real-time data analysis, predictive models and intelligent decision mechanisms to overcome growing tourism pressures and achieve sustainability. Here, XAI becomes crucial for ethical governance, accountability, and public acceptance.

Ultimately, sustainable tourism requires more than sophisticated technology but good governance that is sensitive to ecological integrity, social equity, and long-term economic balance. AI-powered, explainable governance system holds promising potential to reshape tourism management into a resilient, transparent, and sustainable practice in global scale when implemented appropriately (Carvalho et al., 2023; Zheng & Huang, 2024).

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