

Navigating Challenges and Embracing Innovation in Shining a Light on Malaysian Astrotourism.

Abstract

Astrotourism, as a specialised segment within interest-based tourism, offers a unique synergy between scientific exploration, cultural heritage, and sustainable tourism. This study critically examines the development of astrotourism in Malaysia through qualitative thematic analysis grounded in Focus Group Discussions (FGD) involving ten experts from the academic, industry, and policy-making sectors. The findings identify four main dimensions. First, significant challenges include severe light pollution, a lack of infrastructure in remote areas, the absence of designated dark sky reserves, and the lack of a comprehensive regulatory framework. Second, substantial opportunities exist through the potential integration of astrotourism with Islamic tourism and ecotourism, leveraging Malaysia's cultural richness, natural biodiversity, and existing observatory infrastructure. Third, the development of mobile applications is identified as a key innovation capable of enhancing tourist experiences through storytelling, real-time environmental data, and event notifications, while also supporting tourism operators with marketing tools and user feedback systems. Fourth is the policy and social frameworks as drivers of integrated astrotourism development in Malaysia through the restructuring of tourism policies, science communication within space policy, as well as inclusive rural transformation, to demonstrate how astrotourism can be positioned as a cross-sectoral policy driver that contributes to economic development, civic education, and community empowerment. The study proposes a multidisciplinary strategic approach that combines policy support, technological innovation, and cultural context to position Malaysia as a competitive astrotourism destination in the Southeast Asian region. These localised insights contribute to theoretical frameworks and practical action plans for sustainable astrotourism development.

Keywords: Challenges, innovation, Malaysian astrotourism

Abstract

Astrotourism, as a special interest segment within tourism, offers a unique synergy between scientific exploration, cultural heritage, and sustainable tourism. This study critically examines the development of astrotourism in Malaysia through qualitative thematic analysis based on Focus Group Discussions (FGD) involving ten experts from the academic sector, industry, and policymakers. The findings identify three main dimensions. First, significant challenges include severe light pollution, a lack of infrastructure in remote areas, the absence of designated dark sky reserves, and the lack of a comprehensive regulatory framework. Second, substantial opportunities exist through the potential integration of astrotourism with Islamic tourism and ecotourism, leveraging Malaysia's rich cultural heritage, natural biodiversity, and existing observatory infrastructure. Third, the development of a mobile application is identified as a key innovation capable of enhancing the visitor experience through storytelling, real-time environmental data, and event notifications, while also supporting tourism operators with marketing tools and user feedback systems.

Fourth, policy and social frameworks serve as drivers of integrated astrotourism development in Malaysia through the restructuring of tourism policies, science communication within space policy, and inclusive rural transformation, to demonstrate how astrotourism can be positioned as a cross-sectoral policy driver that contributes to economic development, civic education, and community empowerment. This study proposes a strategic, multidisciplinary approach that combines policy support, technological innovation, and cultural context to position Malaysia as a competitive astrotourism destination in Southeast Asia. These local insights contribute to the theoretical framework and practical action plans for sustainable astrotourism development.

Keywords: Challenges, Innovation, Malaysian Astrotourism

1.Introduction

As a specialised form of interest-based tourism, astrotourism is increasingly recognised globally for its potential to combine science education with recreational activities. This tourism segment attracts visitors especially those who are keen to explore the beauty of the night sky and celestial phenomena, creating an engaging synthesis of astronomy and tourism. Malaysia, endowed with rich natural resources and cultural heritage, possesses significant potential to develop astrotourism as an important economic and educational sector. However, like other emerging industries, the development of astrotourism in Malaysia faces various challenges and opportunities. The adoption of modern technologies such as mobile application development offers innovative approaches to overcoming existing barriers and enhancing the overall astronomy tourism experience. This article discusses four main themes related to the development of astrotourism in Malaysia.

The first theme examines the multidimensional challenges hindering the growth of astrotourism in Malaysia. These challenges include light pollution, low public awareness, and a lack of suitable infrastructure. Although Malaysia boasts natural landscapes and highland areas with great potential for stargazing activities, rapid urban development has exacerbated night-time lighting, thereby diminishing the clarity of the night sky. Furthermore, public understanding and interest in astronomy remain low, making it increasingly challenging to promote astrotourism to both domestic and international audiences. In rural areas, which are often the most suitable locations for astrotourism activities, basic infrastructure such as transport, accommodation, and utilities remains insufficient, posing logistical constraints for tourists and organisers. Addressing these barriers is crucial to unlocking the full potential of Malaysian astrotourism. In this context, local wisdom, which encompasses traditional knowledge and practices in harmony with nature, plays a vital role in shaping sustainable and culturally rooted tourism models (Asrial et al., 2022).The second theme focuses on the strategic opportunities available for the development of astrotourism in Malaysia. One of the country's main strengths is its geographic diversity, which provides ideal locations for night sky observation, such as national parks, observatories, and coastal areas. The multicultural fabric of Malaysian society also creates opportunities to integrate cultural narratives, including Islamic astronomy, into astrotourism activities, thereby enriching the tourist experience. Additionally, government initiatives in promoting sustainable tourism are aligned with the principles of astrotourism, which emphasise minimal environmental impact and educational value. If strategically leveraged, these opportunities have the

potential to position Malaysia as a leading astrotourism destination in Southeast Asia. The third theme discusses the role of application development in supporting the growth of astrotourism in Malaysia. In today's digital era, mobile applications can serve as an effective tool for promoting this tourism segment. These applications can provide real-time sky maps and notifications about astronomical events, besides engaging educational content. They can also connect tourists with guides, facilitate visit scheduling, and enable bookings for observatories and accommodations. For Malaysia, application development represents a potential channel to address existing challenges, such as the challenges in increasing public awareness and improving access to locations. Moreover, applications can incorporate elements of local wisdom and cultural features to create personalised and immersive tourism experiences. The fourth theme highlights the strategic alignment between astrotourism and national development policy through an innovative framework that integrates the restructuring of tourism policy, science communication within space policy, and inclusive rural transformation. This study positions astrotourism as a cross-sectoral policy driver that contributes to economic development, civic education, and community empowerment, in line with the strategic framework of the Twelfth Malaysia Plan (RMK12), Malaysia Space Exploration 2030, as well as the Sustainable Development Goals (SDGs) such as SDG 4, 8, 9, 10, 11, and 15. This approach not only emphasises the added value from the perspective of cultural heritage and science education, but also presents astrotourism as a policy implementation tool that is knowledge-based, locally rooted, and contributes to both national sustainability and global sustainable development.

The development of astrotourism in Malaysia reflects a dynamic interplay between challenges, opportunities, technological advancement, and policy and social frameworks as drivers of integrated astrotourism development. By addressing existing barriers, harnessing the country's unique strengths, and strategically embracing digital innovation and policy and social frameworks, Malaysia has the potential to emerge as a pioneer in the global astrotourism landscape.

This study aims to explore these themes in depth, offering scholarly discourse and practical guidance to stimulate the growth of astrotourism that delivers educational, cultural, and economic benefits to the nation.

2. Literature Review

Recent developments in the tourism sector have highlighted significant shifts in tourist motivations, with increasing interest in socio-cultural experiences, traditional customs, environmental appreciation, natural scenery, economic sustainability, and community well-being (Aswita et al., 2024). Within this evolving landscape, astrotourism has emerged as a promising new segment within special interest tourism (SIT), enabling destinations to leverage unpolluted night skies and cultural heritage while reinforcing sustainable tourism practices.

This interdisciplinary field of astrotourism combines scientific research, tourism development, and environmental conservation, thereby appealing to a diverse audience including astronomy enthusiasts, celestial phenomena observers, and dark sky preservation advocates (Cinzano et al., 2001; Falchi et al., 2016). Malaysia holds a strategic position to benefit from the growth of this sector, given its rich

astronomical traditions and abundant natural landscapes. Nonetheless, progress in this sector is still hindered by several key challenges, such as widespread light pollution, insufficient supporting infrastructure, and low public awareness of the importance of astronomy and the night sky. Therefore, this literature review aims to synthesise current findings on astrotourism by examining the main challenges, emerging opportunities, and innovative strategies identified. At the same time, it highlights research gaps and inconsistencies within existing discourse, providing a foundation for more targeted development of the astrotourism sector in Malaysia.

2.1 Theoretical Framework in Astrotourism

Academic writings in the astrotourism sector are rooted in the theories of SIT, sustainable tourism, and environmental conservation. Trauer (2006) defines SIT as a category of tourism that focuses on tourists' specific motivations, such as an interest in stargazing and cultural astronomy. In parallel, the dark sky conservation theory emphasises the importance of preserving nightscapes for ecological and cultural benefits (Cinzano et al., 2001). Both frameworks highlight the dual role of astrotourism in fostering environmental sustainability and enriching tourist experiences. The integration of astrotourism into broader sustainable tourism frameworks is increasingly central to current academic discourse and research. Rodrigues et al. (2015) stress the synergy between astronomical tourism and UNESCO World Heritage Site principles, particularly the crucial role of dark sky reserves in preserving night sky visibility, which is a core asset for astrotourism destinations. Although these frameworks provide useful guidance, their application in the Southeast Asian context remains underexplored, reflecting a significant gap in special interest tourism scholarship.

Within this discourse, cultural elements emerge as a critical dimension. Culture exists in both material and spiritual forms and, as defined by Tylor, encompasses the totality of human expression (beliefs, arts, customs, and social capacities) that shape the collective identity of a society (Buseri, 2017). Culture not only influences how a community views and interacts with tourism but also shapes the way tourism experiences are designed, delivered, and interpreted. As argued by Pamela et al. (2017), culture plays a major role in determining social behaviour, values, and interactions in diverse contexts, directly impacting tourism development. Therefore, sustainable tourism should be managed holistically by considering three main pillars: the preservation of natural and cultural resources, the empowerment of local community well-being, and ensuring tourist satisfaction throughout their interaction with the destination (Aswita et al., 2015).

2.2 Current Practices and Prospects

Globally, astrotourism has experienced impressive growth, with destinations such as Chile, Namibia, and New Zealand capitalising on their pristine night skies to attract visitors. Malaysia's potential lies in its deep cultural connections to astronomy, including the use of stars in traditional navigation and agriculture. Research by Jacobs et al. (2020) emphasises the role of cultural narratives in enriching the astrotourism experience, an aspect that is highly significant in the context of Malaysia's multicultural society.

The future of astrotourism in Malaysia is strongly influenced by the adoption of technological innovation. Technologies such as augmented reality (AR) for stargazing guidance and mobile applications for celestial navigation have enhanced tourist engagement and enriched the overall tourism experience (Chung et al., 2015). Furthermore, Malaysia's strategic location near the equator allows for year-round night sky observation. All these factors offer significant potential for astrotourism development. However, current efforts remain fragmented and are not supported by comprehensive planning, integrated coordination, or robust marketing strategies. This situation has limited Malaysia's ability to emerge as a competitive player in the global astrotourism landscape. Additionally, international experience demonstrates that the construction of a sustainable, economically valuable tourism system that supports local communities, preserves cultural identity, and strengthens infrastructure is a complex, long-term endeavour fraught with challenges (Munkhuu et al., 2023).

2.3 Challenges and Gaps

Challenges and gaps in the development of astrotourism refer to factors that hinder the comprehensive advancement of this sector, including physical constraints, institutional weaknesses, and mismatches between field potential and implementation capacity. Common challenges involve issues such as light pollution, policy constraints, and infrastructural limitations, while gaps refer to the absence of integrated collaboration, lack of local data, and disparities in knowledge, technology, and public awareness. This concept underscores the need for an interdisciplinary approach capable of addressing the structural and functional factors that restrict the sustainable development of astrotourism in Malaysia.

Among the main challenges in astrotourism development is light pollution, which affects not only urban but also rural areas in Malaysia. Studies by Falchi et al. (2016) and Kyba et al. (2015) provide extensive data on light pollution at the global level, yet findings that are localised and specific to the Malaysian context remain scarce. The absence of such focused research makes it difficult to implement effective mitigation strategies. Another challenge is the lack of collaboration among stakeholders. Local communities, government agencies, and tourism operators often operate in isolation, resulting in disjointed and less effective astrotourism promotion. Jacobs et al. (2020) emphasise that the success of astrotourism initiatives requires an integrated approach involving community participation, policy support, and sustainable practices. These gaps highlight the need for interdisciplinary research capable of addressing specific challenges within the Malaysian context.

2.4 Innovation in Astrotourism

Technological advancements play a crucial role in addressing some of the challenges that hinder the development of astrotourism. For instance, AR and virtual reality (VR) technologies enable the creation of immersive experiences that compensate for suboptimal sky conditions in urban areas (Rodrigues et al., 2015). Furthermore, the development of probabilistic models to forecast night sky brightness, as proposed by C-Sánchez et al. (2019), serves as a significant analytical tool in supporting more effective and data-driven astrotourism planning.

and marketing strategies. Malaysia can also learn from international best practices. For example, the Alqueva Dark Sky Reserve in Portugal demonstrates how the integration of stargazing tourism with cultural tourism can create unique and globally competitive offerings (Rodrigues et al., 2015). Implementing similar initiatives in Malaysia requires an approach tailored to local cultural and environmental contexts. A critical synthesis of the existing literature reveals several consistent findings, including the importance of dark sky conservation, the role of technological innovation, and the necessity of community engagement. However, these factors are addressed unevenly across different regions. For instance, although light pollution is a globally recognised challenge, mitigation strategies vary widely and have yet to be fully adapted to the tropical climate and urbanisation patterns of Malaysia.

The body of knowledge built through previous studies provides guidance for the development of astrotourism in Malaysia, emphasising the need for a specialised approach that balances ecological preservation and tourism development. By addressing existing gaps, including the lack of a robust strategic framework and insufficient local research, Malaysia has the potential to emerge as a leader in astrotourism within the Southeast Asian region. Astrotourism offers a unique platform for Malaysia to integrate cultural heritage, environmental sustainability, and technological innovation. This review highlights the main themes, critical challenges, and prospects for the sector, while identifying gaps that must be addressed to advance the country's astrotourism development. Future research should focus on the development of local frameworks, the empowerment of multi-stakeholder collaboration, and the exploration of innovative technologies that can enrich the tourist experience. By leveraging these insights, Malaysia can illuminate its night skies for the benefit of tourists and local communities, ensuring a sustainable and high-value future for astrotourism.

3. Research Methodology

The methodology of this study is structured according to the unit of analysis, research design, data sources, data collection, and data analysis.

Unit of Analysis

The unit of analysis in this study is the Study Participants (SPs), comprising individuals directly involved in the development and implementation of astrotourism in Malaysia. Participants were selected through purposive sampling to ensure representation from various stakeholders, including academics, tourism practitioners, local authorities, private sector operators, and experts in astronomy, environmental science, and application development technology. This unit was chosen because members possess relevant knowledge, experience, and influence in shaping the direction of astrotourism sector development, thus enabling in-depth exploration of challenges, opportunities, and suitable solutions within the Malaysian context.

Research Design

This study adopts a qualitative approach using the Focus Group Discussion (FGD) method, which is suitable for in-depth exploration of complex issues, particularly in

interdisciplinary fields such as astrotourism. This research design allows the researcher to obtain diverse perspectives from participants representing scientific, cultural, and policy dimensions. The FGD was designed to be semi-structured, employing open-ended questions and guided prompts to facilitate the dynamic development of ideas while remaining aligned with the study's objectives. The focus of the study is to identify key themes that can inform integrated and sustainable astrotourism development strategies.

Data Sources

The primary data source for this study is the direct collection of primary data from FGD participants. This includes verbatim transcripts of discussions, observer field notes, as well as reflections and notes gathered throughout the session. These sources are considered rich and valid as they are obtained from authoritative and relevant stakeholders in their respective fields, within a discussion environment that encourages the sharing of authentic and in-depth information. Additionally, contextual information acquired non-verbally, such as body language cues and social interactions, was also considered to provide a more holistic understanding of the topics discussed.

Data Collection

Data collection was conducted through a single FGD session lasting three hours in a conducive and neutral setting. The session was recorded with the participants' consent to ensure data accuracy and completeness. In addition, an observer was assigned to record non-verbal cues and group dynamics that could not be captured through audio recording. The discussion was structured around four main pre-determined themes: (1) challenges in astrotourism development; (2) opportunities based on local strengths; (3) the role of technology in supporting the industry; and (4) policy and social frameworks as drivers of integrated astrotourism development. This approach enabled comprehensive and relevant data collection in line with the research objectives.

Data Analysis

The data were analysed manually using thematic analysis. The analytical process began with the transcription of recordings, followed by a thorough review to identify recurring patterns and themes. Data were categorised according to four main domains: challenges, opportunities, innovation, and policy and social frameworks, and supported by key quotations from participants to provide an in-depth empirical account. Triangulation was carried out by comparing perspectives among participants from various backgrounds to enhance the reliability of the findings. This approach not only enabled the researcher to identify relationships among policy, technical, and social issues, but also provided a foundation for formulating a more comprehensive action plan for the development of astrotourism in Malaysia.

4. Findings and Discussion

Result 1: Challenges in the Development of Astrotourism in Malaysia



Figure 1: Challenges for astrotourism in Malaysia

Figure 1 summarises the various challenges that influence the development of astrotourism in Malaysia. This visualisation is organised based on triangulated data involving FDG with stakeholders, document analysis, and a review of previous literature. Overall, Figure 1 shows the existence of three main groups of challenges, namely structural, environmental, and socio-cultural in nature. This infographic not only visualises the findings thematically, but also functions as a conceptual framework for understanding the dynamics and complexities that exist in efforts to develop a sustainable and competitive astrotourism sector.

This study strengthens the finding that the development of astrotourism in Malaysia still faces various tangible constraints. One of the most critical challenges is light pollution, which has a direct impact on the quality of the night sky. This was emphasised by SP1, who stated: "The oil platform near the Al-Khawarizmi Observatory has ruined the night sky; it used to be ideal for astrotourism, but now it is too bright." This situation illustrates how uncontrolled industrial activities can affect locations that were once strategic for astronomical tourism. Furthermore, SP2 voiced concern over the absence of officially gazetted dark sky areas: "Our country still does not have any officially gazetted dark sky areas, and although there are efforts in that direction, it remains a major challenge." This policy gap opens the door for urban and industrial development to disrupt high-potential areas. This indicates that structural and legislative issues have not yet been comprehensively addressed, thereby affecting Malaysia's potential to compete at the regional level.

Apart from issues of pollution and policy, operational and human resource constraints have also been identified as major barriers to the growth of this industry. SP3 emphasised: "We lack guides who are sufficiently skilled in night sky knowledge and equipment such as telescopes." The shortage of specialised skilled workers

means that the tourist experience cannot be maximised, subsequently affecting satisfaction and the reputation of destinations. In terms of accessibility, many suitable observation locations are situated in remote areas with limited basic infrastructure. SP3 also added: “How accessible are these locations to the public? If they are too remote or underdeveloped, they will not attract visitors.” Even from the investment perspective, he expressed the concerns of operators: “Operators will not develop packages unless they see clear financial benefits.” This statement highlights the importance of developing attractive business models and clear support policies. Therefore, comprehensive interventions encompassing lighting regulations, workforce capacity development, infrastructure improvement, and investment incentive schemes are essential for making Malaysia a sustainable and competitive astrotourism destination.

Result 2: Opportunities for Developing Astrotourism in Malaysia



Figure 2: Opportunities for astrotourism in Malaysia

Figure 2 illustrates the key opportunities in the development of astrotourism in Malaysia, identified based on input from FGD, policy document analysis, and scholarly references. These opportunities are summarised across several main domains, such as integration with existing cultural and tourism narratives, targeting the growing niche market, and leveraging infrastructure and institutional support through multi-sectoral collaboration.

This framework demonstrates how the richness of natural resources, Islamic cultural heritage, and existing institutional support can serve as the foundation for the sustainable and competitive growth of the astrotourism sector. In this framework, the combination of cultural tourism, ecotourism, and halal tourism (HT) elements is outlined as a main driver that can increase economic value and visitor experience. Regions such as Aceh are examples of successful historical and cultural tourism, but the effectiveness of such efforts depends on the availability of skilled human resources and strong institutional support (Fitriah et al., 2024). Therefore, the integration of cultural tourism with educational infrastructure and professional training in the tourism sector is important. In line with this, the alignment of astrotourism with the principles of HT enables this segment to attract more Muslim tourists. Core values such as convenience, reliability, safety, trust, openness, and continuous improvement are central to the implementation of HT (Abdul Manan et al., 2023). The application of these principles, from the provision of Shariah-compliant facilities to the development of culturally sensitive tourism personnel, can strengthen Malaysia's position as a halal-friendly astrotourism destination.

Moreover, in this context, Hariyanto et al. (2024) emphasise that HT must meet basic criteria such as the provision of halal food, prayer spaces, Shariah-compliant activities, suitable locations, and adequate basic facilities. The potential outlined in this visualisation needs to be analysed more deeply in terms of its strategic added value in the context of tourism and national development. This study asserts that astrotourism should not be viewed merely as a special interest tourism segment, but as a transformative driver towards integrative development anchored in science, locality, and sustainability. This is in line with the integrated tourism approach that encompasses cultural, environmental, and spiritual values, particularly the Islamic narrative, which forms an important foundation in the Malaysian context. The innovative framework proposed aligns astrotourism with national and global strategic policies including RMK12, Malaysia Space Exploration 2030, and the UN SDGs, to ensure that it not only contributes economically, but also plays a role in advancing education, environmental preservation, and social and spatial equity.

The opportunities for developing astrotourism in Malaysia are highly dependent on the ability to integrate local strengths with broader tourism strategies. One of the approaches identified is the combination of astrotourism with Islamic tourism and ecotourism. SP4 emphasised this potential by stating: "Astrotourism can be made part of Islamic tourism by involving observatories and Islamic astronomy such as the study of stars and the moon for prayer times and navigation." This view is supported by SP5, who gave an example from abroad: "In Uzbekistan, they have made the Ulugh Beg Observatory a main tourist attraction, showcasing the contributions of Islamic scholars in the field of astronomy. We could emulate this approach." In addition, there are significant opportunities in the positive response from niche tourists such as Gen Z and millennials, who are more inclined to seek authentic and unique experiences. SP6 explained: "Gen Z and millennials seek unique experiences; they are adventurous and prefer niche tourism over mainstream attractions." This shows that astrotourism can be positioned as an alternative product that meets the tastes of the modern market.

Based on the alignment and policy principles outlined, the practical implementation of astrotourism in Malaysia requires an approach based on local strengths as well as the existing institutional ecosystem. In fact, a key feature of astrotourism development opportunities is the existence of institutional ecosystems and available infrastructure support. According to SP2: “We already have observatories in almost every state, which can serve as main sites for astrotourism.” This view shows that technical elements and physical facilities are not the main constraints, but should instead be leveraged strategically through collaboration and synergy. SP7 also emphasised the importance of collaboration with organisations such as Apadilangit, stating: “Collaboration with groups like Apadilangit opens opportunities to obtain grants and access to dark sky areas.” In fact, SP2 also linked the potential of astrotourism to the national agenda: “Astrotourism is part of the space economy as outlined in the Malaysia Space Exploration Plan, which targets integration between education and tourism in the space sector.” Overall, these opportunities must be harnessed through a systematic approach involving investment in professional training, business model development, and the empowerment of local astronomical tourism brands so that Malaysia can compete with global destinations in this segment.

Result 3: Application Development



Figure 3: Applications for app development in Malaysia

Based on the FDG conducted, policy document analysis, and findings from scholarly references, three main subthemes forming the foundation for the development of an astrotourism application in Malaysia have been identified: enhancement of user experience, dual functionality for operators and tourists, and scalability with long-term value. In the first subtheme, SP6 stated: “The application should assist tour guides in storytelling... including both conventional and Islamic elements,”

emphasising the need for culturally and locally relevant narratives. Meanwhile, SP8 suggested: "There should be user reviews and information about areas affected by light pollution," indicating the need for real-time environmental data to support trip planning. For the second subtheme, SP2 asserted: "This application can be used by operators and tourists to explore dark skies... We want this application to be sustainable, and operators can use it to promote their respective areas." This statement is supported by SP5's suggestion to conduct user segmentation studies. Finally, in the third subtheme, SP6 recommended that the application promote complementary tourism activities such as "water rafting or night walks," while SP2 added: "We want this application to be more than just an information platform; we want it to evolve for both local and international users."

Overall, the analysis shows that the development of an astrotourism application must go beyond merely providing information and should be driven by an approach that integrates user experience, the needs of tourism operators, and technical features that enable continuous growth. All three subthemes highlight that an effective application is one that can provide informative content and culturally relevant narratives, while supporting interactivity and usability for various target groups. The emphasis on practical value and promotion by operators, as presented by SP2 and SP5, reflects the need for robust dual functionality. Meanwhile, the suggestions by SP6 and SP2 regarding complementary activities and international market potential underscore that the application should be designed for scalability and long-term adaptability.

From these findings, several critical features for application development can be identified. First, the application should include interactive narrative elements based on Islamic heritage and local traditions, in line with SP6's emphasis on storytelling functionality. Second, the application should provide space for users to rate and review, as suggested by SP8, to create a real-time information ecosystem that builds trust and supports the selection of observation sites. Third, the application should be designed to meet the needs of both operators and tourists simultaneously, supporting promotional, management, and trip planning functions without compromising ease of use, as highlighted by SP2 and SP5. Finally, application development should pay attention to global scalability and the integration of complementary tourism activities, as recommended by SP6 and SP2, so that the application is not only resilient but also contributes to the broader and more sustainable growth of the tourism sector.

Result 4: Policy and Social Frameworks as Drivers of Integrated Astrotourism Development in Malaysia

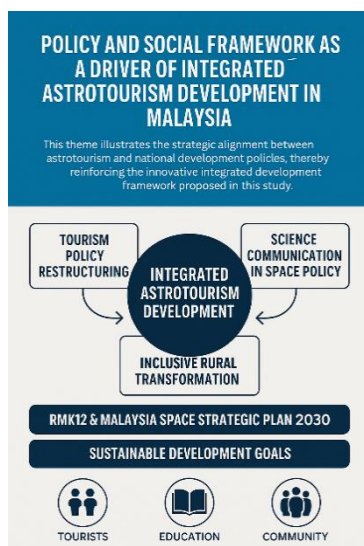


Figure 4: Policy and social framework as a driver of integrated astrotourism development in Malaysia

Figure 4 presents the strategic alignment between astrotourism and national development policy, thereby reinforcing the innovative framework for integrative development proposed in this study. Through the combination of three main domains—restructuring tourism policy, science communication within space policy, and inclusive rural transformation—this model demonstrates how astrotourism can be positioned as a cross-sectoral policy driver contributing to economic development, civic education, and community empowerment. This alignment is not only integrated with RMK12 and the Malaysia Space Strategic Plan 2030, but is also harmonised with various SDGs such as SDG 4 (Quality Education), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), SDG 10 (Reduce Inequalities), SDG 11 (Sustainable Cities and Communities), and SDG 15 (Life on Land). This visualisation serves as an important conceptual foundation for understanding the potential of astrotourism as a cross-sectoral policy tool that is holistic and contributes to the transition towards knowledge-based and sustainable development. It illustrates the interlinked roles of tourism, science, and governance, each reinforcing national aspirations and the SDGs in a systematic and practical manner.

This study asserts that astrotourism should not be viewed merely as a special interest tourism segment, but as a transformative driver towards integrative development anchored in science, locality, and sustainability. The proposed innovative framework aligns astrotourism with both national and global strategic policies, including RMK12, Malaysia Space Exploration 2030, and the United Nations SDGs, ensuring that it not only contributes economically but also advances education, environmental conservation, and social and spatial equity. In the context of RMK12, this framework supports policy drivers such as Smart Tourism and the Digitalisation of the Tourism Sector, as well as rural development initiatives through community-based tourism leveraging local resources and the involvement of vulnerable groups. The emphasis on science- and heritage-based tourism also

aligns with the Strategic Thrusts of RMK12, which focus on human capital development, innovation, and sustainability. Meanwhile, the Malaysia Space Strategic Plan 2030, as outlined in Malaysia Space Exploration 2030, also provides a platform for linking national space policy with social development through initiatives in astronomy education, space science, and celestial mapping. Astrotourism is positioned as a practical platform for extending space science communication to the public through interactive and contextual outdoor learning approaches, thereby strengthening the nexus between the tourism, education, and national space technology sectors. From a global perspective, alignment with the SDGs enables astrotourism to play a direct role in achieving key targets such as SDG 4 through astronomy education and environmental awareness; SDG 8 through the creation of green jobs and community enterprises; SDG 9 through the application of observational technology and digital storytelling; SDG 10 and 11 through the empowerment of rural communities; and SDG 15 through the conservation of dark skies and biodiversity. This strategic alignment makes astrotourism not only relevant within the national framework, but also a supporting component of the global sustainable development agenda grounded in knowledge and community engagement. Education emerges as a central pillar in this framework, particularly in fostering environmental awareness, responsible tourism practices, and long-term stewardship, thereby strengthening sustainability goals within the tourism sector (Aswita, 2018).

The proposed framework details how astrotourism can be institutionalised through existing policies and measurable implementation mechanisms. In terms of tourism policy, it introduces a new typology of cultural-scientific tourism based on dark sky conservation and Islamic astronomical heritage, in line with the demands of RMK12 and SDGs 8 & 11. In the dimension of education and science, this approach bridges the gap between space policy and the public community through innovative pedagogy such as augmented storytelling and real-time celestial mapping, contributing to the achievement of SDGs 4 & 9. From the perspective of rural development, astrotourism is positioned as a high-impact strategy for enabling local economies sustainably through community enterprises, astro-ecolodges, and biodiversity conservation, thereby supporting SDGs 1, 10, and 15. Overall, the findings of this study open the way for the formulation of new tourism policies that are more responsive, locally rooted, and cross-sectoral in strengthening the future of a scientifically literate and resilient Malaysia.

Conclusion

This study asserts that astrotourism holds significant potential as a driver of multidimensional sustainable development in Malaysia. Although the country possesses rich natural resources and cultural heritage suitable for night sky tourism, several key challenges persist, such as light pollution, limited public awareness, underdeveloped infrastructure, and fragmented governance. However, the convergence of scientific interest, cultural heritage, and demand for meaningful tourism experiences opens opportunities to reposition astrotourism as a high-value segment within the national tourism strategy. By integrating SIT theory and diverse stakeholder perspectives, this study offers a holistic understanding of how

astrotourism can be leveraged not only as a recreational activity but also as a platform for education, environmental advocacy, and community empowerment.

To ensure sustainable progress, astrotourism development in Malaysia requires comprehensive policy support, investment in human capital, and close alignment with national and international frameworks such as the 12MP, Space Plan 2030, and the SDGs. Strengthening public-private-academic partnerships will be key to coordinated planning, innovation driving, and inclusivity. Importantly, integrating cultural sensitivity, sustainability principles, and technological advancements such as augmented reality and digital applications into the astrotourism experience can enhance Malaysia's competitiveness on the global stage. This study calls for a paradigm shift in tourism governance and thinking frameworks, emphasising astrotourism's role as a strategic pathway towards resilient, culturally grounded, and knowledge-driven development.

Acknowledgements

This study received support from the UKM Translation Grant (Ref: UKM-TR2023-05) for the project titled "Empowering Astrotourism as a Mainstream Tourism Industry Product," as well as from the Sheikh Abdullah Fahim Chair (Ref: RH-2024-003) for the project "Feasibility Study of Astronomy Tourism Application among Tourists in Malaysia." Sincere appreciation is also extended to the Arab Cultural Sustainability and Islamic Civilisation Group, Faculty of Islamic Studies, Universiti Kebangsaan Malaysia, and the Sheikh Othman Sarawak Waqf Chair, Faculty of Islamic Studies UKM, for their support and collaboration throughout the study.

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