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Literature Review

CARBOSAKA (Carbon and Responsible-Based Scheme for Knowledge Area): Innovation of Educational Mangrove Ecotourism Based on Tourists' Carbon Footprint

Alvin Pratama[1*], Sabila Martin Dalimunte[1], Mohamed Khalfan[2]
[1]Department of Geography Education, Faculty of Social Sciences, Universitas Negeri Medan, Indonesia
[2]Abdulrahman Alsumait University, Zanzibar, Tanzania

Correspondence Email: alvnprtm21@gmail.com

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Abstract: The mangrove ecosystem contributes to carbon sequestration and coastal protection; however, unmanaged tourism activities may increase carbon emissions and degrade environmental quality. The low awareness of tourists regarding their carbon footprint highlights the need for innovative approaches in sustainable tourism management. This research designs and analyzes the concept of CARBOSAKA (Carbon and Responsible-Based Scheme for Knowledge Area), an educational mangrove ecotourism scheme based on the calculation of tourists' carbon footprint. The methodology involves literature research and qualitative analysis of sustainable ecotourism practices, accompanied by the design of a conceptual model built on three main pillars: education, economy, and ecology. The education pillar focuses on daily monitoring of tourists' carbon footprint, the provision of carbon information podiums supported by QR codes, and monthly rewards in the form of locally crafted merchandise produced by the community. The economic pillar encourages community involvement in producing environmentally friendly food, emphasizing energy-efficient dishes made from local ingredients. These products are sold at the tourism site as a means of both economic empowerment and environmental education. The ecological pillar emphasizes direct tourist engagement in mangrove planting or donations for restoration, as well as eco-friendly management of the area. These three pillars form the Triple E approach, manifested in a Venn diagram where the elements interrelate, reinforcing the synergy between education, economic empowerment, and ecological action. The concept enhances environmental awareness, strengthens the local economy, and delivers tangible contributions to carbon emission reduction in mangrove-based tourism areas.

Keywords: Carbon, Ecotourism, Mangrove, Carbon Footprint, Climate Mitigation.

1. INTRODUCTION

Indonesia is a tropical archipelago with the third-longest coastline in the world, spanning more than 108,000 kilometers across more than 17,000 islands. According to Akram et al. (2023) this geographical position, Indonesia is one of the countries with the richest coastal ecosystems, including mangrove forests that are widely distributed across regions such as Sumatra, Kalimantan, Papua, and Sulawesi. Based on data from the Ministry of Environment and Forestry (KLHK) in 2022, Indonesia has approximately 3.39 million hectares of mangroves, covering around 20 to 23 percent of the world's total mangrove area. This makes Indonesia the country with the largest mangrove ecosystem globally and positions it as a central actor in maintaining coastal environmental stability, particularly in Southeast Asian deltas and worldwide (Lovelock et al., 2022).

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Mangrove ecosystems play vital ecological and socio-economic roles for coastal communities by reducing wave energy, preventing shoreline abrasion and seawater intrusion, and providing habitats for diverse marine and bird species that support local fisheries and livelihoods (Su et al., 2021). Beyond their ecological services, mangroves are among the most efficient carbon sinks, capable of absorbing five to ten times as much carbon as tropical terrestrial forests. According to the Peatland and Mangrove Restoration Agency, Indonesia's mangroves store over 3.14 billion tons of carbon, underscoring their importance in achieving the national target of carbon neutrality by 2060 and highlighting the urgency of maintaining and enhancing their conservation through integrated, cross-sectoral strategies (Hagger et al., 2022).

The Indonesian government has launched a national mangrove restoration agenda targeting 600,000 hectares by 2024 as part of its Nationally Determined Contribution (NDC) under the Paris Agreement, involving BRGM, KLHK, and the Ministry of Marine Affairs and Fisheries with support from the World Bank's Mangroves for Coastal Resilience program. By early 2024, over 185,000 hectares had been rehabilitated and 265 million mangrove seedlings planted. Alongside these efforts, mangrove ecotourism offers a strategic opportunity to integrate conservation and environmental education, as exemplified by initiatives such as the Jerowaru Mangrove Ecotourism Area in East Lombok. However, its development remains uneven due to limited infrastructure and low public awareness of sustainable tourism, underscoring the need for more systematic educational and management approaches.

Ecotourism is an environmentally friendly form of tourism that aims to conserve natural ecosystems and improve the welfare of local communities (Mu'tashim & Indahsari, 2021). According to the International Ecotourism Society (TIES), ecotourism is defined as responsible travel to natural areas that conserves the environment, sustains local communities, and involves learning about and interpreting nature. Ecotourism plays a strategic role in raising environmental awareness through direct experience and education in fragile ecosystems such as mangrove forests (Utomo & Pulungan, 2023). Mangroves, with their high ecological value, are ideal for conservation-based ecotourism and serve as natural learning spaces (Huang et al. 2023). Well-designed ecotourism integrates recreation with conservation, drives local economic growth, and transforms ecological awareness among communities and tourists (Manan, 2020; Nicha & Zulkarnaini, 2025). Sustainable practices emphasize environmental education, community participation, and carbon emission management, making ecotourism both a conservation strategy and a transformative learning platform (Hofman et al., 2022; Nguyen et al., 2023).

Mangrove forests, as unique coastal ecosystems, thrive in intertidal zones and play essential ecological roles such as protecting coastlines from erosion, reducing wave energy, preventing seawater intrusion, and providing habitats for fish and crustaceans while functioning as natural carbon sinks (Kusmana & Rifana, 2023; Harefa et al., 2023). Their capacity to sequester carbon is significant, estimated to be three to ten times that of tropical terrestrial forests, making them a vital component of blue carbon ecosystems (Adame et al. 2024). In addition to ecological services, mangroves support coastal livelihoods through fisheries, aquaculture, and community-based ecotourism, while also serving as outdoor educational spaces (Permana et al., 2024; Ersan et al., 2022). Given the threats posed by climate change and coastal development, strengthening local communities through conservation-oriented ecotourism is crucial (Srifitriani et al., 2025). Their ecological resilience and role in long-term carbon storage highlight mangroves as a cornerstone of climate change mitigation and as part of Indonesia's national strategy for emission reduction through rehabilitation programs led by the Peatland and Mangrove Restoration Agency.

One aspect that has received insufficient attention in ecotourism development is tourists' understanding of their contribution to carbon emissions. Tourism activities, such as the use of motorized vehicles, energy consumption in accommodations, and the consumption of single-use packaged products, directly increase greenhouse gas emissions. Unfortunately, most tourists remain unaware that the recreational activities they engage in contribute to the climate crisis. This lack of awareness is primarily due to the absence of information systems that explicitly link tourism activities to environmental consequences, such as information boards, carbon-footprint tracking applications, or eco-friendly tourism guidelines.

The lack of integration between tourism activities and environmental education creates a gap between enjoyable tourist experiences and an understanding of their impacts. Many destinations prioritize aesthetics and comfort without providing opportunities for tourists to reflect on ecology. Yet innovative approaches are needed to integrate recreation, education, and tangible environmental action. Despite the growing number of

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mangrove ecotourism initiatives in Indonesia and globally, most existing models primarily emphasize conservation and community participation without integrating quantitative environmental assessment tools such as carbon footprint analysis. Current ecotourism frameworks, such as community-based mangrove management in Bintan and education-oriented models in Lombok and North Sumatra, tend to focus on awareness-building rather than on measurable climate-mitigation outcomes. This reveals a research gap in linking tourists' behavioral education to actual carbon-emission reduction mechanisms.

The CARBOSAKA model seeks to fill this gap by positioning itself as an innovation that combines environmental education, local economic empowerment, and ecological restoration through a carbon-responsibility framework. Unlike conventional ecotourism models that rely on qualitative awareness indicators, CARBOSAKA employs a quantitative approach to assess, visualize, and mitigate tourists' carbon footprints, thus aligning tourism practices with national and global climate targets. The introduction of tourism concepts that quantify tourists' carbon footprints presents a new and relevant approach to mangrove ecotourism. This concept allows tourists to engage in experiences that are both reflective and responsible. Within this framework, the idea of carbon footprints becomes highly relevant. A carbon footprint measures the total greenhouse gas emissions resulting from human activities, including tourism, and is expressed in tons of CO_2e per year.

Globally, tourism accounts for approximately 8–9 percent of emissions, totaling 5.2 gigatons of CO_2e in 2019, with transportation as the most significant contributor (Sun et al., 2024). Tourists' carbon footprints include emissions from transport, food and beverage consumption, accommodation energy use, and waste generation (Sun et al., 2020). Measuring these emissions is essential for sustainable tourism development as it allows destinations to map their contributions to climate change and evaluate ecological impacts (Campos et al., 2022). In mangrove ecotourism areas, accurate carbon footprint data are critical, as these ecosystems are both highly vulnerable and key carbon sinks (Palit et al., 2022). Tools such as the Environmentally Extended Input-Output (EEIO) model are useful for large-scale assessments, whereas bottom-up approaches are more practical for community-based tourism. Providing tourists with carbon footprint information has been shown to encourage behavioral change Song et al. (2024). At the same time, visual representations of emissions data increase awareness and willingness to take compensatory actions, such as mangrove planting or conservation donation (Peixoto de & Macario, 2024). Thus, integrating carbon footprint education into ecotourism strengthens conservation outcomes and promotes responsible environmental behavior.

This research stems from the urgent need to develop the CARBOSAKA concept within sustainable mangrove ecotourism management. CARBOSAKA is designed as an educational innovation that integrates the calculation of tourists' carbon footprints with mangrove ecosystem conservation efforts and community empowerment. This approach positions tourism as a recreational activity aligned with environmental education and ecological reflection, emphasizing responsibility for sustainability. This research is expected to provide benefits in two domains. Theoretically, this study enriches the concept of ecotourism through environmental education by using carbon footprints as a learning medium. In practice, this study serves as a reference for managers in designing sustainable mangrove ecotourism, increasing tourists' environmental awareness, and strengthening the role of local communities through environmentally based economic activities. The scientific novelty of this study is further underscored by the development of a roadmap for the CARBOSAKA model, which outlines the stages of transformation from a conceptual framework to national and international implementation, thereby providing a structured and applicable scientific contribution. The CARBOSAKA Model Roadmap is presented below.

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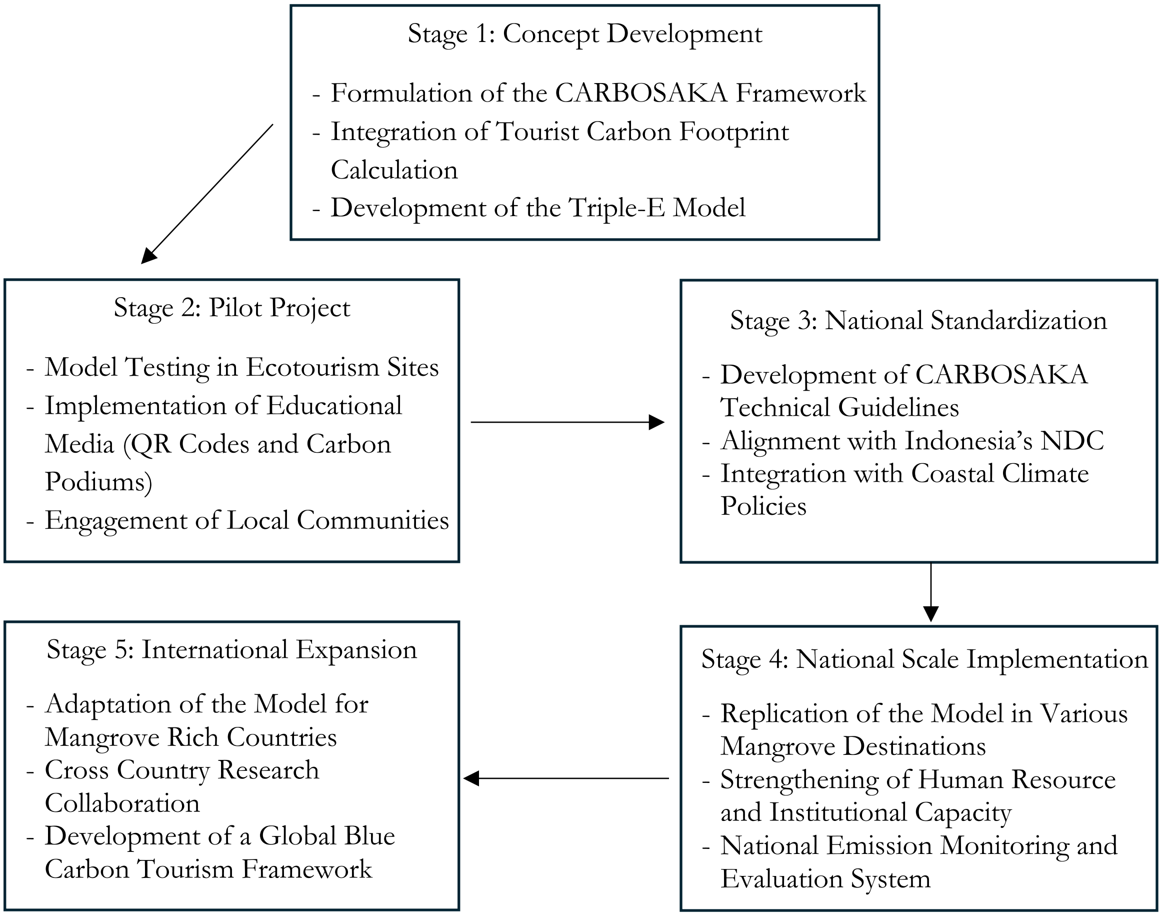

Figure 1. Roadmap for the Development of the CARBOSAKA Model

2. RESEARCH METHODS

This research employed a qualitative-descriptive approach with conceptual design research. This approach was chosen because it was suitable for designing and formulating an innovative model based on sustainability principles, namely CARBOSAKA (Carbon and Responsible-Based Scheme for Knowledge Area). The primary focus of the research was the development of a tourism education concept grounded in carbon footprint calculations for mangrove ecotourism areas, designed to bridge the economic, ecological, and educational dimensions, known as the Triple E.

To calculate carbon emissions generated by tourists, a bottom-up approach was used, based on actual field activity data. This approach is more appropriate for micro-scale applications, such as tourist villages or community-based ecotourism destinations, because carbon footprint measurements can be conducted with greater specificity and accuracy, given the relatively limited number of activities and emission sources. Furthermore, involving residents facilitates the tailoring of interventions, enables faster and more cost-effective monitoring and evaluation of impacts, and can directly affect tourist behavior, which in turn can affect conservation and local livelihoods.

To apply this method effectively, the carbon footprint calculation in this ecotourism design is carried out through several stages, namely: Here is the English version rewritten as full sentences: The identification of emission sources is carried out by categorizing them into several main groups, namely transportation to and within the tourist area, food and beverage consumption, and energy use in accommodations and tourist facilities. Activity data are collected by requiring each tourist to complete a form or use an activity-recording application that includes information on travel distance, mode of transportation, types and portions of

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consumption, duration of facility use, and the amount of waste generated. The application of emission factors uses values sourced entirely from the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories to ensure that the calculations are consistent, internationally recognized, easily updated, and aligned with the emission reporting standards adopted by the Indonesian government in its Nationally Determined Contribution (NDC). The next stage is the calculation of total emissions using the following formula Froemelt et al. (2021).

$$Total\ Emissions\ (kgCo_2e) = \sum(Activity_i \times Emission\ Factor_i)$$

Description:
$Activity_i$ = number of activity units
$Emission\ Factor_i$ = CO_2e emission conversion per activity unit

After the calculation is performed using this formula, the results are analyzed and interpreted. The results are processed to determine the contribution of each activity category to the total tourist carbon footprint. This information is then presented in an easy-to-understand visual format and becomes part of the educational media within the CARBOSAKA concept.

At these stages, carbon footprint measurements yield quantitative data describing the emissions contributions of each category of tourist activity. These data serve as a baseline for understanding the emissions profile in mangrove ecotourism areas and can inform more efficient and environmentally friendly management planning. The calculation results are processed to determine the contribution of each activity category to the total tourist carbon footprint. This information is then presented in an easy-to-understand visual format and becomes part of the educational media within the CARBOSAKA concept. To clarify the carbon calculation process, the following table presents an illustration of carbon footprint measurement from Medan City to the Dogang ecotourism area in Langkat Regency.

Table 1. Illustration of Carbon Footprint Calculation for Dogang Ecotourism

arbon Footprint Calculation Using Froemelt et al. (2021) Formula	Carbon Emission Source			
	Round-trip Transportation Distance (Medan–Dogang)	Food Consumption	Food Consumption	Total (Σ $Activity_i \times EF_i$)
$Activity_i$ (Activity Unit)	160 Km	2 Porsi	1 Jam	-
$Emission\ Factor_i$ (kg CO_2e/unit)	Mobil: 0,192 Motor: 0,072	1.00	0.75	-
Tourist Using Cars ($Activity_i \times EF_i$)	30.72 kg	2.00 Kg	0.75 Kg	33.47 kg CO_2e
Tourist Using Motorcycles ($Activity_i \times EF_i$)	11.52 kg	2.00 Kg	0.75 Kg	14.27 kg CO_2e
All Tourist (10 cars & 10 Motorcycles)	(10×30.72) + (10×11.52 = 422.4 kg	20 tourist × 2 portions = 40 portions → 40.0 kg	20 × 0.75 = 15.0 kg	2579.0 kg CO_2e (≈ 2.579 ton)

Through these stages, the carbon footprint measurement produces quantitative data that describes the emission contributions of each category of tourist activity. These data provide a baseline for understanding the emission profile of the mangrove ecotourism area and can inform the planning of more efficient and environmentally friendly management strategies. The measurement results from the Dogang ecotourism

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destination can later be used to demonstrate how each activity category contributes to emissions and to help readers understand the practical application of the CARBOSAKA method.

3. RESULTS AND DISCUSSION

The identification of emission sources in mangrove ecotourism indicates significant contributions from tourist transportation, the consumption of high-carbon-footprint products, and on-site energy use. These findings form the foundation for developing the CARBOSAKA scheme, based on the Triple E concept (Education, Economy, Ecology), designed to address these issues in an integrated manner through behavioral change, local economic empowerment, and environmental conservation.

1) Education

The education pillar focuses on shaping tourists' understanding and awareness of the environmental impacts of their activities at ecotourism sites. Permanent carbon information kiosks equipped with QR codes are installed at strategic locations, providing data on carbon footprints, emission-reduction tips, and information on environmentally friendly modes of transport. With this direct access, tourists gain a clear picture of their contribution to emissions and can immediately take corrective actions. This channel is reinforced through regular publications on ecotourism social media platforms, broadening the reach of sustainability messages while strengthening the destination's identity as an environmentally oriented tourism site.

This educational approach is conceptually aligned with the Theory of Planned Behavior, which emphasizes that environmentally responsible actions are influenced by tourists' attitudes, social norms, and perceived behavioral control (Ajzen, 1981). By providing accessible information through QR codes and interactive displays, the CARBOSAKA framework aims to strengthen these determinants, shaping tourists' positive attitudes toward low-carbon behavior, reinforcing social norms of sustainability, and enhancing their perceived ability to make eco-friendly choices. Furthermore, this approach reflects the Value–Belief–Norm (VBN) Theory, suggesting that environmental education can transform personal values and ecological beliefs into a moral commitment to act responsibly (Stern, 2000).

A reward system for tourists with the lowest carbon footprint is designed to provide positive reinforcement. Rewards include low-carbon local products, such as herbal tea or keychains made from recycled materials, distributed monthly after data recapitulation. This form of appreciation encourages tourists' active involvement in selecting transportation modes, consumption patterns, and other behaviors that contribute to emission reduction. By combining accessible information and tangible incentives, the education pillar acts as the initial driver of individual behavioral change.

2) Economy

The economic pillar emphasizes empowering local communities to produce environmentally friendly products for marketing within the tourism area. Training programs are organized to process local raw materials into low-carbon foods and to create souvenirs from recycled materials, thereby maximizing the use of resources already available in the surrounding environment. Ingredients such as cassava, moringa leaves, and mangrove-based products are selected for their abundance, energy-efficient production processes, and distinctive qualities that enhance the tourism experience.

Community involvement in the sustainable product supply chain yields dual benefits: it generates stable business opportunities and enhances the destination's distinctiveness in visitors' eyes. The products themselves embody a sustainability narrative that tourists can directly experience, fostering an emotional connection with the visited area. This reinforces the perception that sustainability is not an abstract concept but a tangible dimension of the interactions among communities, the environment, and tourists.

3) Ecology

The ecology pillar focuses on the direct mitigation of emissions from tourism activities. Mangrove planting or adoption programs are offered to tourists with higher carbon footprints, providing opportunities for them to take part in environmental restoration. These activities are accompanied by field-based education sessions on the ecological functions of mangroves and their role in carbon sequestration.

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Planting mangroves provides multiple benefits, ranging from coastal protection against erosion to improved water quality and habitat for various coastal species. By directly involving tourists in the planting process, the experience becomes more personal and impactful, thereby embedding conservation messages more effectively. This approach reinforces the notion that ecotourism management is inseparable from a commitment to environmental sustainability, which underpins the long-term viability of mangrove areas.

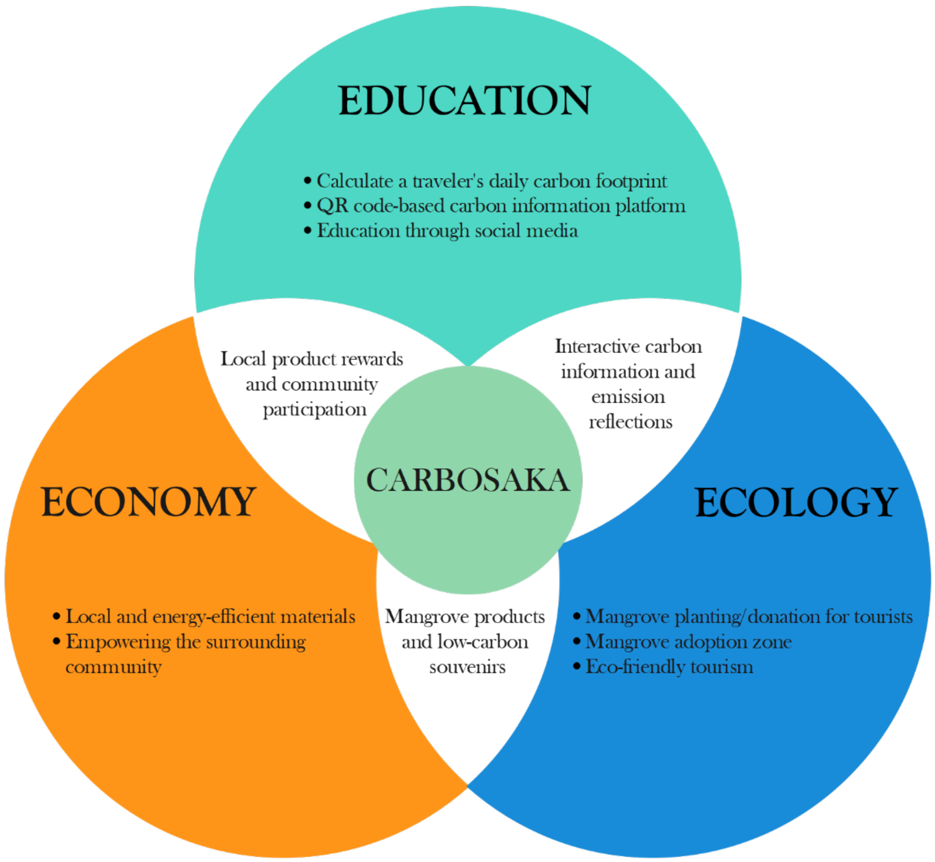

Figure 2. CARBOSAKA Concept

The Triple E Model in the CARBOSAKA Scheme uses a Venn diagram to emphasize the interconnectedness and unity of the three pillars. This model was chosen because it demonstrates dynamic interrelationships, with each pillar having its own role while simultaneously intersecting in carbon-emission management efforts. This visual format simplifies planning and evaluation, as intersection points can serve as focal areas for collaboration, yielding greater impact than separate efforts.

The Triple E framework was chosen because it integrates behavior change, local economic strengthening, and ecosystem protection into a single, mutually reinforcing framework. Education serves as the foundation for building understanding, the economy serves as the driving force for community participation, and ecology maintains the environmental carrying capacity that underpins tourism activities. This approach ensures that innovation is not confined to a single dimension but encompasses all aspects that shape a destination's sustainability.

Furthermore, the colors in the Venn diagram of the CARBOSAKA concept represent the character and focus of each low-carbon ecotourism pillar. Turquoise for Education reflects freshness, renewal, and the growth of knowledge; orange for Economy symbolizes the energy, enthusiasm, and creativity of local communities; and blue for Ecology emphasizes the connection with nature, the ocean, and clean air. The meeting point of the three uses a soft green color as a symbol of harmony and synergy among education, economy, and ecology, thereby emphasizing the integration of all elements for environmental sustainability and community welfare.

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Table 2. Strategic Objectives, Roles, and Expected Results of Triple E in CARBOSAKA

Pillar	Strategic Objective	Role in the System	Expected Outcome
Education	Increase tourist awareness of carbon footprints	Provide information, shape tourist behavior	Tourists adopt environmentally friendly habits during their visits
Economy	Mobilize community participation in the sustainable value chain	Optimize local potential to support the destination	Community income increases while maintaining sustainability
Ecology	Offset and reduce carbon emissions from tourism activities	Implement conservation actions based on participation	Coastal ecosystems are preserved and carbon sequestration functions are enhanced

As shown in Table 1, each pillar of the CARBOSAKA framework has complementary strategic objectives, clearly defined roles, and expected outcomes that support the development of low-carbon ecotourism. Education aims to shape tourist behavior by providing information that promotes environmental awareness; economics mobilizes local resources to generate sustainable economic benefits; and ecology ensures the sustainability of ecological carrying capacity through conservation actions. The synergy of these three pillars creates a system that regulates interactions among tourists, communities, and the environment, while also establishing a long-term foundation for destination sustainability.

4) Urgency and Background of the Development of the CARBOSAKA Concept

Mangrove ecosystems are susceptible to environmental changes, both from human activities and from climate change. As natural carbon sinks, mangroves play a crucial role in mitigating global warming and also act as a natural barrier against abrasion and seawater intrusion. However, increasing tourist visits without adequate management can place significant pressure on these ecosystems. This challenge requires an ecotourism management model that balances recreation and environmental sustainability. Beyond ecological factors, the development of mangrove ecotourism is also influenced by the social and economic aspects of coastal communities. Well-directed and managed tourism activities can be a promising alternative source of income for residents. However, without a clear framework, this economic potential often neglects conservation considerations and can accelerate environmental degradation. Therefore, a management plan is needed that synergizes economic value with nature conservation.

On the other hand, tourists' limited awareness of the carbon footprint of tourism activities is one of the causes of the high environmental impact of natural destinations. Many tourists are unaware that their use of transportation, consumption of packaged products, and energy use at tourist sites directly increase carbon emissions. The lack of information linking these activities to their ecological consequences often leads to this issue being overlooked. Providing informative and interactive educational media can be a first step in building this awareness. Recognizing this challenge, the CARBOSAKA concept was designed to address the need for a mangrove ecotourism model that is educational, participatory, and oriented toward reducing carbon emissions. This concept combines three pillars: education, economics, and ecology, in a mutually supportive system, and is expected to serve as a benchmark for sustainable community-based destination management.

5) CARBOSAKA Concept Design in Integration of Education, Community Empowerment, and Conservation

The education pillar provides a platform for tourists to gain deeper insight into the relationship between their activities and carbon emissions, through interactive QR code-based media and information podiums available on-site. Visitors are invited to observe the direct impact of their behavior on the surrounding environment, thereby fostering greater awareness and a stronger sense of responsibility for maintaining the sustainability of the mangrove ecosystem. This aligns with findings from Verawati & Idrus (2023), which indicate that mangrove ecotourism can deepen understanding of the role of mangrove ecosystems in protecting coastal environments. Furthermore, ecotourism can also foster greater motivation for environmental protection. Therefore, the development of mangrove ecotourism is highly appropriate as both an educational tool and a conservation-based tourist destination.

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In line with this educational function, the economic aspect of CARBOSAKA seeks to highlight and integrate local values as part of a sustainable ecotourism management strategy. The use of local and recycled materials in food and souvenir production provides tourists with an authentic experience while simultaneously creating opportunities to improve the well-being of the local community. These products also contain an implicit educational element, fostering synergy between economic empowerment and increased environmental awareness. The role of ecotourism becomes even more crucial when optimally managed, as it can increase community income while also contributing to infrastructure improvement and ecological preservation. Findings Islam & As (2025) suggest that the economic success of ecotourism can have a multiplier effect on the quality of life of coastal communities. Support for appropriate management innovations can unleash the potential of ecotourism to empower communities for sustainable development.

In addition to the educational and economic pillars, CARBOSAKA emphasizes the ecological pillar, which focuses on implementing conservation programs to sustain coastal ecosystems. Through mangrove planting and adoption, these activities contribute to carbon sequestration and protect coastlines from abrasion, which can disrupt the natural balance. These conservation activities are also packaged as field education tools to enable tourists to directly observe and understand the vital role of mangroves in maintaining coastal environmental stability. This approach encourages close interaction between visitors and nature, while simultaneously strengthening a shared commitment to ecosystem preservation.

Ecotourism, when designed with practical strategies and innovations, can have positive impacts on both social and economic aspects. Research findings from Silalahi et al. (2024) emphasized that successful ecotourism management integrates ecological, educational, and financial benefits into a mutually supportive whole. Therefore, CARBOSAKA serves as a framework for mangrove ecotourism management that combines three main pillars: education, economics, and ecology into a mutually supportive, integrated system. Visitors are encouraged to raise awareness of the environmental impact of their activities. At the same time, local communities are empowered by the use of locally sourced and recycled materials as economic resources. Meanwhile, the mangrove conservation program sequesters carbon while protecting the coast and serving as a field education platform for tourists. This triple E approach creates a balanced synergy between increasing understanding, strengthening the economy, and preserving the environment, thus supporting sustainable, low-carbon ecotourism.

6) Potential Emission Reduction under Full-Scale CARBOSAKA Implementation

If the CARBOSAKA model were fully implemented, a substantial reduction in tourism-related carbon emissions could be achieved. Based on a simulation of the Dogang mangrove ecotourism case, the average per-tourist emission is estimated to range from 14.27 to 33.47 kg CO_2e, depending on the mode of transport. Assuming an annual visitation rate of approximately 5,000 tourists, the total baseline emissions are estimated at around 92–167 tons of CO_2e per year. Through behavioral changes (e.g., shifting to low-carbon transportation and reducing high-carbon food consumption), the use of locally produced low-emission products, and ecological offset programs (e.g., mangrove planting), the model is projected to achieve emission reductions of approximately 20–40%. This indicates that the CARBOSAKA model has the potential to reduce CO_2e emissions by approximately 18–67 tons per year within a single mangrove ecotourism area.

At the national scale, if applied to 50 mangrove ecotourism destinations, the potential reduction in emissions could reach 900–3,350 tons of CO_2e per year, demonstrating the strategic contribution of this model to climate change mitigation in the tourism sector. These findings are supported by (Macreadie et al., 2021), who highlighted that mangrove ecotourism, as part of blue-carbon ecosystems, has a significant capacity to sequester carbon, enabling mangrove ecosystems globally to function as natural carbon sinks with high sequestration rates and long-term storage in biomass and sediments.

Mangrove conservation and rehabilitation not only reduce emissions through lower-carbon tourist behavior but also increase carbon sequestration in biomass and soil, as noted by (Arifanti et al., 2024). Therefore, the combination of low-carbon actions and mangrove restoration supports the plausibility of the 20–40% emission reduction estimated in the CARBOSAKA simulation. Nevertheless, actual outcomes depend on the effectiveness of interventions, the level of visitor adoption, and local conditions; thus, long-term field research and quantitative monitoring are required to confirm the model's mitigation impacts.

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7) Potential Challenges and Implementation Barriers

Although the CARBOSAKA framework shows strong potential for promoting sustainable mangrove ecotourism, its implementation may face several practical challenges. One of the most significant issues concerns tourists' resistance to behavioral change, particularly in adopting low-carbon transportation, reducing single-use products, and engaging in educational activities. Research on sustainable tourism behavior indicates that barriers such as value perceptions, image concerns, and perceived risks often hinder behavioral change among tourists. These factors may reduce the willingness to adopt eco-friendly practices, even when awareness is high (Zhang et al., 2024). To address this issue, CARBOSAKA needs to strengthen its educational reinforcement mechanisms through reward systems, social modeling, and experiential learning that encourage gradual shifts in tourist behavior.

Another critical challenge concerns the capacity of local human resources. The implementation of the CARBOSAKA model requires staff who are capable of managing data collection, interpreting carbon footprint results, maintaining QR-based educational systems, and communicating sustainability messages effectively. A study Dasan et al. (2022) conducted in community-based ecotourism sites in Sabah, Malaysia, found that limited managerial, marketing, and hospitality skills constrained the long-term success of ecotourism initiatives. This finding implies that, without ongoing capacity-building and technical training, the educational and economic pillars of CARBOSAKA may face operational difficulties, particularly regarding data accuracy and tourist engagement. The issue of infrastructure and stakeholder coordination also plays a crucial role. Research Alemayehu (2024) on community participation in ecotourism highlights that unequal distribution of benefits, weak institutional collaboration, and social conflicts can undermine the sustainability of tourism programs.

In mangrove-based tourism, inadequate infrastructure, such as limited access to carbon information facilities or the absence of low-emission transportation options, could limit the practical implementation of CARBOSAKA's educational and ecological initiatives. The success of this framework, therefore, depends on multi-level collaboration between local governments, private stakeholders, and community groups to ensure coherent planning and consistent support. From a tourism management perspective, another potential concern is the perception of crowding and the destination's environmental carrying capacity. Rapid tourist growth without adequate capacity controls may degrade the quality of the visitor experience and place pressure on sensitive mangrove ecosystems. Recent coastal tourism studies show that managing visitation limits and ecological thresholds is critical to maintaining both environmental integrity and social well-being (Xu & Li, 2025).

4. CONCLUSION

The CARBOSAKA concept presents an integrated model of mangrove ecotourism management that combines three main pillars: education, economy, and ecology within a unified and mutually reinforcing framework. The educational component, developed through the calculation of tourists' carbon footprints, enhances understanding of environmental impacts and strengthens awareness of responsible tourism behavior. The economic pillar focuses on community empowerment through the production of environmentally friendly local products, while the ecological pillar promotes active participation in mangrove planting and conservation programs. The integration of these three elements is designed to create a sustainable system that maintains ecosystem balance and supports the well-being of coastal communities.

This study is conceptual and descriptive in nature, emphasizing model formulation rather than field implementation. The main limitation lies in the absence of empirical data, including quantitative measurement of behavioral change and direct assessment of economic and ecological outcomes. Future research is encouraged to explore these aspects through empirical and longitudinal approaches. Field-based studies that apply the CARBOSAKA framework can provide practical evidence of its effectiveness in reducing carbon emissions and enhancing local sustainability. Such research will contribute to strengthening theoretical development and support the broader application of educational and community-based strategies in mangrove ecotourism.

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