Environmental Impact Assessment of Tourism Activities in Kenyir Lake: A Life Cycle Approach

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Abstract. This study evaluates the environmental impacts of tourism activities at Kenyir Lake, focusing on houseboat and resort operations using a Life Cycle Assessment (LCA) approach. The research aims to identify key contributors to environmental degradation by systematically analyzing the inputs and outputs associated with these activities. Primary sources collected through interviews and water sample collection for laboratory analysis, supported by secondary literature, and analyzed using SimaPro 9.1.1.1 software following the CML-IA method, which evaluates ten impact categories. The findings highlight those operations, especially energy consumption and waste management, are significant contributors to environmental impacts, with substantial effects on global warming, ozone layer depletion, and various forms of ecotoxicity. The study emphasizes the need for sustainable practices in tourism operations, particularly in reducing energy use and improving waste management. The results provide critical insights into the sustainability and efficiency of tourism infrastructure at Kenyir Lake, offering valuable recommendations for mitigating adverse environmental impacts and promoting sustainable tourism practices in the region.

1 Introduction

Kenyir Lake is an artificial lake located in Hulu Terengganu, Malaysia. The lake was created by the construction of the Sultan Mahmud Power Station, which began in 1978 with the damming of the Kenyir River. The project was completed in 1985 and the lake was officially opened in 1987 [1]. The inundation of the Hulu Terengganu catchment significantly altered the region's ecological landscape, leading to the formation of a vast water body [2]. Since its creation, Kenyir Lake has evolved into a major eco-tourism destination, with a focus on cultural and provisioning services [2]. Tourism has become a key economic driver for the state of Terengganu [3]. Notably, the area has developed a robust tourism infrastructure centered around houseboats and resorts, which attract a significant portion of the visitors to the lake. These houseboats provide a unique floating accommodation experience, allowing tourists to fully immerse themselves in the natural beauty of the lake, while the resorts offer

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a range of amenities and activities designed to enhance the eco-tourism experience. The growth of eco-tourism at Kenyir Lake began in the early 1980s with the introduction of nature-based activities. By the year 2000, the number of tourism enterprises in the area had increased substantially, reflecting the growing popularity of the lake as a destination for both local and international tourists [4].

Since the inundation of Lake Kenyir, the ecological characteristics of the forested land have gradually adapted to a lacustrine environment [5]. At the same time, tourism has become a significant contributor to the state of Terengganu. Since 1993, the area has been developed for eco-tourism, focusing primarily on cultural and provisioning services [6]. The East Coast Economic Region (ECER) Master Plan identifies Lake Kenyir as a promising ecotourism site due to its natural beauty, recreational facilities, and tourism activities. The key elements of ecotourism in this area include natural and environmental attractions, educational and cultural experiences for visitors, conservation and ecological adventures, and the active participation of local communities in tourism activities. Despite the economic benefits of tourism at Kenyir Lake, the rapid development of tourism infrastructure has raised concerns about its potential environmental impact. Firstly, the expansion of houseboats and resorts has led to increased water pollution, primarily from waste disposal and fuel leakage, which threatens the lake's water quality and aquatic life [7]. Secondly, the construction and operation of these facilities have resulted in habitat destruction, disrupting the local flora and fauna and leading to a loss of biodiversity in the region [8].

Life Cycle Assessment (LCA) has become a key tool for evaluating environmental impacts and identifying the contributions of various production processes. Numerous environmental studies of significant global concern, such as those addressing ozone layer depletion, global warming, and acidification, have utilized LCA to highlight the impacts of various activities and production processes. In the tourism industry, LCA is utilized to understand and mitigate the environmental effects of various tourism activities and accommodations. To address the environmental challenges posed by tourism development at Kenyir Lake, including water pollution and habitat destruction, LCA can be employed to assess the sustainability and efficiency of the tourism infrastructure. Previous studies have demonstrated the utility of LCA in the tourism sector, including various types of accommodations and recreational activities [9], [10].

Hence, the objective of this study is to evaluate the environmental impacts of tourism activities at Kenyir Lake using a Life Cycle Assessment (LCA) approach. By systematically analyzing the environmental effects of various tourism-related infrastructures and activities, including houseboats and resorts, this study aims to identify the key contributors to environmental degradation. The findings will provide a comprehensive understanding of the sustainability and efficiency of the tourism infrastructure at Kenyir Lake, offering valuable insights for mitigating adverse environmental impacts and promoting sustainable tourism practices in the region.

2 Methodology

2.1 Life Cycle Assessment (LCA)

The primary objective of using LCA is to minimize environmental impacts by guiding the decision-making process towards more sustainable solutions [11]. The LCA for houseboats and and resorts, as depicted in Fig. 1, follows a structured process as outlined by ISO 14040 and 14044 standards. The assessment comprises four phases: goal definition and scope, inventory analysis, impact assessment, and interpretation. The goal definition and scope phase establishes the purpose and boundaries of the study, while the inventory analysis phase involves collecting data on inputs, outputs, and emissions. The impact assessment phase evaluates the potential environmental impacts based on the collected data, and the interpretation phase uses these results to make informed recommendations. This comprehensive approach utilizes qualitative and quantitative data collection methods, the SimaPro 9.1.1.1 software, and the CML-IA method, which focuses on ten impact categories, to ensure accurate and detailed environmental impact assessments for these applications.

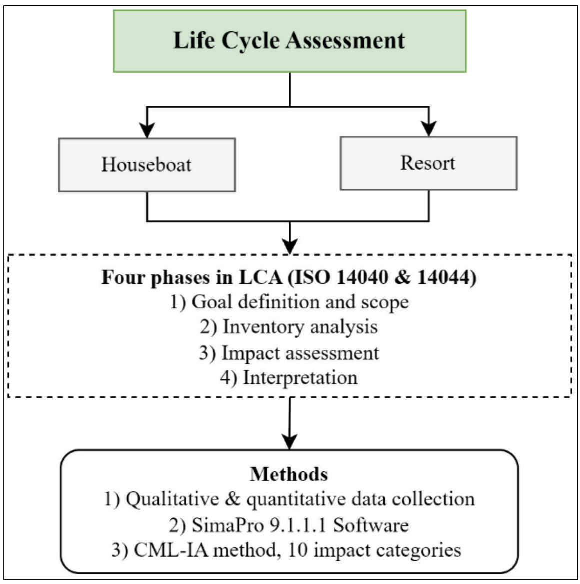

Fig. 1. Methodology framework for LCA.

Life cycle invemtory (LCI) results include inventory data through a survey questionnaire, on-site data, laboratory, literature reviews and several databases, namely Agri-footprint, Ecoinvent 3, European Reference Life-Cycle Database (ELCD), and Industry Data 2.0. The LCA method is conducted following the CML-IA [12]. This method evaluates the environmental impact from process flow on the activities in Kenyir Lake area. CML-IA evaluates ten different impact categories, namely abiotic depletion (AD), global warming (GW), ozone layer depletion (OLD), human toxicity (HT), freshwater ecotoxicity (FET), marine aquatic ecotoxicity (MET), terrestrial ecotoxicity (TET), photochemical oxidation (PO), acidification (ACD) and eutrophication (EUT) [13].

2.2 Study area and system description

The study focused on the Kenyir Lake area, with particular emphasis on tourism activities involving houseboats and resorts. The data collection was carried out at several key locations around the lake, including Rimba Flora Floriculture (RFF), Tanjung Mentong Resort (MR), Kenyir Eco Resort (KER), Rumah Peranginan Persekutuan (RPP), Musang Kenyir Resort (MKR), and Suria Rakit Resort (SRK), as well as 10 designated houseboat areas identified as H1 through H10. These houseboat areas (H1-H10) represent the specific locations where houseboats are typically parked overnight, providing a comprehensive understanding of the operational aspects and environmental impacts of tourism in the region. Fig. 2. illustrates the geographical distribution of these sampling points, highlighting the study's extensive coverage across Kenyir Lake. The inclusion of both houseboat and resort locations ensures a robust analysis of tourism activities, capturing the diverse nature of tourism infrastructure within the lake area.

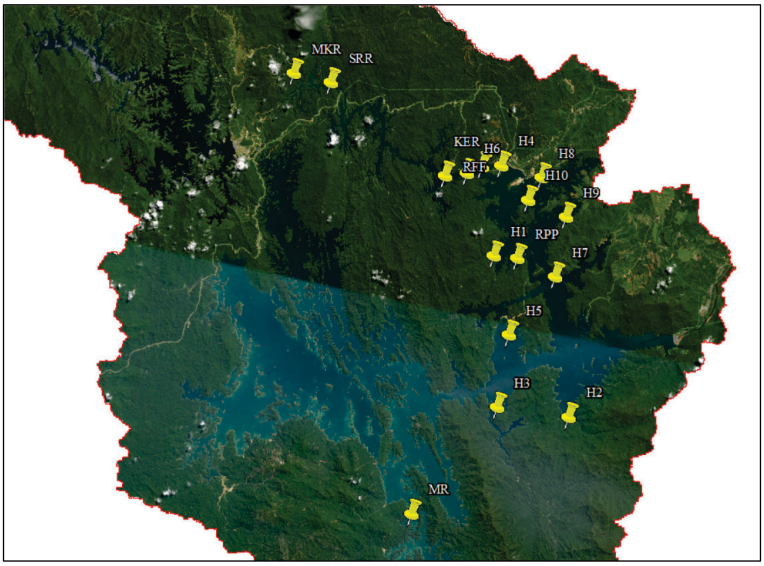

Fig. 2. Geographical Distribution of Sampling Points for in Kenyir Lake.

The interviews gathered essential company information, such as addresses and contact details, as well as operational data related to water, electricity, fuel, machinery, detergents, and transportation usage. Additionally, waste management practices were examined, with respondents detailing the types and quantities of waste generated, including municipal solid waste, wastewater, food waste, plastics, metals, and papers, along with their disposal methods, whether through landfill, incineration, recycling, or other means.

In parallel, water quality data were collected from tourist attraction areas, specifically the mentioned resorts and houseboats, during both dry (March 2019) and wet (December 2019) seasons. The water samples were manually collected by personnel traveling between the sampling points via boat. Samples were taken from the drains of each tourist area and from 0.3 meters below the water surface at the fish farm areas, using HDPE bottles of 1.5-liter capacity. Immediately after collection, the water samples were stored in ice boxes and transported to the environmental laboratory at Universiti Tenaga Nasional (UNITEN), where they were refrigerated at 3ºC - 4ºC until water quality tests were conducted.

In addition to water quality assessments, emissions to the air were also calculated. Waste-related emissions were calculated using the IPCC 2006 guidelines, ensuring accuracy and consistency in estimating environmental impacts. All data obtained from the interviews and field data collection in this study were crucial as inputs and outputs for life cycle inventory (LCI). This meticulous approach ensured a robust and comprehensive assessment of both water quality and air emissions across Kenyir Lake, with the geographical distribution of sampling points providing extensive coverage to accurately evaluate the environmental impacts of tourism activities in the region.

3 Results and Discussion

This subsection illustrates the life cycle inventory and environmental impacts of tourism activities, specifically focusing on resorts and houseboat operations at Kenyir Lake.

3.1 Life cycle inventory (LCI)

The life cycle inventory (LCI) for Kenyir Lake, as presented in Table 1, provides comprehensive data on the inputs and outputs associated with various activities in the area, specifically focusing on houseboat operations and resort activities. The LCI data includes the amounts of energy and materials consumed, as well as the quantities of emissions released into the environment from these tourism-related activities. This data was meticulously collected from primary sources, supplemented by secondary literature and databases available in SimaPro 9.1.1.1, ensuring a robust and accurate representation of the environmental impacts within the Kenyir Lake region.

Table 1. Inventory data resort and houseboat.

Category	Input/Output	Unit	Amount	Notes
Resort Operation	Electricity	kWh/day	90	For overall operation
	Water (tap water, tank, pump)	L/day	200	For guest services (20 guests/night)
	Food consumption (various)	kg/day	35.13	Includes breakfast, lunch, dinner, eggs, milk
	Sewage system (wastewater treatment, solid waste)	guest/night	20	Waste management for 20 guests/night
	Kitchen utilities (microwave, refrigerator, dishwasher)	kWh/day	28	Energy consumption by kitchen appliances
	Room utilities (lights, air conditioners, heaters)	kWh/day	70	Energy consumption for room utilities
	Furniture & appliances	guest/night	20	Mattresses, hair dryers, furniture, etc.
Houseboat Operation	Diesel Engine Consumption	L/day	95	For boat operation
	Batteries & Generator	kWh/day	50	Energy consumption for operations
	Water (tap water)	L/day	200	For guest services
	Food consumption (various)	kg/day	35.13	Includes breakfast, lunch, dinner, eggs, milk
	Sewage system (wastewater treatment, solid waste)	guest/night	20	Waste management for 20 guests/night
	Kitchen utilities (stove, oven, microwave)	kWh/day	37	Energy consumption by kitchen appliances
	Room utilities (lights, air conditioners, heaters)	kWh/day	70	Energy consumption for room utilities
Output to Environment	Methane (CH_4)	kg	1.69	Emission to air
	Biochemical Oxygen Demand (BOD)	kg	5.328	Water pollutant
	Chemical Oxygen Demand (COD)	kg	5.04	Water pollutant
	Total Suspended Solid (TSS)	kg	100.8	Water pollutant
	Ammonia-Nitrogen (NH_3-N)	kg	0.7344	Water pollutant
	Phosphorus (P)	kg	0.648	Water pollutant
	Nitrogen (N)	kg	0.72	Water pollutant

3.2 Life Cycle Impact Assessment (LCIA)

3.2.1 Environmental impact categories for Resorts

Fig. 3. illustrates the environmental impact of various operational areas across different impact categories, including AD, GW, OLD, HT, FET, MET, TET, PO, ACD, and EUT. A critical examination of the graph reveals that Operation generally has the highest impact across most categories, particularly in AD, GW, OLD, TET, PO, and ACD. This suggests that the processes and energy consumption associated with operations are significant contributors to these environmental issues. Food Consumption also shows considerable impact, especially in categories such as GW and HT, indicating the substantial environmental burden associated with food sourcing and preparation. Waste management is another major contributor, particularly in categories like OLD, PO, and ACD, further emphasizing the environmental challenges associated with waste disposal practices. Lastly, Room Facilities and Kitchen activities, while less impactful than operations and waste, still contribute notably to categories like FET, MET, and EUT, highlighting the need for sustainable practices in these areas as well.

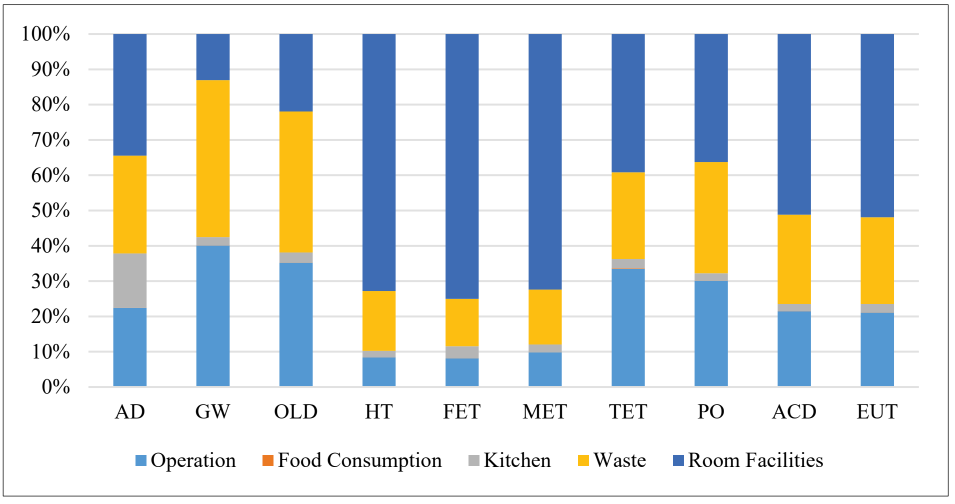

Fig. 3. Environmental impact contributions from resort activities.

The high contributions to AD and GW from operations and room facilities are consistent with findings from similar studies. For instance, Becken et al., [14] highlighted that energy use in hotel operations, particularly in heating, cooling, and lighting, is a major driver of greenhouse gas emissions in the tourism sector. Similarly, Gossling et al., [15] found that energy consumption in hotel facilities can account for a substantial portion of the overall environmental footprint, particularly in regions with high electricity demand for air conditioning.

Furthermore, the impact of food consumption on GW and HT observed in this study aligns with the findings of Filimonau et al., [16], who demonstrated that food production and consumption in hotels contribute significantly to carbon emissions and environmental toxicity, particularly through the sourcing and preparation of food items. The waste management impacts, particularly in FET and ACD, are also in line with the conclusions drawn by Styles et al., [17], who emphasized the importance of sustainable waste management practices in reducing the environmental impacts of the hospitality sector. These comparisons underline the critical need for targeted strategies to mitigate energy use and improve waste management in resort operations to reduce their environmental footprint.

3.2.2 Environmental impact categories for Houseboats

For houseboat activities, as illustrated in Fig. 4, a similar trend can be observed, though the distribution of impacts may vary slightly depending on the specific activities and energy use patterns associated with houseboat operations. Operation in houseboat activities is also likely to be a significant contributor to AD and GW due to the reliance on diesel engines and generators for power. Food Consumption aboard houseboats would contribute notably to GW and HT, similar to the resort findings, due to the sourcing and preparation of meals. Waste management aboard houseboats would also be a critical area, particularly concerning OLD, PO, and ACD, given the confined space and the need for effective waste disposal practices. Kitchen and Room Facilities on houseboats, while smaller in scale compared to resorts, would still impact categories like FET, MET, and EUT, underlining the importance of implementing energy-efficient appliances and sustainable practices even in these mobile accommodations.

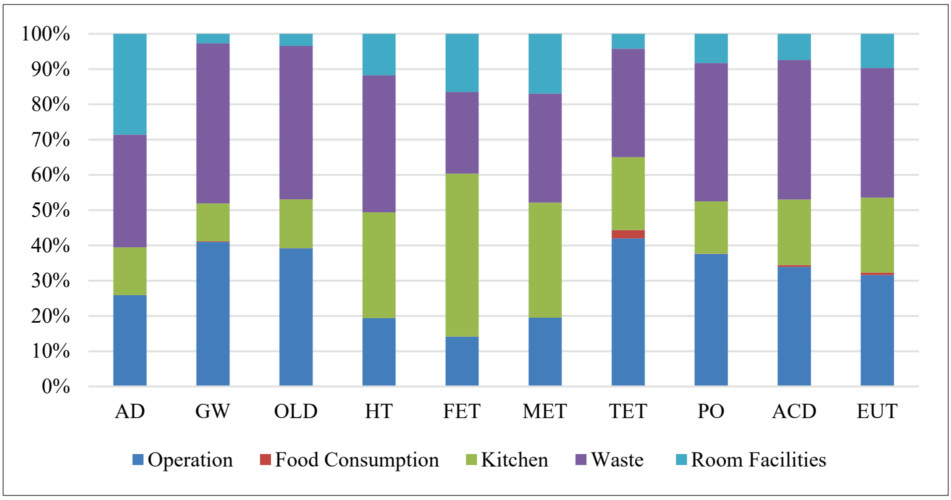

Fig. 4. Environmental impact contributions from houseboat activities.

Previous research shows that waste management and operational activities have high environmental impacts across multiple categories, particularly in human toxicity, freshwater ecotoxicity, and marine ecotoxicity. This aligns with the figure where waste and operations dominate these impact categories [18]. Studies also indicate that kitchen activities have significant impacts, especially in categories such as freshwater ecotoxicity and marine ecotoxicity. This is reflected in the provided figure, where kitchen shows substantial impacts in these categories [19]. Comparing these findings with previous studies, a study by [20] on diesel generators highlighted their substantial contributions to OLD and GW, corroborating the high impacts recorded in these categories.

The release of pollutants into marine environments through effluent discharge can have detrimental effects on marine organisms. Studies by Li et al., [21] show that waste water effluents often carry microplastics and other contaminants that accumulate in marine ecosystems. ACD impact is greater for waste, this reflects the consumption of non-renewable resources in the treatment processes. EUT is also higher for waste. The discharge of nutrient-rich effluents from wastewater treatment plants can lead to algal blooms and oxygen depletion in water bodies. Research by Malik et al., [22] highlights the role of nutrient discharge from wastewater in promoting eutrophication in aquatic environments.

4 Conclusion

The LCA of tourism activities at Kenyir Lake reveals that both houseboat and resort operations significantly contribute to environmental impacts, primarily through energy consumption and waste management. The operations category, which includes energy use for daily activities, shows the highest impact across multiple categories, including global warming, ozone layer depletion, and terrestrial ecotoxicity. Specifically, the reliance on conventional energy sources such as diesel for houseboats and electricity for resorts plays a crucial role in exacerbating these impacts. Waste management practices, particularly related to the disposal of municipal solid waste and wastewater, also contribute notably to environmental degradation, with significant effects observed in acidification, eutrophication, and ecotoxicity categories. These findings underscore the urgent need for adopting more sustainable practices within the tourism sector at Kenyir Lake.

To address these impacts, the implementation of energy-efficient technologies, coupled with improved waste management strategies, could significantly reduce the environmental footprint of tourism activities. Specifically, adopting renewable energy sources like solar or wind power for resort and houseboat operations offers a practical solution to decrease reliance on fossil fuels, thus reducing greenhouse gas emissions. Improved waste management can be achieved through the integration of advanced treatment technologies and by promoting recycling and composting practices, which would reduce the burden on landfill and mitigate associated environmental impacts. Furthermore, creating an action plan for tourism operators that includes concrete steps such as monitoring energy use, adopting renewable energy sources, and optimizing waste management practices will be essential for translating these recommendations into practice.

Additionally, raising awareness among stakeholders—including tourists, operators, and local authorities—about the environmental impacts of tourism is crucial for fostering a collective commitment to sustainable practices. Future work should explore the long-term effects of renewable energy integration and advanced waste treatment on reducing environmental impacts. By prioritizing these sustainable practices and evaluating their effectiveness over time, Kenyir Lake can serve as a model for sustainable tourism in ecologically sensitive regions, providing a clear roadmap for tourism operators to follow in achieving these sustainability goals.

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