Assessing the Effectiveness of Solid Waste Management in Thailand's Tourist Industry via the Use of DEA-Based Methods

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***Abstract*—Effective solid waste management is paramount for sustainable tourism destinations, ensuring the preservation of natural resources and promoting eco-friendly practices. This research comprehensively assesses the solid waste management systems across various locations, considering both socioeconomic and environmental factors. Utilizing primary and secondary data, we investigate waste management policies, practices, and infrastructure, employing methodologies such as trash generation data analysis, infrastructure assessments, and surveys targeting municipal authorities, waste management entities, and tourists. The study evaluates key aspects of waste management, including collection, recycling, disposal, and sustainability, utilizing non-parametric Data Envelopment Analysis (DEA) and its variants. Our analysis involves efficiency ratings for 20 tourism locations or 4 provinces in 5 Thai regions, using inputs and outputs such as recycling rate, trash diversion rate, the number of restaurants, hotels, tourism destination size, tourist numbers, and waste management complaints. To enhance clarity and consistency, we reorganized the abstract, presenting the original contributions after synthesizing the main results. This research identifies high-performing regions that can serve as models and proposes strategies for improving less successful areas. The findings not only contribute to the development of solid waste management plans tailored to each community's unique requirements, culture, and resources in Thailand but also advocate for data-driven decision-making in waste management and resource efficiency within the tourism industry.**

***Keywords*—solid waste management, tourism destinations, super-efficiency, data envelopment analysis, sustainability, efficiency, regional comparisons, eco-friendly practices**

I. Introduction

Tourism has grown globally, boosting economic growth and cultural exchange. However, the exponential rise of the tourist sector has created several complications, including sustainability. If not addressed, large-scale waste management can impede sustainable tourism. In Thai locations, where tourism is vital to the economy, solid waste management is essential for environmental and social preservation. This study uses Data Envelopment Analysis (DEA) and its variants as comprehensive analytical techniques to examine this key component of sustainable tourism.

Thailand's waste management system is overburdened by its growing tourist population. These regions' ecological balance and cultural identity are at risk without a solid waste management system. Thus, efficient waste management techniques must be identified and implemented quickly to address urgent challenges and ensure the tourism industry's long-term survival [1–3]. The tourism business in Thailand is developing rapidly, but managing the enormous amounts of solid trash created by tourists is a difficulty. Demand on waste disposal systems has degraded the ecosystem and caused public health problems even in formerly pristine locations.

To enhance sustainable tourism growth and handle these difficulties, it is necessary to understand the situation and analyze solid waste management procedures in popular tourist sites. This study evaluates waste management programs in tourist-heavy Thailand, focusing on Bangkok, Phuket, Pattaya, Chiang Mai, and Krabi. This study seeks to uncover trash management practices that may be used in other popular tourist locations nationwide. Despite the urgency of waste management, Thailand's top tourist destinations have no national solid waste management research project.

The objective of this inquiry is to enhance the sustainable tourism paradigm in Thailand and suggest a global model. Through the completion of this detailed investigation, the aim is to contribute to the sustainable tourism discourse and highlight the significance of research in fostering a symbiotic link between tourism and environmental protection. The findings of this research are anticipated to encourage Thai authorities to adopt sustainable tourism policies. The implementation of responsible waste management practices holds potential benefits for both the environment and the tourism industry. Cross-regional comparisons and evaluations of solid waste management strategies in Thai tourist locations could play a crucial role in achieving this objective.

The remaining document sections are structured as follows: The next part reviews literature. Section III provides a complete overview of solid waste management in numerous popular Thai tourist sites and data envelopment analysis-based methodologies. The evaluation's results and interpretations compare the prevalence of many tourist attractions in Thailand, including recommendations for improving solid waste management in popular tourist areas. The paper's conclusion summarizes its results and highlights sustainable waste management for Thailand's tourism sector.

II. Literature Review

Thai destinations distinguish out as tourism evolves. Thailand draws travelers from around the world with its vibrant culture, gorgeous landscape, and unique activities.

Tourism has hampered solid trash management. Tourism is destroying Thailand's waste management system, endangering its culture and ecology. The intricate link between visitor development, trash generation, and waste management in Thailand is studied in sustainable tourism. Modern methodologies like Data Envelopment Analysis (DEA) and its variants were used to develop waste management solutions that tackle pressing problems and maintain tourism. This study provides a fresh perspective and fills gaps in the literature to enable Thai authorities and stakeholders make informed decisions and build a more resilient and sustainable tourism paradigm.

Combining studies shows sustainable resource management's complexity. An analysis during the COVID-19 pandemic in Wuhan, Hubei Province, China, found that public health epidemics greatly increase medical waste output, challenging treatment systems. Improved medical waste (MW) management efficiency using DEA-integrated LCA. It supports mobile organic Rankine cycle incinerators and renewable fuels [4]. Iranian MSW management is thoroughly examined for sustainability. Anaerobic digestion compared. landfills utilizing CHP eco-efficiency metrics. Ads and landfills favor different waste streams, but CHP-less systems are inefficient [5].

Layer-by-layer examination of China's industrial water infrastructure indicates sub-stage resource usage improvements. Researchers discovered that water supply component performance affects system efficacy, emphasizing the need for government labor performance engagement [6]. Industrial transformation has increased business refuse output in Taiwan's robust economy. A dynamic undesirable data envelopment analysis model [7] shows that lucrative refusal-treatment businesses grow in Chiayi City, Kaohsiung City, Taitung County, and Yunlin County.

A novel method for merging partial performance indicators into composites for Portuguese urban solid refuse management utilities is proposed. Old model has unwanted variables and regulatory constraints fixed in new model. A new framework is compared to existing models [8]. Data Envelopment Analysis examined Tuscany towns' solid waste generation's environmental cost and found that tourism's environmental costs affect waste management efficiency seasonally. The paper suggests flexible waste management and incentives to extend tourist stays to prevent seasonality [9].

Environmental and eco-efficiency was high in Chilean MSW services but low in technical efficiency. Population density boosts environmental efficiency, but tourism decreases it. This helps policymakers develop circular economy and sustainable municipal solid waste management [10]. Additional Chilean research study how MSW recycling and selective collection affect municipal operations. Selection and recycling boost municipal performance, but the survey found few eco-efficient and efficient communities, suggesting room for improvement. Serviced population, density, tourism, and waste per capita affect eco-efficiency [11].

Medium and big Sri Lankan hotels have 61% operational efficiency, according to data envelopment. Water utilization decreases environmental impact, improving energy and trash management. The study's findings can assist hoteliers and the government improve environmental and technical management [12]. DEA assesses coastal socioeconomic activity vulnerability to sea. It grades European Atlantic Area nations and regions on important indicators. The research says Ireland has the strongest Atlantic European shoreline and the UK the most vulnerable [13].

DEA metafrontier research examines Tuscany municipal solid waste management eco-efficiency by ownership. Publicly owned companies, greater populations, and higher population densities make communities more eco-efficient, whereas smaller municipalities and those with less visitors have better waste management. Better communication is needed amongst policymakers [14]. Waste drives global greenhouse gas emissions. 15 European nations' waste production environmental efficiency from 2001 to 2015. Economically and environmentally, Sweden, Luxembourg, the UK, the Netherlands, and Belgium excel. Luxembourg was most efficient from 2001 to 2015. Low economic growth and high trash sector carbon reductions are ideal decoupling circumstances. To meet EU waste management standards and climb the "waste hierarchy" [15], countries must recycle.

Brazilian solid waste management endogenous factors were explored using data envelopment analysis. Successful public resources, municipal resource optimization, and public expenditures are evaluated. Results show waste management affects solid waste collection and efficiency [16]. Twenty-one Croatian counties' environmentally conscious tourist business was investigated in 2011–2015 Data Envelopment Analysis. This pioneering research in Croatia and the Balkans found that most counties improved waste management and attracted tourists. Waste management improvements address inefficiency [17, 18].

Sustainable tourism and waste management are acknowledged in the literature, but no systematic research has applied DEA and its modifications to Thailand. To solve this mismatch, this study applies a unique waste management technique adapted to Thai tourism and efficiency analysis. This study matters outside academia. This study provides ideal waste management techniques at Thai sites to help other big tourist destinations with comparable issues. Additionally, this study will empower industry players, politicians, and local authorities with the knowledge they need to make informed decisions regarding sustainable tourism development, preserving cultural heritage and natural resources.

This study aims to enhance Thailand's sustainable tourism strategy and create a global model. This extensive study intends to add to the sustainable tourism conversation and show how research may relate tourism and environmental conservation. This research will encourage Thai authorities to promote sustainable tourism. Responsible waste management may help tourism and the environment. Cross-regional comparisons and assessments of Thai tourist solid waste management techniques may assist.

III. Materials and Method

A. Solid Waste Management in Tourist Destinations in Thailand

Since COVID-19, it has been increasingly difficult to

collect solid waste in important tourist spots due to the influx of visitors to Thailand. Due to their inadequacies in the face of an increase in solid waste generation, current waste management systems pose a threat to the environment and public health. In this part, we'll discuss the problems and solutions associated with solid waste management in popular Thai tourist areas.

As illustrated in Fig. 1, the substantial quantity of solid refuse produced in Thailand's well-known tourist destinations is closely associated with a multitude of factors denoted by the chosen input variables. The aforementioned variables comprise the recycling rate, waste diversion rate, number of dining establishments, number of lodging facilities, size of the tourist destination, number of tourists or visitors, and waste management complaint count. Regions exhibit variations in waste composition and management as a consequence of these distinct factors. Coastal regions, including islands and shore facilities, are particularly confronted with issues pertaining to disposable products, food packaging, and single-use plastics. Urban and cultural hubs, which are distinguished by a dense clustering of hotels, restaurants, stores, and markets, make a substantial contribution to the total waste generated.

These areas accumulate a wide variety of waste materials, including plastic bottles, tubs, silverware, as well as restaurant and agricultural refuse. In order to thoroughly examine and tackle these obstacles, the research utilizes a rigorous methodology, which is exemplified by the selected output variables. The output parameters comprise various aspects of waste management, including recycling budget, collection frequency, waste disposal vehicle count, waste management staff count, and initiatives such as recycling campaigns. The aforementioned output variables function as crucial metrics for evaluating the efficacy and efficiency of refuse management strategies implemented in the designated tourist locales.

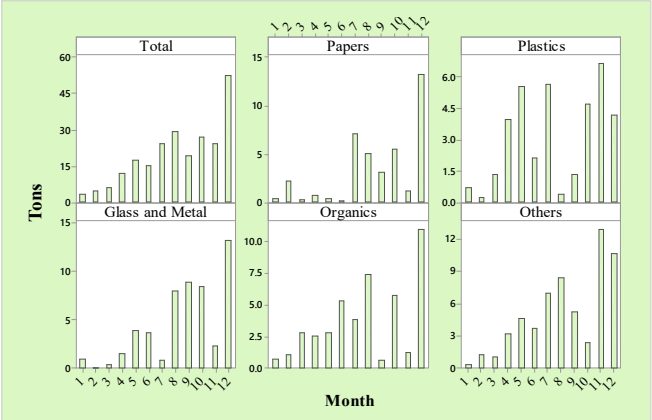


Fig. 1. Quantity of solid waste generated across several categories over the period spanning from July 2021 to June 2022.

The management mechanisms at many of Thailand's most visited attractions are already stretched thin. Many areas lack sufficient waste collection, transportation, and disposal services, in contrast to highly populated cities and popular tourist sites. Waste management challenges, such as full garbage cans, illegal dumping, and littering, are the result of inadequate infrastructure. In addition, many popular tourist areas do not separate their solid waste. Recycling and resource recovery are already time-consuming and difficult processes, and improper sorting of recyclables, organic solid waste, and general rubbish just makes things worse.

Solid waste in tourist locations must be collected by a variety of parties. Sustainable waste management processes need major investment from local governments, tourism operators, solid waste management corporations, and the general public [19, 20]. However, comprehensive waste management systems may struggle to be implemented due to the low levels of engagement and cooperation among stakeholders. Insufficient collaboration between important agencies, weak enforcement of regulations, and inadequate education of both tourists and locals about the necessity of appropriate waste disposal all contribute to the current state of solid waste management [21, 22].

Thailand's ecology and society suffer greatly from poorly managed solid waste at tourist hotspots. Improper garbage disposal may have detrimental effects on the beauty and biodiversity of coastal regions by polluting streams, degrading soil, and harming marine ecosystems. Furthermore, waste accumulation in public places and tourist attractions lowers the quality of life for everyone, which might have a negative effect on the economy. The repercussions on society and the economy are also significant. The hygiene of public areas and the health of the local people have both been connected to ineffective garbage management. It might also put pressure on infrastructure and resources, detracting from other areas of growth that could use the help [23].

In order to develop effective strategies and interventions, it is important to have an understanding of the current state and difficulties of solid waste management in Thailand's tourist attractions. In order to discover successful solutions and provide ideas for sustainable waste management in Thai tourist locations, the following sections of this research will assess and compare waste management practices.

B. Data Envelopment Analysis (DEA)

DEA is used to evaluate solid waste management methods in popular Thai tourist sites. Data Envelopment Analysis (DEA) is a non-parametric method for comparing decision-making units like tourism destinations. This assessment uses several input and output parameters [24, 25]. DEA (Data Envelopment Analysis) evaluates trash management in prominent tourist sites using a variety of criteria. Effective waste management techniques, solid infrastrucure, and public awareness campaigns may handle waste management concerns. Waste collection frequency, recycling rates, and hygienic procedures at final disposal locations can be used to evaluate outcomes.

The first step in the DEA approach is to specify the inputs and outputs that will be evaluated. These metrics should be relevant, quantifiable, and indicative of how well tourist hotspots handle waste. Then, for each site in the research, we collect information on these factors. The DEA technique may be used to compare how well different tourist hotspots handle their solid waste. The most efficient sites are determined by comparing their input-output ratios to those of other places. The DEA research classifies vacation spots as either productive or wasteful. Waste management may be improved in places that are less efficient by studying the methods used there. Locating ineffective last points of arrival reveals promising avenues for development.

The DEA technique has the great benefit of allowing for comparisons to be made across different vacation spots. Successful practices and methods employed by efficient destinations may be identified by comparing efficiency ratings and performance data. Effective waste management strategies may be shared and replicated thanks to this comparison study, which allows for benchmarking and learning from the most efficient sites. A thorough assessment of the efficiency of solid waste management procedures in Thai tourist hotspots is provided by the DEA analysis results. They help policymakers, stakeholders, and other decision-makers pinpoint problem areas and make educated choices to improve waste management efficiency.

DEA is a powerful tool for assessing efficiency, but its limits must be recognized. For DEA to work, it relies heavily on complete and reliable data. In order to get reliable findings, it's important to gather data thoroughly and methodically. Additionally, it is important to pick the variables that most properly reflect the waste management performance of the destinations, both input and output choices might affect the findings. Despite these caveats, DEA is a valuable framework for comparing the efficacy of different approaches to solid waste management in popular Thai tourist areas. It reveals the advantages and disadvantages of various waste management approaches, pinpoints problem areas, and makes it easier to make decisions based on hard data, all of which contribute to making tourism more environmentally friendly.

The DEA approach is employed to do an analysis on the comparative effectiveness of DMUs within a subgroup, using the screened components of input and output. DMUs with a higher efficiency can serve as benchmarks for the other DMUs within subgroups that exhibit lesser efficiency. The present study employed both CCR (Charnes–Cooper–Rhodes) and the BCC (Banker–Charnes–Cooper) models of Data Envelopment Analysis (DEA). The models employed in this study encompassed the best practice frontier (BPF), super-efficiency (SUP), and the worst practice frontier (WPF). The CCR model is predicated on the assumption of constant returns to scale, which is sometimes referred to as fixed scale returns [26]. On the other hand, the BCC model facilitates the incorporation of variable scale returns, which refers to the ability to achieve different levels of efficiency as the scale of production changes.

The evaluation of a DMU's efficacy may be measured by considering the weighted sum of its outputs and inputs. The CCR and BCC models provide the objective function and constraints for determining the optimal solution space. The utilization of a super-efficient DEA model is employed to rank the various DMUs. In contrast to the basic performance function (BPF), this strategy enables a highly efficient unit to attain an efficiency score greater than one by excluding the unit from the reference set [27, 28]. As a benchmark, the DEA's evaluation of enterprise efficiency is regarded as the best practice frontier because it requires leadership that other organizations have followed. However, it is beneficial for high-risk businesses such as banks, financial institutions, insurance companies, and waste management-related businesses.

For various benefits, decision makers may wish to identify agencies with the worst practice frontier. These include a notice of a company's crisis when its performance is at its lowest, so that managers can take immediate action to prevent corporate failure. A use of a method to evaluate the WPF combined with the BPF plans the development of the enterprise to make sustainable progress, an analysis of risk of an enterprise operating in a similar context, and information to the agency or relevant agencies in assisting, supervising, and resolving organizational problems prior to the problem becoming widespread and expanding in scope [29–33]. Developing a model capable of assessing and prioritizing various units to identify those with the poorest performance within a context emphasizing efficiency optimization is a more logical approach. The following models pertain to the CCR's BPF (1), SUP (2), and WPF (3). The models evaluates the relative efficiency for the kth DMU (τ_k) of all n DMUs, each with m inputs and s outputs denoted by x_{ij} and y_{rj}, respectively. The variables v_i and u_r are the weights that will be decided by the solution of the issue.

$$Max\ \tau_k = \sum_{r=1}^{s} u_r y_{rk} \quad (1)$$
Subject to
$\sum_{i=1}^{m} v_i x_{ik} = 1$ $\quad i = 1, 2, \ldots, m$
$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0$ $\quad j = 1, 2, 3, \ldots, n$
$u_r, v_i > 0$ $\quad r = 1, 2, \ldots, s$

$$Max\ \tau_k = \sum_{r=1}^{s} u_r y_{rk} \quad (2)$$
Subject to
$\sum_{i=1}^{m} v_i x_{ik} = 1$ $\quad i = 1, 2, \ldots, m$
$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0$ $\quad j = 1, 2, 3, \ldots, n$
$u_r, v_i > 0$ $\quad$ and $j \neq k$
$\quad r = 1, 2, \ldots, s$

$$Min\ \tau_k = \sum_{r=1}^{s} u_r y_{rk} \quad (3)$$
Subject to
$\sum_{i=1}^{m} v_i x_{ik} = 1$ $\quad i = 1, 2, \ldots, m$
$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \geq 0$ $\quad j = 1, 2, 3, \ldots, n$
$u_r, v_i > 0$ $\quad r = 1, 2, \ldots, s$

In the following sections, the DEA and its variants will be used to assess and compare how well different tourist sites in Thailand deal with solid waste. The findings will shed light on successful methods, highlight areas for growth, and help craft efficient waste management plans that meet the specific needs of each final destination.

IV. Results and Discussions

This section provides an overview of the numerical findings derived from the use of the Data Envelopment Analysis (DEA) and its variations in evaluating the efficacy of sustainable solid waste management in different tourism locations. The thorough assessment encompasses a collection of inputs pertaining to waste management methods and tourist features, with outputs that signify the efficacy and efficiency of waste management operations. The objective of this analysis is to identify tourism locations that exhibit exceptional efficiency in waste management, hence attaining the greatest degree of performance in this aspect. The findings of this study offer useful insights that may contribute to the improvement of sustainability within the tourism industry.

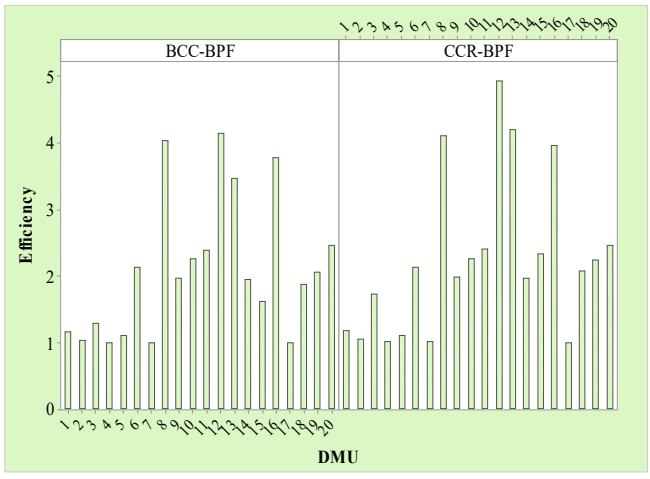
The data utilized in this study was obtained from a

comprehensive range of tourism sites, encompassing prominent tourist attractions from various geographical areas. The sample encompasses a combination of established and new locations in order to facilitate a thorough examination. The dataset comprises data pertaining to many variables, such as the recycling rate, trash diversion rate, number of dining places, number of lodging facilities, size of the tourism destination, number of tourists or visitors, and complaints associated with waste management. Moreover, the output data includes variables such as the frequency of waste collection, the money allocated for resource recycling, the quantity of waste disposal vehicles, the human resources engaged in waste management, and the efficacy of recycling programs (Table 1).

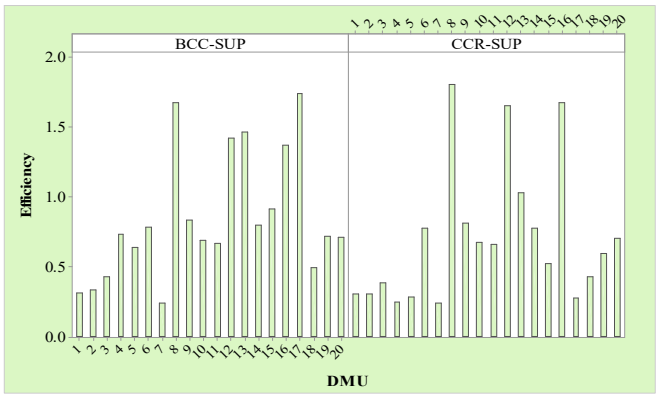
Table 1. Input and output variables for DEA models

	Variable	Sources
Input	Recycling Rate	The recycling rate is the proportion of garbage recycled. Waste management organizations, recycling centers, and environmental reports for each vacation destination provided recycling rate data [9].
	Waste Diversion Rate	The waste diversion rate shows how much garbage is recycled, composted, or otherwise diverted from landfills. Waste authorities and sustainability reports provided this data [17].
	Number of Dining Establishments	Tourism departments, municipal records, and business directories provided data on restaurants, cafés, and food sellers.
	Number of Accommodation Facilities	Official tourist databases counted hotels, resorts, guesthouses, and lodges.
	Tourist Destination Size	Tourism destinations were sized by land area. National tourism and statistics agencies provided this data.
	Number of Tourists or Visitors	Tourism authorities, airport/entry records, and accommodations provided visitor data.
	Waste Management Complaints	Government organizations, tourism boards, and public records provided trash management complaint data. Littering, incorrect trash disposal, and insufficient garbage pickup may be complaints.
Output	Collection frequency	Waste collection frequency. Garbage collection companies or local governments provided frequency statistics.
	Recycling Budget	Waste recycling and sustainability budget. Data came from budgets, financial reports, and waste management agencies [13].
	Waste-Disposal Vehicles	Waste management or municipal transportation authority reported the total number of garbage collection and transportation trucks.
	Waste Management Staffs	Waste managers gather, recycle, and manage rubbish. Data from waste management, labor, and government sources.
	Recycling campaigns	Waste management agencies or recycling program reports in each tourism location supplied recycling campaign efficacy statistics like increased recycling rates or participant participation [16].

The current study utilized the analytical functionalities of Data Envelopment Analysis (DEA) in conjunction with two widely recognized models: the Charnes–Cooper–Rhodes (CCR) and the Banker–Charnes–Cooper (BCC) models. The aforementioned models are essential elements of the DEA methodology, which evaluates the efficacy of waste management systems in a variety of tourist destinations that are being investigated. The intricate computations and assessments executed utilizing the CCR and BCC models, respectively, are illustrated in Fig. 2 and Fig. 3.



(a)



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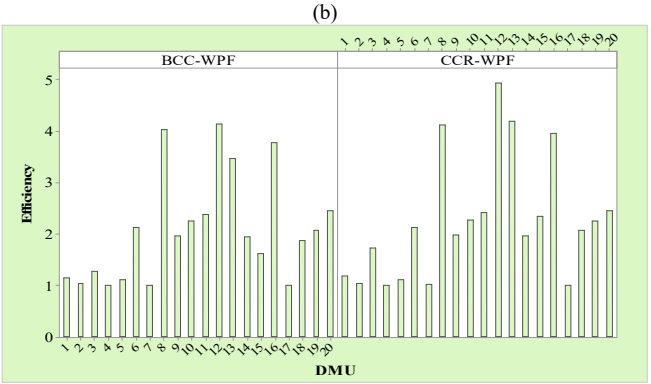
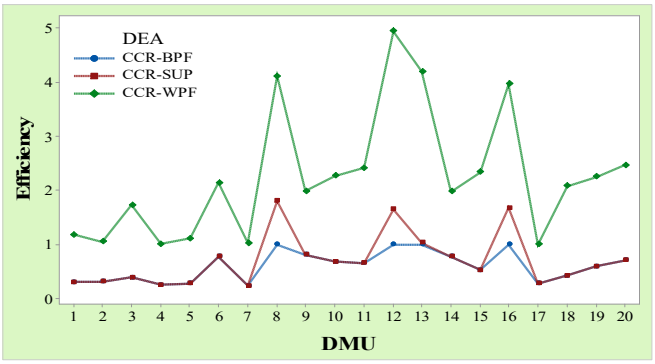
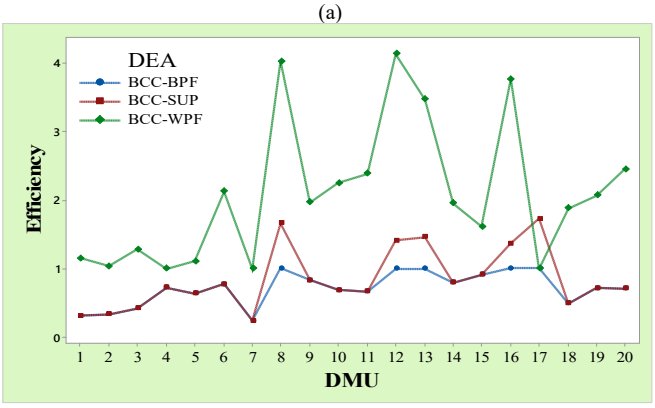


(c)

Fig. 2. Variations in efficiency ratings based on the DEA model and its variants of (a) BPF, (b) SUP and (c) WPF, respectively,



(a)



(b)

Fig. 3. Most efficient tourist destinations categorized by two models of (a) CCR and (b) BCC, respectively.

The analysis is rendered more comprehensive through the incorporation of the Best Practice Frontier (BPF), Super-Efficiency Frontier (SUP), and Worst Practice Frontier (WPF) into these models. In addition to generating benchmarking Decision Making Units (DMUs) that serve as prime examples of optimal approaches, these methodologies also furnish a reliable metric for assessing efficiency. By employing the BPF and SUP to identify benchmarking DMUs, alternative destinations can utilize them as valuable references to enhance the efficiency of waste management. This practice ultimately contributes to the sustainability of the tourism sector.

Detailed below are the results of Data Envelopment Analysis (DEA) and its innumerable modifications. The researchers conducted a comparative analysis of the waste management effectiveness of different visitor destinations by employing DEA models and their variants [34–36]. The results provide valuable insights regarding the most efficient locations, serving as a manual for the enhancement of waste management approaches by others. Further, the model facilitates the recognition of potential areas for improvement in destinations that are comparatively less efficient. Three DEA variants of the Best (BPF), Worst (WPF), and Super-Efficiency (SUP) practice frontiers are investigated in this study.

To begin with, destinations that operate at the pinnacle of efficiency function as prototypes that other organizations strive to replicate and incorporate the best practice frontier (BPF). By drawing lessons from these exemplary destinations, tourism destinations that currently operate with lower efficiency levels have the opportunity to enhance their waste management systems, mitigate environmental impacts, and promote overall sustainability.

By applying DEA analysis to the concept of "Super-Efficient", it becomes possible to discern tourism destinations that are exceptionally efficient. These specific sites exemplify the most efficacious approaches and principles in the implementation of sustainable solid waste management within the tourism sector. The achievement of the organization can be ascribed to a synergistic blend of efficient waste management policies, judiciously designed recycling initiatives, and astute resource distribution.

In the worst-case scenario, the DEA analysis performed at the Worst Practice Frontier is regarded as an evaluation and classification of units. DMUs with an efficacy score of 1 are designated as the units exhibiting the lowest performance by the WPF model. In addition, units that failed to present themselves as feeble are assigned an efficiency score exceed 1 according to this model. A concise summary of the quantitative outcomes obtained through the implementation of Data Envelopment Analysis (DEA) in its various iterations for all 20 tourist destinations is provided in Table 2.

Table 2. Efficiency categorized by DEA models

DMU	CCR			BCC		
	BPF	SUP	WPF	BPF	SUP	WPF
1	0.305	0.305	1.182	0.315	0.315	1.157
2	0.310	0.310	1.047	0.339	0.339	1.036
3	0.389	0.389	1.724	0.427	0.427	1.284
4	0.249	0.249	1.010	0.730	0.730	**1.000**
5	0.283	0.283	1.113	0.641	0.641	1.112
6	0.776	0.776	2.136	0.781	0.781	2.126
7	0.240	0.240	1.021	0.244	0.244	**1.000**
8	1.000	1.803	4.111	1.010	1.669	4.031
9	0.813	0.813	1.987	0.835	0.835	1.970
10	0.679	0.679	2.264	0.692	0.692	2.252
11	0.657	0.657	2.415	0.671	0.671	2.389
12	1.000	1.653	4.935	1.005	1.416	4.137
13	1.000	1.029	4.195	1.004	1.465	3.475
14	0.777	0.777	1.971	0.798	0.798	1.952
15	0.526	0.526	2.337	0.915	0.915	1.614
16	1.000	1.674	3.959	1.007	1.367	3.771
17	0.279	0.279	**1.000**	1.006	1.735	**1.000**
18	0.428	0.428	2.081	0.494	0.494	1.881
19	0.594	0.594	2.250	0.720	0.720	2.067
20	0.708	0.708	2.459	0.714	0.714	2.453
Mean	0.601	0.709	2.260	0.717	0.848	2.086
SD	0.279	0.486	1.179	0.246	0.447	1.036

According to the DEA-CCR model, DMU7, DMU12, and DMU16 are identified as destinations exhibiting a significant degree of efficiency. These three destinations can be located inside the realm of the best practice frontier (BPF). It is common practice to consider the destinations DMU6, DMU9, DMU10, DMU11, DMU14, DMU19, and DMU20 to be among the options that offer the greatest time savings. The destinations DMU1, DMU2, DMU3, DMU4, DMU5, DMU8, DMU13, DMU15, DMU17, and DMU18 are rated as having a level of efficiency that is somewhere in the middle. According to the DEA-BCC model, DMU8 and DMU12 are considered to be destinations that have an exceptionally high level of efficiency. The DMU6, DMU9, DMU10, DMU11, DMU13, DMU14, DMU16, DMU17, DMU19, and DMU20 are all examples of destinations that operate at a fairly high degree of effectiveness. It is generally agreed that the destinations DMU1, DMU2, DMU3, DMU4, DMU5, DMU7, DMU15, and DMU18 have a moderate level of efficiency (Fig 2(a)).

Based on the results obtained from the DEA-CCR model,

it is determined that the destinations DMU8, DMU12, DMU15, DMU16, and DMU19 exhibit a high level of super-efficiency. The aforementioned conclusion was derived from the concept of Super-Efficiency. The destinations DMU6, DMU9, DMU10, DMU11, DMU13, DMU14, DMU17, and DMU20 are often regarded as exemplary instances of exceptional efficiency. The utilization of the DEA-BCC model facilitates the identification of a noteworthy observation, namely that the destinations DMU8, DMU12, and DMU16 exhibit a considerable degree of super-efficiency. This observation can be made. Fig. 2(b) indicates that destinations DMU6, DMU9, DMU10, DMU11, DMU14, DMU17, DMU19, and DMU20 are considered to have fairly high levels of efficiency.

An evaluation of the effectiveness of a particular tourist destination that was given the designation of DMU17 was carried out using the worst practice frontier (WPF), which called for an examination of the DEA-CCR model. The findings of this investigation showed that DMU17 was able to achieve an efficiency score of 1, indicating that it is likely to be categorized as WPF-efficient. On the other hand, it can be demonstrated that the remaining 19 tourist destinations all have efficiency scores higher than 1, which indicates that they are inefficient with regard to WPF. According to the DEA-BCC model, it was found that the tourist sites DMU4, DMU7, and DMU17 each had a WPF efficiency score of 1, which indicated their WPF efficiency. This was obtained by comparing their scores to those of other destinations. On the other hand, the efficiency ratings of the remaining 17 tourism places were larger than 1, suggesting that they were inadequate in comparison to WPF (Fig. 2(c)).

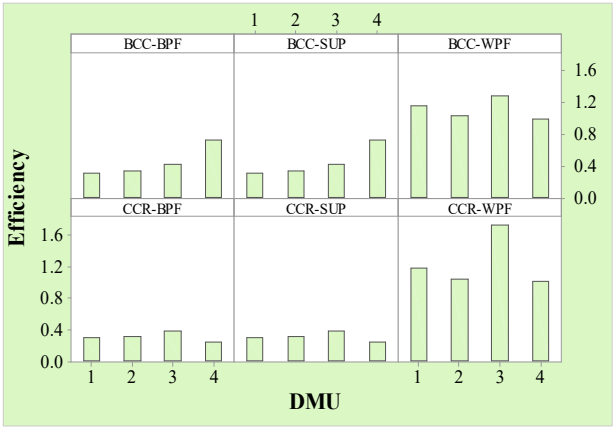
Some tourist destinations (DMU8, DMU12 and DMU13) for enhancing comprehension of the environmental management of solid waste in various tourist sites are to classify them based on both DEA models of CCR (Fig. 3(a)) and BCC (Fig. 3(b)) and their corresponding BPF, Super-Efficient, and WPF DEA outputs. Locations that are deemed highly efficient are those that achieve the utmost level of efficiency, whereas destinations that are usually efficient or moderately efficient may still have room for enhancement. The highly efficient destinations demonstrate a degree of efficiency that surpasses even the most exceptional performance in the BPF scenario, providing evidence of their supremacy over other locales.

Based on the information shown in Fig. 4(a), the following analysis of each region's performance is one possible conclusion that might be drawn. The CCR and BCC performance ratings for each of the DMUs that are located in the north, which are DMU1 and DMU2, respectively, are both lower than 1. On the other hand, DMU1 possesses a better BCC score when contrasted with the scores of the other DMUs. The score that DMU2 received for its CCR performance is pretty outstanding when compared to the scores that other DMUs received for their performances. However, both its CCR-WPF and its BCC-WPF values are equal to 1, making it impossible to distinguish between the two. This suggests that the second DMU is situated on the boundary between the best and worst practices. To put it another way, DMU1 is performing at the greatest possible level of operations while simultaneously having the lowest potential risk of any operational failure.

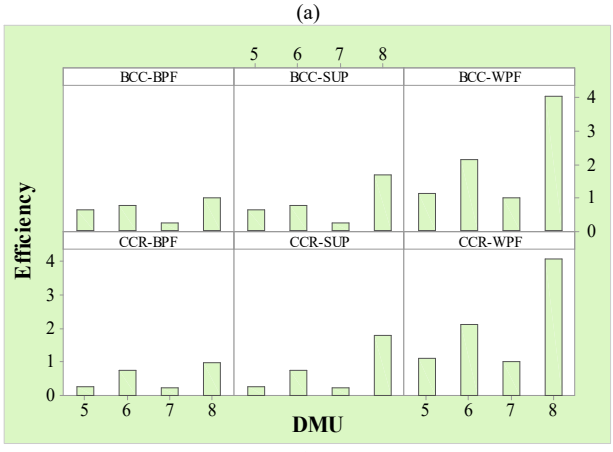
Although the likelihood of an operational breakdown will be very minimal, practically all of the DMUs in the Northeast, with the exception of DMU6, will have lower levels of efficiency than what is now expected of them. In addition, with regard to issues with BPF and SUP, the CCR and BCC efficiency ratings for DMU5 are at their absolute highest attainable level. In addition, its performance score on the WPF-CCR scale, which is more than 1, is without a doubt the worst conceivable result that can be achieved (Fig. 4(b)).

The most promising DMU was found to be DMU9 (Fig. 4(c)), which brings the result for the Central region into line with the primary findings for the Northeast. Both the CCR and BCC performance ratings for each of the East's DMUs, namely DMU13 and DMU16, are greater than 1, indicating that these DMUs are performing above average. CCR-WPF and BCC-WPF values for each DMU are both greater than 1. This demonstrates that DMU13 and DMU16 are operating at the highest level possible while simultaneously posing the lowest risk of operational failure. This situation benefits both parties (Fig. 4(d)).

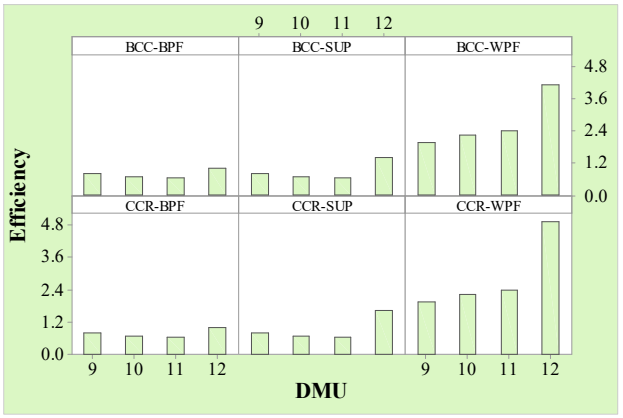
The CCR and BCC performance ratings for DMU20, which is located in the South, are both equal to 1 (BCC-BPF) and greater than 1 (BCC-SUP), respectively. However, the other DMUs had a higher WPF score than the first group. When compared to the scores that other DMUs obtained for their performances, the score that DMU20 received for its WPF performance is lower than the scores that other DMUs received for their performances. Even though these DUMs give lower levels of the BPF and SUP on both the CCR and the BCC models, this shows that DMU17 and DMU18 might be preferred when the WPF is taken into consideration (Fig. 4(e)).



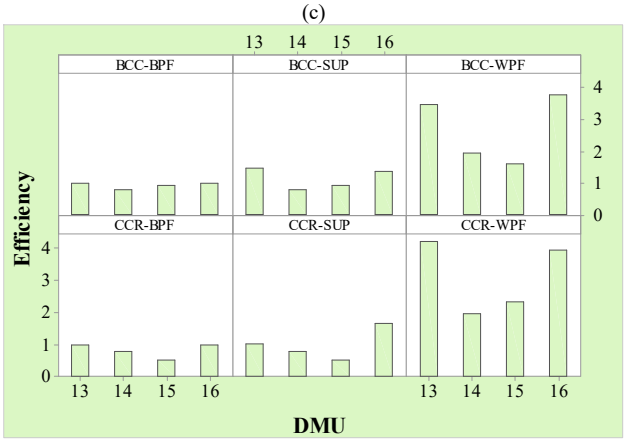
(a)



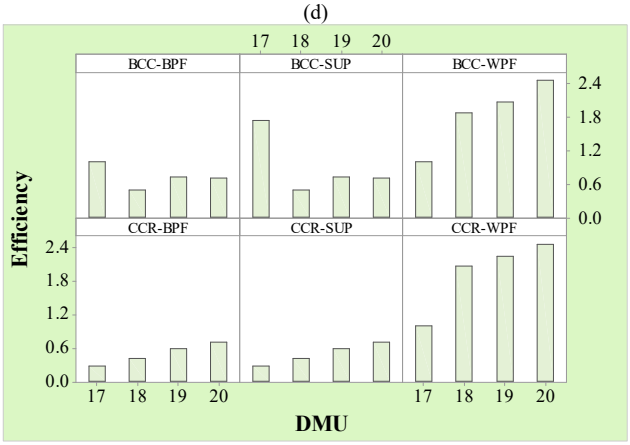
(b)



(c)



(d)



(e)

Fig. 4. Scenarios and benchmark ranking by region subgroup DEA model.

The implications of the study's results for the sustainability of waste management in the tourism industry are significant. These findings are consistent with the wider discussion on adaptive frameworks in the face of public health emergencies, such as the ongoing COVID-19 pandemic. The implementation of Data Envelopment Analysis (DEA) underscores the need for all-encompassing strategies that can effectively address unanticipated obstacles, thereby assuring the durability and flexibility of waste management systems. The emphasis on data accessibility and the examination of underlying assumptions are pertinent to broader dialogues regarding the challenges and complexities associated with applying these frameworks in various contexts. They offer valuable insights into the prioritization of waste in the face of technological presumptions and diverse waste streams.

Furthermore, the research underscores the significance of governmental intervention in order to optimize labor productivity, which aligns with the wider body of literature that promotes cooperative endeavors to tackle environmental issues. This correlation serves to emphasize the complex and multifaceted characteristics of waste management in industrial processes and enhances our comprehension of the intricacies inherent in waste management dynamics. Fundamentally, the empirical results augment understanding and emphasize the importance of adaptable methodologies that are in line with the specific needs and obstacles encountered by diverse tourism locales.

By drawing connections between the study's findings and pre-existing literature, the research gains greater significance and wider ramifications. The research not only validates but also broadens existing knowledge, thereby strengthening the complex nature of refuse management in various tourist destinations and industrial operations. In general, the results of this study make a valuable contribution to the continuous discourse surrounding sustainable waste management. Specifically, the findings help policymakers develop targeted waste management strategies for various tourist settings, all the while advocating for the overarching ideals of environmental preservation.

The results of this research emphasize the significant correlation between the efficiency of solid waste management and the promotion of sustainable development in the thriving tourism sector of Thailand. By employing Data Envelopment Analysis (DEA) techniques, we have acquired significant knowledge regarding the present condition of waste management in diverse tourist hotspots. This has established a fundamental basis for comprehending the obstacles and prospects associated with the pursuit of sustainability.

An important contribution of our research is the identification of obstacles that impede efficient waste management. The findings of our study suggest that substantial obstacles are presented by the utilization of single-use plastics, ineffective recycling methods, and deficiencies in waste disposal infrastructure. These obstacles impede not only the long-term viability of the tourism industry but also the ecological integrity of these popular tourist destinations. It is of utmost importance to confront these obstacles, as doing so will not only safeguard the local ecosystem but also guarantee a constructive and conscientious tourism encounter.

When considering the practical implications, inadequate waste management practices in tourist destinations have extensive ramifications. Inadequate refuse management not only has immediate environmental consequences but also endangers public health, causes ecological harm, and detracts from the overall attractiveness of these locations. Due to the significant economic impact of tourism on Thailand, such repercussions may have far-reaching implications for the country's socioeconomic fabric.

Practical strategies are required to alter and enhance the current state of affairs. This entails the enforcement of rigorous waste management regulations, the establishment of contemporary waste disposal infrastructure, and the advocacy for environmentally sustainable practices among both local enterprises and travelers. Effective collaboration among governmental entities, local communities, and the tourism sector is critical for the successful implementation of these strategies. By integrating sustainable waste management strategies, Thailand has the potential to enhance its standing as a tourist destination that prioritizes environmental

consciousness.

Anticipating the future, this research endeavor will encompass the investigation of cutting-edge technologies and solutions that have the potential to optimize waste management operations within the tourism industry. A more sustainable future can be achieved through the examination of waste-to-energy initiatives, the incorporation of intelligent waste receptacles, and the development of recycling technologies. Moreover, it is imperative to acknowledge the significant social ramifications of these measures. Increased environmental awareness among both visitors and residents can cultivate a sense of accountability and make a positive contribution towards the overarching objectives of sustainable development.

V. Conclusions

This research transcends scholarly domains and possesses significant practical implications, particularly in influencing waste management policies and practices in tourist destinations. The results of this study have practical ramifications for a wide range of stakeholders, such as environmental organizations, policymakers, and local authorities and actors in the tourism industry.

The classification of regions into categories based on their efficiency, reasonable efficiency, or inefficiency provides policymakers and local authorities with actionable insights. Efficient regions serve as paragons for less effective regions, enabling the smooth transfer and execution of effective waste management strategies. By doing so, not only are decision-making processes streamlined, but resources are also managed more efficiently in support of tried and true solutions.

The comprehensive evaluation criteria, which include variables associated with tourism, waste diversion rate, and recycling rate, provide a pragmatic structure for assessing and comparing the efficacy of waste management. The aforementioned data is of immense value to waste management organizations and local governing bodies, as it enables them to customize approaches in accordance with distinct regional attributes and the needs associated with tourism. The suggestion to incorporate effective waste management strategies into plans for tourism development is consistent with the increasing international focus on sustainable tourism methods. This would enable policymakers to recognize environmental sustainability as an essential component of destination growth.

Moreover, the recognition of regional discrepancies in the effectiveness of waste management by the study underscores the necessity for tailoring strategies to specific contexts. By capitalizing on this comprehension, policymakers and local authorities can develop waste management policies that are specifically tailored to the obstacles and advantages of individual regions.

Fundamentally, this study's utility resides in its potential to inform tangible measures and judgments concerning waste management in tourist destinations. The study's findings directly contribute to the advancement of sustainable tourism development, improvement of waste management practices, and promotion of environmental preservation through the provision of practical classifications, assessment criteria, and implementation strategies.

The main objective of this research was to classify tourist destinations in Thailand according to the effectiveness of their refuse management protocols, using Data Envelopment Analysis (DEA) and its derivatives. The precise objective was to categorize regions into three discrete groups—efficient, moderately efficient, and inefficient—so as to provide a more nuanced comprehension of the efficacy of refuse management. Additionally, the research aimed to develop assessment standards that would encompass recycling rates, refuse diversion rates, and a range of factors associated with tourist activities. Furthermore, the objective was to ascertain optimal strategies in refuse management, with a specific focus on regions renowned for their exceptional efficiency, and develop suggestions for policymakers and local governing bodies. The primary objective of the study was to clarify the pivotal significance of efficient waste management practices in the wider domain of sustainable tourism, thereby offering a substantial contribution to that line of inquiry.

The research effectively achieved its goals by providing an all-encompassing classification of tourist areas according to the efficacy of their refuse management approaches. By utilizing DEA models, the regions were precisely categorized as either highly efficient, moderately efficient, or inefficient, thereby establishing a reliable system for classification. The assessment criteria were methodically implemented, providing a comprehensive perspective on the effectiveness of waste management through the incorporation of recycling and diversion rates, as well as factors associated with tourist activities. In addition to identifying effective waste management strategies implemented in efficient regions, the study provided policymakers and local governments with actionable recommendations. As a result, the study successfully accomplished its primary objective of making a scholarly contribution to the conversation surrounding sustainable tourism through its emphasis on the critical significance of efficient waste management in promoting environmentally conscious and long-lasting tourism practices.

For environmental sustainability, the waste reduction techniques and their practical applications may reduce solid waste in tourist areas. This protects ecosystems and natural resources. Additionally, community engagement and aggressive garbage management regulations improve local inhabitants' living circumstances, improving their quality of life. The research shows how effective waste management procedures make tourist locations more appealing, boosting economic growth, job creation, and sustainability. The research's sophisticated methodology helps policymakers customize waste management programs to regional variations. Context-specific techniques improve waste management legislation, according to the research. Finally, the study's implications extend to educational activities that promote responsible tourism and ecologically conscious conduct among travelers, encouraging a sense of responsibility for the areas they visit. This research offers practical, real-world applications that might improve tourism destination trash management, supporting sustainability and well-rounded advancement.

In addition to its scholarly ramifications, this research serves as a fundamental component in tackling urgent issues related to refuse management in tourist destinations, thereby making significant societal contributions. The results of this

study have significant ramifications for numerous parties involved in society, underscoring the critical connection between ecological sustainability and the welfare of nearby populations. The study's notable contribution is its focus on sustainable waste management practices, which offers a practical guide for reducing the ecological consequences of solid refuse in tourist destinations. By classifying areas according to the effectiveness of waste management, the research serves as a catalyst for the conservation of natural resources, the protection of ecosystems, and the mitigation of pollution; thus, it promotes a more sustainable relationship between the tourism industry and the environment.

An additional significant contribution is the acknowledgement of the crucial role that local communities play in waste reduction and recycling initiatives. The research strongly supports proactive waste management policies and community engagement, which not only serve to improve environmental sanitation but also positively impact the welfare of nearby inhabitants. In addition to its positive impact on the environment, the research contributes to the expansion and long-term viability of the tourism sector. Efficient waste management practices contribute to the enhancement of tourist destinations' allure, thereby attracting travelers who prioritize environmental sustainability and facilitating economic expansion, employment generation, and community progress.

Furthermore, the comprehensive comprehension of waste management obstacles provided by the study enables policymakers to develop specific regulations that take into account the distinct attributes of individual regions. This ultimately improves the effectiveness of waste management policies. Simultaneously, the research supports wider societal objectives by advocating for educational initiatives that encourage visitors to engage in responsible tourism, dispose of waste appropriately, and practice recycling. This would foster environmentally conscious conduct and instill a sense of accountability towards the destinations that individuals visit. Overall, this study provides significant contributions in various domains, including community welfare, environmental preservation, the expansion of the tourism sector, well-informed policymaking, and educational endeavors. It advocates for a more harmonious and sustainable relationship between tourist destinations and the communities in which they are situated.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Danupun Visuwan, Pinsuda Luangpaiboon and Pongchanun Luangpaiboon contributed to the design, conceptualization, methodology, software, validation, visualization of the research, an implementation, formal analysis, investigation, gathering and organizing the data of the research, analysis of the results and the writing - review & editing of the manuscript and to approve the final version.

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