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Prioritizing Criteria for Reducing Single-Use Plastic Waste in Foodservice: A Fuzzy Analytic Hierarchy Process (FAHP)-Based Study with Key Player Insights

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Abstract The increase in reliance on online meal delivery services and take-outs due to changes in consumer behavior has resulted in an escalation in the consumption and disposal of single-use plastics. With the mounting apprehension over the ecological consequences of the increased plastic waste, finding effective solutions is a crucial concern. This study aims to determine the priority of criterion for reducing plastic waste in the foodservice sector using the Fuzzy Analytic Hierarchy Process (FAHP) method. An on-site survey via questionnaire was conducted to gather responses from 16 key players who were involved directly and indirectly in plastic waste mitigation initiatives. The findings revealed that the key players prioritize the criteria related to harmonizing environmental impact, whereas public acceptance was assessed as being of lower priority. This article offers practical insights into single-use plastics in foodservice, using real data and perspectives from experts in the field to build on existing research.

Keywords Plastic Waste; Foodservice; Fuzzy AHP; Key Players; Mitigation Actions.

Mathematics Subject Classification 91B06, 90B50, 68T37.

1 Introduction

In recent years, plastic waste emerged as a critical environmental issue, particularly within the foodservice sector, which significantly contributed to the proliferation of plastic packaging waste such as bottles, cups, cutlery, containers, straws, polystyrene, and plastic bags [1]. Despite measures to discourage single-use plastics, the foodservice sector remained a top contributor to plastic waste due to reliance on takeaway and delivery services [2, 3]. If left unaddressed, this shift could lead to a substantial increase in the use and disposal of plastic.

Malaysians generate about 14 million tonnes of trash annually, with dry recyclables including plastics making up 43.7% of it [4]. However, the current waste management systems in Malaysia are inadequate to cope with this growing volume of plastic waste [5], with the country primarily relies on landfills and domestic burning to manage plastic waste, both of which pose significant risks to the environment and public health [6].

Several approaches have been implemented in Malaysia to address the plastic waste issue. In 2011, the Ministry of Domestic Trade Cooperatives and Consumerism (MTDC) introduced a RM0.20 charge and a No Plastic Bag Day (NPBD) campaign, which banned plastic bags in grocery stores [7]. Following this, the Ministry of Energy, Science, Technology, Environment, and Climate Change (MESTECC) launched Malaysias Roadmap Towards Zero Single-Use Plastics 2018-2030, which imposes charges on consumers and single-use plastic manufacturers for pollution [8]. The latest roadmap for managing plastic waste in Malaysia is known as the "Malaysia Plastics Sustainability Roadmap 2021-2030". This document outlines Malaysia's strategy for addressing plastic pollution and advancing towards a more sustainable plastics economy [9].

The growing concern over plastic pollution led to increased scrutiny of how food-related plastic waste was managed and mitigated. Addressing this issue necessitated a detailed examination of various strategies to manage and reduce plastic waste effectively. Although there was an increase in publications related to plastic waste in recent years, these studies largely focused on behavioral constructs, views, and opinions through self-reported questionnaires, using descriptive analysis to predict participation in 3Rs programs and the success of mitigation strategies [10-13]. However, this approach did not guarantee actual behavioral change, thus diminishing the effectiveness of the mitigation strategies.

To date, no studies have specifically applied Multi-Criteria Decision-Making (MCDM) methods to plastic waste mitigation strategies within the foodservice sector in Malaysia. While related research exists, it tends to focus on different aspects. For example, Sindhwani *et al.* [14] and Suvitha *et al.* [15] examine plastic waste management after consumption, and Jeon *et al.* [16] explore the selection of flexible packaging as an alternative to single-use plastics. Similarly, Soni *et al.* [17] assesses the potential of using recycled plastics in construction, which can have indirect implications for plastic waste mitigation. Their studies explore broader concepts that are applicable to various industries but do not directly address the consumer-based actions in the foodservice sector. Therefore, this study was designed to identify appropriate criteria for evaluating plastic mitigation strategies, using an advanced analytical method known as the Fuzzy Analytical Hierarchy Process (FAHP).

1.1 Fuzzy Analytical Hierarchy Process (FAHP)

The Analytic Hierarchy Process (AHP) was introduced by Thomas L. Saaty in 1984 [18] to tackle complex decision-making scenarios inside intricate contexts. It is a comprehensive and systematic framework that integrates principles from psychology and mathematics to assess the relative priority among a given set of choices. The primary concept underlying the AHP is to reframe a multifaceted problem by organizing it into a hierarchical framework comprised of distinct elements: the overarching goal (i.e., the problem's objective), criteria (which constitute the second level), and alternatives (which represent the last level within the hierarchy) [19]. It uses pairwise comparisons on a 9-point scale to assess the relative importance of criteria and aims to ensure consistent and reliable judgments by checking consistency ratios. However, AHP has limitations, such as an imbalanced 9-point scale and reliance on subjective assessments, which can affect accuracy. To address these limitations, Buckley introduced the Fuzzy Analytic

Hierarchy Process (FAHP) in 1985 [20] which incorporates fuzzy sets to allow decision-makers to use interval values instead of fixed ones, providing a more flexible approach in uncertain situations.

The Fuzzy AHP method is preferred for its robustness and ability to handle uncertainty in decision-making, and the fuzzy weight obtained can be used in other Multi-Criteria Decision-Making (MCDM) tools for evaluating alternatives. The AHP and Fuzzy AHP methods have proven effective in handling complex decision-making scenarios and have been successfully utilised in various studies within the sustainability field [21–24]. However, there are no existing studies that have applied Multi-Criteria Decision-Making (MCDM) methods to plastic waste mitigation initiatives specifically within the foodservice sector in Malaysia. While previous studies have explored various aspects of plastic waste - from post-consumption management to alternative packaging [14–16] - few have focused on practical actions by key stakeholders. This study aims to identify suitable criteria for evaluating strategies to mitigate plastic waste in the foodservice sector, addressing both pre- and post-use stages, within the Malaysian context.

2 Methodology

2.1 Population and Sample Size

Data was gathered from experts engaged in both direct and indirect initiatives to mitigate plastic waste in Kota Kinabalu, Sabah, using purposive (judgement) sampling. The selected individuals represent local councils, policymakers, government officials, NGOs, food and beverage-related associations, waste management companies, academics and researchers, and biodegradable packaging producers. These individuals were considered the most qualified to provide the necessary information for the study. A total of 38 key players were contacted, however only 16 agreed to participate.

The geographical scope of the study was limited to Kota Kinabalu, Sabah, due to several key factors. First, Sabah and several other states in Malaysia are not governed by the Act 672 (Solid Waste and Public Cleansing Management Act 2007) [9], meaning that laws and regulations on solid waste management cannot be effectively enforced in these states. Additionally, Sabah has distinct cultural and societal characteristics compared to West Malaysia, which could lead to different perspectives and attitudes towards environmental issues, particularly regarding plastic waste. These differences make it crucial to focus on the region to better understand the specific challenges and responses related to plastic waste management.

2.2 Research Instrument

Data was collected through an on-site survey via a structured questionnaire consisting of four criteria and eight sub-criteria. The key players assessed the main criteria and sub-criteria based on a given scale. The criteria involved are as follows: $\boldsymbol{C_1}$ represents harmonising environmental impact,$\boldsymbol{C_2}$ represents cost considerations, $\boldsymbol{C_3}$ represents public acceptance, and $\boldsymbol{C_4}$ represents enhancing adoption of plastic waste efforts. The sub-criteria for $\boldsymbol{C_1}$ are reducing plastic waste consumption ($\boldsymbol{SC_1}$) and increasing plastic recycling ($\boldsymbol{SC_2}$). The sub-criteria for $\boldsymbol{C_2}$ are financial implications for consumers or the public ($\boldsymbol{SC_3}$) and financial implications for businesses or infrastructure ($\boldsymbol{SC_4}$), while the sub-criteria for ($\boldsymbol{SC_4}$) are executability ($\boldsymbol{SC_5}$), availability

($\boldsymbol{SC_6}$), convenience ($\boldsymbol{SC_7}$), and readiness ($\boldsymbol{SC_8}$).

Prior to this, an in-depth semi-structured interview was conducted with five key players to identify the main criteria and sub-criteria for plastic waste mitigation. A general list of topics regarding plastic consumption, plastic waste issues, mitigation strategies, and collaboration, was emailed to potential respondents beforehand. The questions were developed by adapting previous scholarly work [25–27] which focuses on opinions and views on plastic consumption and plastic waste issues. Once the interviews were completed, the transcripts were cleaned and analysed thematically using NVivo software. The resulting themes and sub-themes were then used to establish the criteria and sub-criteria for this study.

2.3 Data Analyis

The criteria weighing was determined using the AHP method developed by Saaty [18], while integrating the steps proposed by Buckley [20] and Chang [28] to accommodate fuzzy logic. Initially, fuzzy pairwise comparisons were made to capture the uncertainty in judgments. The defuzzification process was then conducted to convert these fuzzy scores into crisp values. Following this, the standard AHP process was carried out, which included calculating overall priorities for each criterion. The study follows six key steps to accomplish this.

Step 1: Construct the pairwise comparison matrices The respondents evaluated the criteria and sub-criteria to assess their relative importance, producing a paired comparison matrix. To conduct the assessment, the respondents utilised scale in Table 1, which was adapted from Nguyen *et al.* [29].

Table 1: Linguistic Terms and the Corresponding Scale

Linguistic Expression	Equivalent Fuzzy Numbers	Triangular Fuzzy Numbers (l, m, u)
Equal importance	1	(1, 1, 1)
Little importance	3	(2, 3, 4)
Great importance	5	(4, 5, 6)
Very great importance	7	(6, 7, 8)
Extremely important	9	(8, 9, 10)
The intermittent values between two adjacent scales	2	(1, 2, 3)
	4	(3, 4, 5)
	6	(5, 6, 7)
	8	(7, 8, 9)

Step 2: Calculating consistency ratio To ensure the reliability of the experts' judgments, the evaluation's consistency was calculated for each pairwise comparison matrix of experts, by calculating the sum of each column using Equation (1), and then normalising each element by employing Equation (2).

$$S_j = \sum_{i=1}^{n} A_{ij} \tag{1}$$

$$N_{ij} = \frac{A_{ij}}{s_j} \tag{2}$$

Next, the weight vector from the normalized matrix is computed using Equation (3) and subsequently, the original pairwise comparison matrix is multiplied by the weight vector to get the vector as in Equation (4).

$$w_i = \frac{1}{n}\sum_{j=1}^{n} N_{ij} \tag{3}$$

$$v_i = \sum_{j=1}^{n} A_{ij} \cdot w_j \tag{4}$$

Then, λ_{max} is computed by applying Equation (5) and the calculated λ_{max} is used to determine the consistency indexs as in Equation (6).

$$\lambda_{max} = \frac{\sum_{i=1}^{n} v_i}{w_i} \tag{5}$$

$$CI = \frac{\lambda_{max} - N}{N - 1} \tag{6}$$

where,

- CI: Consistency Index
- λ is the largest eigenvalue of the comparison matrix
- N is the dimension of matrix / number of criteria

Finally, the consistency ratio (CR) is computed by applying Equation (7).

$$CR = \frac{CI}{RI} \tag{7}$$

The Random Index (RI) was obtained through Table 2. In general, it had to present a consistency level of CR<0.10.

Table 2: Random Index

n	3	4	5	6	7	8	9	10
RI	0.58	0.9	1.12	1.124	1.32	1.41	1.45	1.49

Step 3: Calculating the aggregated fuzzy numbers The aggregated fuzzy number of preferences was calculated by combining the assessments of the 16 experts using the following formula (Equation (8)).

$$F_i = \left(\frac{1}{n}\sum_{j=1}^{n} l_{ij}, \frac{1}{n}\sum_{j=1}^{n} m_{ij}, \frac{1}{n}\sum_{j=1}^{n} u_{ij}\right) \tag{8}$$

where,

- l_{ij} = lower bound of the fuzzy number provided by expert j for criterion i.
- m_{ij} = middle value of the fuzzy number provided by expert j for criterion i.
- u_{ij} = upper bound of the fuzzy number provided by expert j for criterion i.
- n = total number of experts.

Step 4: Calculating the weight of criterion and sub-criterion The weight of each criterion and sub-criterion was evaluated by calculating the following methods:

(a) Calculation of the Geometric Mean G_i of Fuzzy Comparison values for each criterion and sub-criterion using Equation (9).

$$G_i = n\sqrt{\Pi_{j=1}^{n} F_{ij}} \tag{9}$$

where,

- n = is the number of criteria.
- F_{ij} = is the fuzzy comparison value for criterion C_i compared to criterion C_j .

(b) Calculation of the fuzzy weight of each criterion and sub-criterion based on geometric mean using Equation (10), followed by the computation of the inverse of the sector summation as described in Equation (11).

$$W_i = \left(\frac{l_i}{\sum_{k=1}^{n} l_k}, \frac{m_i}{\sum_{k=1}^{n} m_k}, \frac{u_i}{\sum_{k=1}^{n} u_k}\right) \tag{10}$$

$$W_{inverse} = \left(\frac{1}{W_l}, \frac{1}{W_m}, \frac{1}{W_u}\right) \tag{11}$$

(c) Arranged in increasing order from lower to upper value.

Step 5: Deffuzzification and normalisation Defuzzification and normalisation were conducted to obtain crisp values by employing the following methods:

(a) Defuzzify fuzzy number to obtain crisp value for each criterion and sub-criterion using Equation (12).

$$C_i = \frac{l_i + 4m_i + u_i}{6} \tag{12}$$

(b) After obtaining the crisp values, each element was normalised using Equation (13).

$$N_i = \frac{C_i}{\sum_{j=1}^{n} C_j} \quad (13)$$

Step 6: Calculating the global weight The global weight of each criterion was calculated by multiplying the local weight of the main criteria with the local weight of the sub-criteria, as specified in Equation (14).

$$GW_i = W_i \times W_{j|i} \quad (14)$$

where,

- GW_j = global weight of sub-criterion j
- W_i = local weight of the main criterion i
- $W_{j|i}$ = local weight of the sub-criterion j under criterion i

3 Implementation

This study involves 16 key players as decision makers to provide their evaluation on the importance of criteria and sub-criteria for plastic waste mitigation initiatives using the fuzzy AHP approach. $C_1 - C_4$ represents the main criteria, while $SC_1 - SC_8$ represents the sub-criteria.

Step 1: Construct the pairwise comparison matrix The respondents assessed preference by utilising language variables expressed as in Table 1. This was then converted into corresponding fuzzy numbers. Table 3 displays the criteria evaluation carried out for one of the respondents.

Table 3: Pairwise Comparison Matrix of Criteria

	C_1	C_2	C_3	C_4
C_1	(1, 1, 1)	(0.2, 0.25, 0.3333)	(2, 3, 4)	(0.125, 0.1429, 0.1667)
C_2	(3, 4, 5)	(1, 1, 1)	(2, 3, 4)	(0.25, 0.3333, 0.5)
C_3	(0.25, 0.3333, 0.5)	(0.25, 0.3333, 0.5)	(1, 1, 1)	(0.125, 0.1429, 0.1667)
C_4	(6, 7, 8)	(2, 3, 4)	(6, 7, 8)	(1, 1, 1)

Step 2: Calculating consistency ratio for criteria pairwise comparison matrix A consistency check was performed to ensure reliability of priorities. Table 4 displays the example of consistency ratio (CR) for the pairwise comparison matrix of criteria for one of the respondents. It was achieved using Equation (1) and (2). In general, it must present a consistency level of CR¡0.10.

Table 4: Consistency Ratio of Criteria

λ_{max}	CI	CR
4.224	0.0747	0.083

Step 3: Calculating aggregated fuzzy number By combining the evaluation of each respondent, the aggregated fuzzy number of preferences were generated using Equation (3). Following that, updated comparison matrices for all the criterion and sub-criterion options were produced as shown in Table 5 and Table 6 respectively.

Table 5: Aggregated Fuzzy Number for Criteria

Criteria	C_1	C_2	C_3	C_4
C_1	(1,1,1)	(1.81078, 2.47549, 3.16667)	(2.71568, 3.39412, 4.13235)	(1.83824, 2.17562, 2.56373)
C_2	(0.71667, 0.99868, 1.345589	(1,1,1)	(2.34804 (2.9549 3.58824)	(1.38971, 1.83585, 2.33334)
C_3	(0.66232, 0.94361, 1.29608)	(0.88774, 1.1641, 1.49755)	(1, 1, 1)	(0.86372, 1.13511, 1.46814)
C_4	(1.80547, 2.4008, 2.99951)	(1.38481, 1.82408, 2.28922)	(2.17647, 2.66862, 3.19118)	(1, 1, 1)

Step 4: Computing the weight of criteria and sub-criteria This step involved a sequential computation process. Firstly, the geometric mean of the fuzzy comparisons was determined using Equation (4). Following this, the fuzzy weight for each criterion was calculated using Equation (5). Finally, the inverse of sector summation was performed using Equation (6). These calculations were carried out for all criteria and sub-criteria. The results, detailed in Table 7 include aggregate values, reciprocal values, and values arranged in ascending order.

Step 5: Computing fuzzy preference weights The calculation of the fuzzy preference weights was performed by multiplying the geomean value of each with the inverse of the summation vector in the form of increasing order. The outcomes are presented in Table 8.

Step 6: Defuzzifying the fuzzy preference weights The defuzzified weight of each criterion and sub-criteria to obtain a crisp value were determined by employing Equation (7). The result is presented in Table 9.

Table 6: Aggregated Fuzzy Number for Sub-Criteria

Sub-Criteria	SC_1C_1	SC_2C_1	SC_3C_2	SC_4C_2	SC_5C_4	SC_6C_4	SC_7C_4	SC_8C_4
SC_1C_1	(1,1,1)	(4.71176, 5.47712, 6.24265)	-	-	-	-	-	-
SC_2C_1	(0.69363, 0.77274, 0.86521)	(1,1,1) -	-	-	-	-	-	-
SC_3C_2	-	-	(1,1,1) -	(2.10295, 2.48264, 2.89216)	-	-	-	-
SC_4C_2	-	-	(2.58039¡ 3.1789 3.78432)	(1,1,1) -	-	-	-	-
SC_5C_4	-	-	-	-	(1,1,1) 2.44818,	(1.83725 1.48047, 3.08824)	(1.09811, 1.93487, 1.90849)	(1.47205 2.5)
SC_6C_4	-	-	-	-	(1.40849, 1.80168, 2.25197)	(1,1,1)	(1.37564, 1.74722, 2.13644	(1.84419, 2.33781, 2.85294)
SC_7C_4	-	-	-	-	(1.94673, 2.43977 2.96274)	(2.18775, 2.73585, 3.29902)	(1,1,1)	(2.45294, 3.11485 3.81373)
SC_8C_4	-	-	-	-	(1.14363, 1.69664, 2.26961)	(1.51037, 2.00945, 2.54575)	(1.07171, 1.40161, 1.7732)	(1,1,1)

Table 7: Geometric Mean of Fuzzy Comparison Values for Criteria and Sub-Criteria

Criteria	$\boldsymbol{l}$	$\boldsymbol{m}$	$\boldsymbol{u}$
$\boldsymbol{C_1}$	1.73395	2.06773	2.40668
$\boldsymbol{C_2}$	1.23662	1.52564	1.83207
$\boldsymbol{C_3}$	0.84418	1.05671	1.29926
$\boldsymbol{C_4}$	1.52733	1.84894	2.16358
Total	5.34208	6.49901	7.70158
Inverse	0.18719	0.15387	0.12984
Increasing order	0.12984	0.15387	0.18719
Sub-Criteria	$\boldsymbol{l}$	$\boldsymbol{m}$	$\boldsymbol{u}$
$\boldsymbol{SC_1}$	2.17066	2.34033	2.49853
$\boldsymbol{SC_2}$	0.83284	0.87906	0.93016
Total	3.0035	3.21938	3.42869
Inverse	0.33294	0.31062	0.29166
Increasing order	0.29166	0.31062	0.33294
Sub-Criteria	$\boldsymbol{l}$	$\boldsymbol{m}$	$\boldsymbol{u}$
$\boldsymbol{SC_3}$	1.45015	1.57564	1.70064
$\boldsymbol{SC_4}$	1.60636	1.78295	1.94533
Total	3.05651	3.35859	3.64597
Inverse	0.32717	0.29774	0.27428
Increasing order	0.27428	0.29774	0.32717
Sub-Criteria	$\boldsymbol{l}$	$\boldsymbol{m}$	$\boldsymbol{u}$
$\boldsymbol{SC_5}$	1.31276	1.62732	1.95923
$\boldsymbol{SC_6}$	1.37488	1.64706	1.9248
$\boldsymbol{SC_7}$	1.79783	2.13535	2.47091
$\boldsymbol{SC_8}$	1.16644	1.47851	1.78909
Total	5.6519	6.88824	8.14403
Inverse	0.17693	0.14518	0.12278
Increasing order	0.12278	0.14518	0.17693

Table 8: Fuzzy Weight of the Criteria and Sub-Criteria

Criteria			
	$\boldsymbol{l}$	$\boldsymbol{m}$	$\boldsymbol{u}$
$\boldsymbol{C_1}$	0.22514	0.31816	0.45051
$\boldsymbol{C_2}$	0.16056	0.23475	0.34295
$\boldsymbol{C_3}$	0.10961	0.1626	0.24321
$\boldsymbol{C_4}$	0.19831	0.2845	0.405
Sub-Criteria			
$\boldsymbol{SC_1}$	0.63309	0.72695	0.83186
$\boldsymbol{SC_2}$	0.24291	0.27305	0.30969
$\boldsymbol{SC_3}$	0.39775	0.46913	0.5564
$\boldsymbol{SC_4}$	0.44059	0.53085	0.63645
$\boldsymbol{SC_5}$	0.16118	0.23625	0.34665
$\boldsymbol{SC_6}$	0.16881	0.23912	0.34056
$\boldsymbol{SC_7}$	0.22074	0.31001	0.43718
$\boldsymbol{SC_8}$	0.14322	0.21465	0.31654

Table 9: Deffuzified Weight of Criteria and Sub-Criteria

Criteria/ Sub-Criteria	Defuzzified Weight
$\boldsymbol{C_1}$	0.33127
$\boldsymbol{C_2}$	0.24609
$\boldsymbol{C_3}$	0.1718
$\boldsymbol{C_4}$	0.29593
$\boldsymbol{SC_1}$	0.73064
$\boldsymbol{SC_2}$	0.27522
$\boldsymbol{SC_3}$	0.47443
$\boldsymbol{SC_4}$	0.53597
$\boldsymbol{SC_5}$	0.24803
$\boldsymbol{SC_6}$	0.24949
$\boldsymbol{SC_7}$	0.32264
$\boldsymbol{SC_8}$	0.2248

Step 7: Normalising the defuzzified weight Next, the weights that have been defuzzified must be normalised using Equation (8) before they can be calculated and displayed in Table 10 below, along with the normalised weights for each criterion and sub-criteria.

Table 10: Normalising the Defuzzified Weights of Criteria and Sub-Criteria

Criteria	**Defuzzification**	**Normalisation**
$\boldsymbol{C_1}$	0.33127	0.31698
$\boldsymbol{C_2}$	0.24606	0.23547
$\boldsymbol{C_3}$	0.1718	0.16439
$\boldsymbol{C_4}$	0.29593	0.28316
Total	1.04509	1
Sub-Critera	**Defuzzification**	**Normalisation**
$\boldsymbol{SC_1}$	0.73064	0.7264
$\boldsymbol{SC_2}$	0.27522	0.2736
Total	1.00585	1
Sub-Criteria	**Defuzzification**	**Normalisation**
$\boldsymbol{SC_3}$	0.47443	0.46955
$\boldsymbol{SC_4}$	0.53597	0.53045
Total	1.01039	1
Sub-Criteria	**Defuzzification**	**Normalisation**
$\boldsymbol{SC_5}$	0.24803	0.23735
$\boldsymbol{SC_6}$	0.24949	0.23876
$\boldsymbol{SC_7}$	0.32264	0.30876
$\boldsymbol{SC_8}$	0.2248	0.21513
Total	1.04497	1

Step 8: Computing global weight Since the study involved criteria and sub-criteria, the final step required the calculation of global weights. This was done using Equation (9) and displayed in Table 11. The global weight calculation considered the importance of each criterion and sub-criterion in relation to the overall goal of the study.

Table 11: Global Weight and Local Weight of Sub-Criteria

Sub-Criteria	Local Weight	Global Weight
$\boldsymbol{SC_1}$	0.7264	0.23025
$\boldsymbol{SC_2}$	0.2736	0.08673
$\boldsymbol{SC_3}$	0.46955	0.11057
$\boldsymbol{SC_4}$	0.53045	0.12491
$\boldsymbol{SC_5}$	0.23735	0.06721
$\boldsymbol{SC_6}$	0.23876	0.06761
$\boldsymbol{SC_7}$	0.30876	0.08743
$\boldsymbol{SC_8}$	0.21513	0.06092

4 Results and Discussion

4.1 Main Results

The weights for the criteria and sub-criteria, summarised in Table 12, are based on the data from Table 10. As a result, the table also illustrates the final ranking of the criteria and sub-criteria for plastic waste mitigation initiatives in the foodservice sector. This result provides a comprehensive overview of how each criterion and sub-criterion contributed to the overall ranking, aiding in decision-making processes moving forward.

Table 12: The Summary of Weight and Rank

Criteria/ Sub-Criteria	Weight	Rank
$\boldsymbol{C_1}$	0.31698	**1**
$\boldsymbol{C_2}$	0.23547	3
$\boldsymbol{C_3}$	0.16439	4
$\boldsymbol{C_4}$	0.28316	2
$\boldsymbol{SC_1}$	0.7264	**1**
$\boldsymbol{SC_2}$	0.2736	2
$\boldsymbol{SC_3}$	0.46955	2
$\boldsymbol{SC_4}$	0.53045	**1**
$\boldsymbol{SC_5}$	0.23735	3
$\boldsymbol{SC_6}$	0.23876	2
$\boldsymbol{SC_7}$	0.30876	**1**
$\boldsymbol{SC_8}$	0.21513	4

Based on the evaluation, harmonising environmental impact ($\boldsymbol{C_1}$) was identified as the highest priority among key players (0.31698), whereas public acceptance ($\boldsymbol{C_3}$) was considered a lower priority (0.16439). This indicates that key players place greater emphasis on environmental outcomes when addressing plastic waste mitigation, due to the negative impact of these materials [30]. Past research has supported this focus by including environmental impact as a critical element for assessment [16, 31–33], which is consistent with global trends in waste reduction policies. The results of this study offer important insights for policymakers seeking to improve plastic waste mitigation initiatives. The emphasis on environmental impact ($\boldsymbol{C_1}$) as the main criterion indicates that actions aimed at mitigating the environmental footprint of plastic waste should be prioritised. Policymakers can formulate measures that encourage industries and sectors to embrace eco-friendly practices, such as providing tax incentives or subsidies for businesses that implement sustainable packaging alternatives or reduce plastic consumption. For instance, countries such as Norway and Germany have established extended producer responsibility (EPR) systems, incentivising companies to minimise packaging waste and enhance recycling initiatives [34].

Conversely, public acceptance is often given less importance in determining mitigation strategies, likely because relying solely on public acceptance does not substantially reduce plastic usage and disposal. The findings align with previous studies from various regions around the world, which have consistently identified this criterion as having lower priority [22–24]. While it may not be the highest priority, public acceptance remains essential. Many urban areas struggle with effectively reducing plastic usage and disposal due to insufficient public engagement or awareness. In regions with established recycling programs, the focus has frequently been on technological and infrastructural solutions [33, 35] rather than fostering a culture of public participation. Therefore, policymakers could introduce incentive-based programs such as discounts, rewards, or recognition for individuals and communities that engage in sustainable practices, alongside public campaigns. Successful case studies show the importance of public engagement as seen in South Koreas Volume-Based Waste Fee system [36] whereby the cost of waste disposal is tied to the amount of waste generated, thus encouraging individuals to reduce their waste.

Regarding the sub-criteria for environment, key players rated reducing plastic usage (0.72640) as more important than increasing the recycling rates (0.2736). This preference arises from the view that recycling only perpetuates plastic production [4], and it cannot fully address the plastic pollution crisis. Thus, the most effective strategy is to reduce plastic reliance and consumption at the source, and by doing so, plastic waste can be reduced significantly.

In relation to the financial implications ($\boldsymbol{C_2}$), where businesses were seen to bear more financial responsibility (0.53045), global models like the European Union's Circular Economy Action Plan provide valuable insight [37]. This plan integrates policies that incentivise businesses to take greater responsibility for the lifecycle of their products, particularly in reducing plastic waste. Policies could therefore be designed to place a financial burden on businesses that generate high plastic waste, with incentives for those that demonstrate leadership in sustainability.

In terms of enhancing adoption ($\boldsymbol{C_4}$), the convenience factor is given the highest priority (0.30876), as it is often identified as the main barrier preventing public participation in efforts to reduce plastic waste [35, 38, 39]. To overcome this, policymakers can look to successful international examples to create local systems that remove barriers to public participation such as ensuring convenient access to recycling bins in public spaces or offering incentives for households and businesses to participate in waste reduction initiatives. Australias recycling infrastructure, for example, is built around making recycling as convenient as possible for the public, with accessible bins for waste sorting and collection systems (kerbside collections) that are easy for consumers to use [40]. Within this domain, however, the readiness of the public is given the least priority (0.21513), as it can be significantly improved through the facilitation of even easier processes [41], which highlights the importance of the convenience factor.

The interrelationship of the criterion and sub-criteria is further explored to offer understanding of how changes in one area could affect others. For instance, the emphasis on convenience ($\boldsymbol{C_4}$) as a major driver of adoption is intrinsically related to public acceptance ($\boldsymbol{C_3}$). Public acceptability will likely improve if governments or businesses strive to make waste sorting procedures easier or offer more accessible recycling locations. This might lead to increased participation in waste reduction initiatives since convenience is often cited as the key barrier to public participation. Addressing this issue could help in changing the public's perception and make them more receptive to initiatives intended to reduce plastic waste.

Additionally, the priority placed on reducing plastic use ($\boldsymbol{C_1}$) over increasing recycling rates ($\boldsymbol{C_2}$) implies that the reduction of plastic consumption is seen as a more instant and effective approach. However, efforts to restrict plastic usage can also influence the financial outcomes ($\boldsymbol{C_2}$). Businesses that use less plastic may save money in the long run as less waste is produced and disposal costs are lower. Less plastic consumption may also shift the financial burden more onto businesses and relevant agencies, as they would have less responsibility for managing waste.

Another important relationship is the financial responsibility ($\boldsymbol{C_2}$) shared between organisations and consumers. As key players indicated, businesses or relevant authorities should bear a larger portion of the financial responsibility. Policies that push businesses to engage in sustainable production practices or sustainable packaging could have multiple impacts. Such initiatives benefit both businesses and the environment by reducing plastic usage and supporting $\boldsymbol{C_1}$ goals. On the other hand, if customers are rewarded like getting discounts for bringing their own containers or recycling properly, they will feel more involved in the effort to reduce plastic waste. This kind of shared effort between businesses and customers can make financial strategies work even better.

Overall, the interdependence of criteria and sub-criteria suggests that efforts made to improve one area, such as making public involvement more convenient, can culminate in a cascade of favourable outcomes in other areas, such as public acceptance and waste reduction. Considering this, policymakers need to understand these interactions to come up with more comprehensive and effective solutions.

4.2 Limitation

While the sample size may limit the generalizability of the larger population of the key players, the diversity of participants (i.e. local council, policymaker, NGOs, academician and researchers, and government officials) and the rigorous data collection methods help mitigate this limitation. This broad representation within the sample ensures the findings reflect a range of perspectives from different areas directly engaged in the issue, thus providing valuable insight into the priorities of experts in single-use plastic waste mitigation efforts. Furthermore, the criteria and sub-criteria used in the analysis were derived from in-depth interviews with several experts, enhancing the relevance and context of the findings. Nonetheless, future research could benefit from including a larger and more representative sample of key players to enhance generalizability, as well as employing multiple MCDM approaches to assess the robustness of the findings.

5 Conclusion and Recommendations

The study aims to assess and prioritize criteria for plastic waste mitigation initiatives in the foodservice sector using the FAHP approach. The evaluation draws on inputs from 16 experts in Kota Kinabalu, Sabah, who are involved in plastic waste mitigation efforts. The assessment is based on four main criteria and eight sub-criteria. Among these, harmonising environmental impact is identified as the most critical criterion for selecting plastic waste mitigation actions, while public acceptance is considered the least important in this context.

This research provides several benefits - firstly, it presents a framework for evaluating criteria related to plastic waste mitigation initiatives, based on expert insights. Secondly, it aids decision-makers in formulating action plans with a higher likelihood of success in addressing plastic waste in the food and beverage sector. The framework is also applicable to regions beyond Kota Kinabalu and can be extended to other fields of interest, providing reliable and objective results. Continued evaluation can help in selecting the most efficient actions to address plastic waste. Additionally, experts might explore other MCDM techniques, such as the fuzzy Best-Worst Method and fuzzy TOPSIS, to enhance prioritization and decision-making. Expanding the framework to include additional criteria and sub-criteria could further refine and improve the accuracy of the outcomes.

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