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Assessment of Sustainability of Taxi Services in Manila Using a Modified Fuzzy Evaluation for Life Cycle Integrated Sustainability Assessment (FELICITA)

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Abstract. Sustainability Assessment is an essential process that guides the decision-makers to the most sustainable option. In the case of the Philippine transportation sector, one of the rising transportation systems is the different ride-hailing services. The main objective of this study is to evaluate the overall sustainability of the taxi service operation in Manila and propose improvements for the system's development. This assessment is performed using a modified Fuzzy Evaluation for Life Cycle Integrated Sustainability Assessment (FELICITA). Sustainability indicators are identified as the basis for a sustainable transport system. The data gathered is prepared as inputs to undergo the fuzzy inference system. Based on the threshold values from existing literature/standards, MC taxi, RH taxi, and traditional taxi are not sustainable. The main weakness of the MC taxi service lies in the social aspect, while the main weakness of the RH and traditional taxi is in the economic aspect.

Keywords. Sustainability Assessment, Ride Hailing Services (RHS), MC Taxi, Fuzzy Evaluation for Life Cycle Integrated Sustainability Assessment (FELICITA)

1. Introduction

The world is slowly transitioning into a sustainable future. The concept of sustainable development has been slowly integrated into the different systems and structures. The report by the Brundtland Commission or the World Commission on Environment and Development (WCED) titled Our Common Future defined sustainable development as "the progress that stumbles the needs of the present generation without menacing the capability of future generations to meet their needs" [1]. One of the most popular approaches that helps advocate sustainability is the Sustainability Assessment (SA), a complex procedure that has the objective of evaluating the economic, social, and environmental effects of a product, project, or system [2]. Decision-makers benefit from this essential process by guiding them to the best, or most sustainable, option. Various

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tools and methodologies have been developed throughout the years. As the world transitions to more sustainable options, existing systems are questioned regarding their sustainability. One of the fastest-transitioning sectors is the transportation sector. In the Philippine context, a more recent addition is the ride-hailing services (RHS). One of the most popular to ride-hailing services in the Philippines is the MC taxis. MC taxis are considered one of the fastest ways to traverse the metro. Overall, this new mode of transport helped alleviate various issues in the country, it provided jobs, convenience, faster travel times, and safety during the pandemic. However, the system is still relatively new, and its sustainability might be in question.

2. Methodological Framework

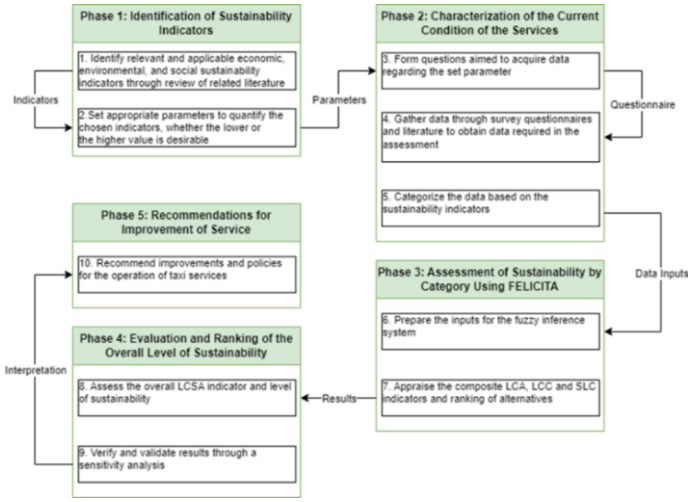

Figure 1. Methodological Framework

Phase 1: Identification of Sustainability Indicators

Stage 1: Identify relevant and applicable economic, environmental, and social sustainability indicators review of related literature.

The process for this SA is guided by the Bellagio STAMP principles [3]. Three categories of sustainability indicators are of concern, environmental, economic, and social. After reviewing related literature about the different sustainability indicators, the researchers evaluated whether the indicators are applicable in the study. The researchers decided on 9 economic indicators, 6 social indicators, and 5 environmental indicators appropriate to use in the methodology [4].

Table 1. List of Chosen Economic, Social, and Environmental Indicators

Economic Indicators	Social Indicators	Environmental Indicators
User Satisfaction	User Rating	Climate Change Emissions
Commute/Travel Time	Affordability	Fuel Efficiency
Affordability	Disabilities	
Cost Efficiency	Children's Travel	
Capital Costs	Inclusivity	

Stage 2: Set appropriate parameters to quantify the chosen indicators, whether the lower or the higher value is desirable.

The indicators set in the first stage are accompanied by the parameters which serve as the measurement element for each indicator. The parameters are based on the description of the indicators, and the current systems of transportation. This stage also establishes the preferred values for these indicators which will be beneficial in Stage 6 of this methodology. It is denoted in the direction column on whether more or less is better.

Table 2. Economic Indicators (LCC)

No.	Indicator	Parameters	Direction	Data Availability
S11	User Satisfaction	Satisfaction rating	More is better	3
S12	Commute/travel time	Average travel time	Less is better	1
S13	Affordability	Average price per ride	Less is better	2
S14	Cost Efficiency	Cost per distance	Less is better	2
S15	Capital Cost	Average cost of equipment and vehicle	Less is better	1

Table 3. Social Indicators (SLCA)

No.	Indicator	Parameters	Direction	Data Availability
S21	User Rating	Satisfaction and comfort rating	More is better	3
S22	Affordability	Portion of daily expenditure for transport	Less is better	2
S23	Disabilities	Access for disabled	More is better	2
S24	Children's Travel	Children compatibility	More is better	2
S25	Inclusivity	Special efforts for vulnerable group	More is better	2

Table 4. Environmental Indicators (LCA)

No.	Indicator	Parameters	Direction	Data Availability
S31	Climate Change Emissions	Per capita N_2O emissions	Less is better	1
S32		Per capita CO_2 emissions	Less is better	2
S33	Fuel Efficiency	Fuel economy	More is better	2

*Data availability: 1 = usually available in standardized form; 2 = often available but not standardized; 3 = limited, may require special data collection.

Phase 2: Characterization of the Current Condition of the Services

Stage 3: Form questions aimed to acquire data regarding the set parameter

For this study, the main research instrument to be utilized is survey questionnaires. These questions will include demographic questions, multiple choice questions, rating scale questions, Likert scale questions, and ranking questions. Apart from that some data is needed as our inputs are available in standardized form through existing literature.

Stage 4: Gather data through survey questionnaires and literature to obtain data required in the assessment

Data collection consists of two methods, survey questionnaires, and existing literature. The deployment of the survey questionnaires was primarily done online through google forms. Data gathered is managed efficiently and visualized with google forms. In terms of data from existing literature, government/national/international databases were the main documents of interest. This ensures the relevance and applicability of the data to the local context. The sustainability thresholds utilized for the comparison of different indicators are based on international standards, sustainable targets, published studies/journals and national averages. The selection of these thresholds has a great effect on the overall results of the assessment, for it acts as the baseline of sustainability.

Stage 5: Categorize the data based on the sustainability indicators

From the questionnaire used, each question or group of question focuses on a specific indicator to describe its sustainability aspect, same with the data gathered from existing literature. Different types of questions are for acquiring different types of data based on the parameter. The data collected is properly categorized in preparation for the next stage, which involves the preparation of the actual inputs for the FELICITA framework. **Figure 2** highlights the decision tree which will be utilized in the assessment.

Phase 3: Assessment of Sustainability by Category Using a modified Fuzzy Evaluation for Life Cycle Integrated Sustainability Assessment (FELICITA)

Stage 6: Prepare the inputs for the fuzzy inference system

This stage deals with preparing the required inputs for the modified FELICITA framework, which utilized the FELICITA framework of Kouloumpis and Azapagic (2018) as its backbone [5]. The original framework is modified to fit a more diverse set of alternatives. The alternatives are to be evaluated against their sustainability threshold to highlight a more equal comparison. The sustainability indicators are estimated through LCA, LCC, and SLCA based on the data gathered.

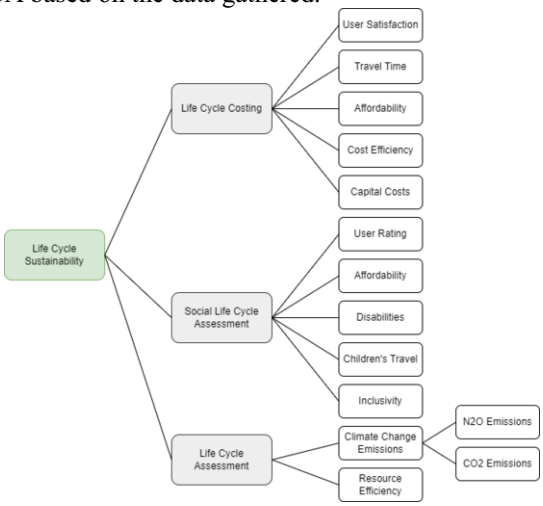

Figure 2. The FELICITA Decision Tree for the Sustainability Assessment of RHS and Traditional Taxis

Utilizing a linear interpolation between the most and least desired values for each sustainability indicator taken into consideration, the input data is normalized. The desirable values were outlined in stage 2. This will give the normalization of the inputs two cases which result in two equations. Equation (1) is utilized to calculate xa,c, which is the normalized value of indicator c for alternative a, if "less is better".

$$x_{ac} = \frac{c_{max} - z_{a,c}}{c_{max} - c_{min}} \quad (1)$$

On the other hand, equation (2) is utilized to calculate $x_{a,c}$ if the higher value is desirable or "more is better".

$$x_{ac} = \frac{z_{a,c} - c_{min}}{c_{max} - c_{min}} \quad (2)$$

The inputs are normalized in Microsoft Excel through a predetermined formula. User satisfaction, user rating, disability, children's travel, inclusivity, and fuel efficiency have the maximum as the most desirable value and the minimum is the least desirable value, while the rest has the is the complete opposite. In this case, data has been normalized directly, instead of the additional logarithmic transportation before the normalization. For this assessment, there will be a total of five (5) alternatives which includes the MC taxi, RH taxi, and Traditional Taxi, and two additional which will be the Sustainable MC Taxi (SMC Taxi), and the Sustainable Taxi (ST Taxi). Instead of ranking taxi services among their alternatives, they will be evaluated against their sustainable forms which will come from the data of the threshold values. This is the modification made to the original FELICITA framework. This can allow a more diverse and fair comparison between various alternatives. The normalized values are tabulated in **Table 7**.

Table 5. Input data of the LCC, SLCA, and LCC indicators for the three categories of Taxi Services

No.	Unit	MC Taxi	RH Taxi	Trad Taxi	SMC Taxi	ST Taxi	min	Max
S11	Qualitative	3.49	2.79	2.48	3.5	3.5	2.48	3.5
S12	Hour	0.57	0.83	0.81	0.48	0.4833	0.48	0.83
S13	PHP	139.03	272.60	232.41	105.9	105.9	105.9	272.5971
S14	PHP/km	15.22	27.71	24.17	11.15	11.15	11.15	27.71
S15	PHP	77,352	921,571	326,429	176,000	1,000,000	77,352	1,000,000
S21	Qualitative	3.89	3.90	3.37	3.5	3.5	3.37	3.90
S22	%	64.51	239.85	150.45	67.83	67.83	64.51	239.8476
S23	Qualitative	2.40	4.01	3.57	3.5	3.5	2.40	4.01
S24	Qualitative	2.36	4.21	3.71	3.5	3.5	2.36	4.21
S25	Qualitative	2.56	4.13	3.64	3.5	3.5	2.56	4.13
S31	g/km	0.001	0.01	0.01	0.07	0.095	0.001	0.10
S32	g/km	57	299.29	312.14	30.7	95	30.7	312.14
S33	km/l	46.81	17.49	17.63	56.11	23.17	17.49	56.11

Table 6. Thresholds selected for the SMC taxi and ST taxi

No.	Unit	SMC Taxi	ST Taxi	Explanation
S11	Qualitative	3.5	3.5	Likert scale mean scoring, qualitative scale with 3.5 = positive attitude
S12	Hour	0.48	0.48	Average duration of daily commute in the Philippines
S13	PHP	105.9	105.9	Average transport fare of different transportation vehicles in the Philippines
S14	PHP/km	11.15	11.15	Average transport fare over average travelled distance in km
S15	PHP	176,000	1,000,000	Average capital cost of vehicle
S21	Qualitative	3.5	3.5	Likert scale mean scoring, qualitative scale with 3.5 = positive attitude
S22	%	67.83	67.83	Average transport fare over average daily budget allocation for transportation in percentage
S23	Qualitative	3.5	3.5	Likert scale mean scoring, qualitative scale with 3.5 = positive attitude
S24	Qualitative	3.5	3.5	Likert scale mean scoring, qualitative scale with 3.5 = positive attitude
S25	Qualitative	3.5	3.5	Likert scale mean scoring, qualitative scale with 3.5 = positive attitude
S31	g/km	30.7	95	Threshold value of standard CO_2 emission of vehicle based on ICCT guidelines
S32	g/km	0.07	0.095	Threshold value of standard N_2O emission of vehicle based on ICCT guidelines
S33	km/l	56.11	23.17	Threshold value of standard fuel efficiency of vehicle based on Clean Technology Environment Policy and Federal Register Rules and Regulation

Table 7. Normalized input data of the LCC, SLCA, and LCC indicators for the three categories of Taxi Services

No.	MC Taxi	RH Taxi	Trad Taxi	SMC Taxi	ST Taxi
S11	0.98955	0.305987	0	1	1
S12	0.749501	0	0.060331	1	1
S13	0.801243	0	0.241052	1	1
S14	0.754431	0	0.213579	1	1
S15	1	0.085004	0.730041	0.893082	0
S21	0.964492	1	0	0.247816	0.247816
S22	1	0	0.509877	0.981048	0.981048
S23	0	1	0.724988	0.682429	0.682429
S24	0	1	0.732483	0.616944	0.616944
S25	0	1	0.689302	0.598184	0.598184
S31	1	0.861702	0.904255	0.265957	0
S32	0.906553	0.045683	0	1	0.771534
S33	0.75917	0	0.00355	1	0.146979

Stage 7: Appraise the composite LCA, LCC and SLC indicators and ranking of alternatives

Fuzzification, fuzzy inference, and defuzzification are the three phases that constitute the process of this framework. Fuzzification will convert these indicators to fuzzy values through the use of membership functions. These functions characterize their performance using corresponding linguistic values (e.g., 'Bad,' 'Average' and 'Good'). The membership functions used are based on the Triangular Membership Functions (TMF) symmetric rule. MATLAB software is the chosen software to program fuzzy inference due to the presence of many predefined functions for fuzzy logic, as well as a user-friendly fuzzy logic designer.

$$\mu_{Bad}(x) = \begin{cases} 1, x \leq 0 \\ -2 \cdot x + 1, 0 < x < 0.5 \\ 0, x \geq 0.5 \end{cases} \tag{3}$$

$$\mu_{Average}(x) = \begin{cases} 0, 0 \leq x \\ 2 \cdot x, 0 < x \leq 0.5 \\ -2 \cdot x + 2, 0.5 \leq x < 1 \\ 0, x \geq 1 \end{cases} \tag{4}$$

$$\mu_{Good}(x) = \begin{cases} 0, x \leq 0.5 \\ 2 \cdot x - 1, 0.5 < x < 1 \\ 1, x \geq 1 \end{cases} \tag{5}$$

In order to aggregate the individual sustainability indicators into composite LCA, LCC and SLCA indices, the Mamdami FIS (Fuzzy Inference System) is applied. This FIS employs predetermined IF-THEN rules and linguistic values. The five linguistic values: 'Very bad,' 'Bad,' 'Average,' 'Good' and 'Very good' are utilized to define their fuzzy outputs. Through the use of five linguistic values instead of three, it provided a better distinction between the outputs of the alternatives. Depending on the input, the number of rules will vary. In the case of LCA, there are 5 inputs so there will be a total of 3^5 = 243 rules. For the Rules r can be described by the following equation:

$$Rule\ r: IF\ x_1\ is\ A_1^{j_1}\ and\ x_2\ is\ A_2^{j_2}\ and\ \ldots and\ x_n\ is\ A_n^{j_n}, THEN\ u\ is\ A^j \tag{6}$$

where,

x_i : the normalised value for the sustainability indicator (linguistic variable) i

$A_i^{j_i}$: the j th term ('Bad', 'Average', 'Good') of linguistic variable i that corresponds to the membership function $\mu_i^{j_i}(x_i)$

A^j : the jth term ('Very bad', 'Bad', 'Average', 'Good', 'Very good') of linguistic variable (LCA, LCC or SLCA) that corresponds to the membership function $\mu^j(u)$.

The next process involves the determination of the degree of match a_r or rule r using the Mamdani 'AND' operator, defined as 'minimum'

$$a_r = min_{i=1,\dots,n}\left\{\mu_i^{j_i}\left(x_i^{input}\right)\right\} \tag{7}$$

where,

$\mu_i^{j_i}(x_i^{input})\}$: the degree of membership of the specific value of x_i^{input} that is used as input for the specific rule r and the jth term of indicator i.

After the following calculations, the result will be the degrees of membership and the degrees of match. To obtain a unique degree of membership corresponding to each of the linguistic values a final calculation using the 'maximum' operator is utilized:

$$\mu^{jLCC} = max\left\{a_r^{jLCC}\right\} \tag{8}$$

where,

μ^{jLCC} : the degree of membership in the linguistic value of LCC, j_{LCC}, which can be 'Very bad', 'Bad', 'Average', 'Good' and 'Very good'

a_r^{jLCC} : the degree of match for every rule r that gives j_{LCC}.

The fuzzy set output of this equation will have five linguistic variables and a unique degree of membership. This output is to be used for the defuzzification process, the last phase. The center of area (COA) equation, Zimmerman (2001), is utilized as the defuzzification method for this model. Results of this can be ranked according to the LCA, LCC, and SLCA indicators.

$$u^{COA} = \frac{\int_u^U u \cdot \mu(u) du}{\int_u^U \mu(u) du} \tag{9}$$

where,

u^{COA} : the crisp value derived as the output of the defuzzification process for each composite indicator,

$\mu(u)$: the membership function for each linguistic value (e.g. 'Very bad'; 'Bad', 'Average', 'Good', and 'Very good') of the output fuzzy set and $u\ \varepsilon\ U$ is the maximum degree of membership which belongs to the set U of all the degrees of membership that correspond to the specific linguistic value.

After the input data underwent the fuzzy inference system, it resulted in crisps values for each of the indicators for LCC, SLCA, and LCA. The values are presented in **Table 8**.

Table 8. Crisp values for the composite LCC, SLCA, and LCA indicators

	Composite LCC indicator	Composite SLCA indicator	Composite LCA indicator
MC taxi	0.7780	0.2490	0.8230
RH taxi	0.0897	0.9200	0.2720
Traditional Taxi	0.3330	0.6380	0.2470
SMC Taxi	0.9160	0.6180	0.7870
ST Taxi	0.7500	0.6180	0.3130

Phase 4: Evaluation and Ranking of the Overall Level of Sustainability

Stage 8: Assess the overall LCSA indicator and ranking of alternatives

The final and second stage are similar, the only difference is in their inputs. Instead of using the with the values of the full set of LCA, LCC, and SLCA indicators, this stage utilizes the crisp numerical values obtained from the composite LCA, LCC, and SLCA indices. Similarly, inputs are fuzzified, and then using the membership functions and five, instead of three, linguistic values, it is aggregated into an overall LCSA index. Then, it is defuzzified which results to crisp numerical values for the LCSA indicator for each alternative, which will allow researchers to rank their overall life cycle sustainability. The same membership functions and rules will be applied for this stage.

Table 9. Crisp values for the overall LCSA indicator

Overall LSCA indicator	
MC Taxi	0.582
RH Taxi	0.410
Traditional Taxi	0.385
SMC Taxi	0.779
ST Taxi	0.584

Stage 9: Verify and validate results through a sensitivity analysis

Due to the reliance on methodology to the rules and function, a sensitivity analysis must be performed. The membership function type, and defuzzification method are three elements of the FELICITA model that can be changed depending on various user requirements. This evaluates the robustness of the FIS, for it illustrates the variable changes due to changes in assumption. A general view of the uncertainty level can be gained through the introduction of various uncertainties.

Phase 5: Recommendations for Improvement of Service

Stage 10: Recommend improvements and policies for the operation of MC taxi

Based on the ranking results, each's alternatives, strengths, and weaknesses of each are discovered. Recommendations on the system's operation and policies are given to address specific weaknesses. This allows decision-makers to shift focus to the more sustainable modes of transportation, which can improve the entire transportation sector in the country.

3. RESULTS AND DISCUSSION

3.1. Composite LCC Indicator

Life Cycle Costing (LCC), as a sustainability tool, deals with the entirety of the flow from the production up to the consumption of products or services. Based on **Table 10**, all the three taxi services have lower values than their sustainable counterparts. This

denotes that, at their current condition, the taxi services are not economically sustainable. MC taxi has a value of 0.778, while SMC taxi led with a value of 0.916. Based on the indicators, MC taxi only has a favorable value for capital costs against the sustainability threshold. Generally, the motorcycles used for MC taxis have lower cylinder capacities which range from 100-200 cc. Motorcycles of this type are typically cheaper than those with larger engines. In the case of the four (4) other economic indicators, the values of the MC taxi are quite close, but not enough to be deemed sustainable. Although the MC taxi is cheap and fast, average commute prices and travel times are slightly better.

Table 10. Ranking of the Alternatives Based on the Crisp Values for LCC indicator

Composite LCC Indicator	
Motorcycle	1. SMC Taxi (0.9160)
	2. MC Taxi (0.7780)
Passenger Car	1. ST Taxi (0.7500)
	2. Trad Taxi (0.3330)
	3. RH Taxi (0.0897)

In the case of the passenger cars, The ST taxi has the highest value with 0.75, followed by traditional taxi (0.333) and RH taxi (0.0897). There is a great disparity with their values, specially between the ST taxi and the RH taxi. The trend is the same with the MC taxi, in which the RH and traditional taxi are only better in capital costs against its sustainable counterparts. The ST taxi is better in 4 out of the 5 indicators. The huge difference is their crisp values is due to their large differences with the sustainability thresholds. The two options are quite expensive services compared to most alternatives. The main difference between RH and traditional taxi is that RH taxi is obviously a more expensive option than traditional taxi.

3.2. Composite SLCA Indicator

Social life cycle assessment (S-LCA), as a sustainability tool, deals with the evaluation of the positive and negative outcomes of a service or a production relation to its life cycle in the social aspect. **Table 11** above shows that the MC taxi has a crisp value of 0.249, while the SMC taxi has a value of 0.618. This means that the MC taxi is not sustainable in terms of the SLCA indicator.

Table 11. Ranking of the Alternatives Based on the Crisp Values for SLCA indicator

	Composite SLCA Indicator
Motorcycle	1. SMC Taxi (0.618)
	2. MC Taxi (0.249)
Passenger Car	1. RH Taxi (0.920)
	2. Trad Taxi (0.638)
	3. ST Taxi (0.618)

Out of the five parameters, the MC taxi has a favorable result for user rating and affordability, however, the results for the 3 other parameters did not meet the threshold values for social sustainability. In terms of user rating, it shows that MC taxi had met all the standards for its overall service including cleanliness, adequacy, and waiting and travel time. This shows that MC taxi is a convenient service for passengers concerning travel time and its affordability. Contrarily, the MC taxi has a poor rating in terms of inclusivity factor which resulted to a lower value of sustainability for SLCA.

For passenger cars, both RH (0.92) and Traditional taxi (0.638) have a higher value to the ST taxi (0.618). This shows that both passenger cars are sustainable with regard to the SLCA indicator. Although the RH taxi did poorly in terms of affordability, it dominated 4 out of 5 of the social indicators (user rating, disabilities, children's travel, and inclusivity). This is the same case with traditional taxis, which did poorly in terms of affordability due to the high cost of service. Even though both services are considered expensive modes of transportation, both services have good feedback in terms of inclusivity as they could provide comfort to PWD and are safe for children's travel.

3.3. Composite LCA Indicator

Life cycle assessment (LCA), or the life cycle analysis, is a sustainability tool that deals with the repercussions of a product, process, or service in the aspect of the environment. Based on **Table 12**, MC taxi is sustainable in terms of the LCA indicator, while the other taxi services are not sustainable. MC taxi has a value of 0.823, while SMC taxi has a value of 0.779. In 2 out of the 3 parameters, MC taxi was worse than its sustainable counterpart, however, it is so much better in the N_2O emissions. Apart from that, although the threshold values are better for the CO_2 and fuel efficiency, their differences are quite minimal

Table 12. Ranking of the Alternatives Based on the Crisp Values for LCA indicator.

Composite LCA Indicator	
Motorcycle	1. MC Taxi (0.823)
	2. SMC Taxi (0.779)
Passenger Car	1. ST Taxi (0.313)
	2. RH Taxi (0.272)
	3. Trad Taxi (0.247)

In the case of the passenger cars, both RH taxi (0.272) and traditional taxi (0.247) is not sustainable because ST taxi has the highest value with 0.313. The N_2O emissions for the two taxi services are very low so they did not exceed the threshold. However, their CO_2 emissions are quite high, and do not conform with the sustainable goal. Their fuel economy is also quite less than their sustainable counterpart. In terms of the comparison between RH taxi and traditional taxi, RH taxi has a higher crisp value due to it utilizing newer car models, which generally has better technology to lessen the emissions and improve fuel efficiency.

3.4. Overall LCSA Indicator

Life Cycle Sustainability Assessment (LCSA) refers to the combined assessment of the economic, social, and environmental benefits and drawbacks of a product or service. Motorcycle taxis, ride-hailing taxis, and traditional taxis are not sustainable based on the sustainability thresholds in this assessment. In both cases, their sustainability counterparts, SMC taxi (0.779) and ST taxi (0.584) had higher crisp values. In the case of the MC taxi, it is only sustainable in terms of the LCA indicator or the environmental dimension. It did not pass the sustainability thresholds for the economic and social dimensions. Although it is the cheapest option among the taxi services, it is still slightly more expensive than the national average commute fares. In the case of the social aspect,

MC taxis lack the inclusivity factor due to the nature of the motorcycle. Due to this, MC taxi (0.582) had a smaller crisp value, so it is not deemed to be sustainable.

Table 13. Ranking of the Alternatives Based on the Crisp Values for LCSA indicator.

Composite LCSA Indicator	
Motorcycle	1. SMC Taxi (0.779)
	2. MC Taxi (0.582)
Passenger Car	1. ST Taxi (0.584)
	2. RH Taxi (0.410)
	3. Trad Taxi (0.385)

RH taxi (0.410) and traditional taxi (0.385) both had lower crisp values than their sustainable counterpart. In 2 out of the 3 composite indicators, LCC and LCA, both are not sustainable based on the sustainability thresholds. In the case of the SLCA indicator, they passed the threshold values. The acceptability and inclusivity factors in passenger car taxis are better compared to the MC taxis. Economically, passenger car taxi services are quite expensive, so they have lower scores for the LCC indicator. Although RH taxi had a significantly smaller value in the LCC indicator, it had higher values with the SLCA and LCA indicators compared to the traditional taxi. This resulted in a slightly higher value for overall sustainability.

3.5. Sensitivity Analysis

A sensitivity analysis is to be performed to test the effect of the change in assumptions and other variables to the. For this case, the following components of the FELICITA model are to be explored and changed: the types of membership functions and the types of defuzzification methods. The effect on the outputs of the following changes is highlighted in the following section.

3.5.1. Different types of membership functions

Apart from the use of triangular membership functions, the FELICITA model can also be performed using Gaussian membership functions (GMF). According to **Table 14**, the ranking for the LCC, SLCA, and LCA composite indicators all remain the same with small differences in values. The difference in values between the two membership functions is relatively small, which is less than 0.05. The only difference in rankings is that in the LCSA indicator the ST taxi and MC taxi interchanged ranking in the GMF. This is not significant because there are no comparisons between MC taxis and passenger car taxis. In all cases, MC taxi, RH taxi and traditional taxis are not sustainable based on the sustainability thresholds. This means that their rankings are not affected by minor changes in functions. In this study, the change in membership function does not bring a significant effect on the results.

Table 14. Ranking of the Taxi Services Alternatives using Gaussian and triangular membership functions

Assessment Type	**Membership Function**	**Taxi Service**				
LCC	TMF	1. SMC taxi (0.916)	2. MC taxi (0.778)	3. ST taxi (0.750)	4. Trad taxi (0.333)	5. RH taxi (0.0897)
	GMF	1. SMC taxi (0.894)	2. MC taxi (0.785)	3. ST taxi (0.741)	4. Trad taxi (0.316)	5. RH taxi (0.123)
SLCA	TMF	1. RH taxi (0.920)	2. Trad taxi (0.638)	3. SMC taxi (0.618)	3. ST taxi (0.618)	5. MC taxi (0.249)

	GMF	1. RH taxi (0.899)	2. Trad taxi (0.619)	3. SMC taxi (0.595)	3. ST taxi (0.595)	5. MC taxi (0.27)
LCA	TMF	1. MC taxi (0.823)	2. SMC taxi (0.787)	3. ST taxi (0.313)	4. RH taxi (0.272)	5. Trad taxi (0.247)
	GMF	1. MC taxi (0.831)	2. SMC taxi (0.768)	3. ST taxi (0.296)	4. RH taxi (0.274)	5. Trad taxi (0.269)
LCSA	TMF	1. SMC taxi (0.779)	2. ST taxi (0.584)	3. MC taxi (0.582)	4. RH taxi (0.410)	5. Trad taxi (0.385)
	GMF	1. SMC taxi (0.760)	2. MC taxi (0.558)	3. ST taxi (0.531)	4. RH taxi (0.401)	5. Trad taxi (0.366)

3.5.2 Different defuzzification methods

Apart from the COA defuzzification methods utilized in this study, there are various other methods that can be applied in the FELICITA model. For this study, the researcher explored the use of the bisector, the largest of maximum (LOM), the middle of maximum (MOM) and the smallest of maximum (SOM). Based on the results in **Table 15**, there are noticeable differences in values between the different defuzzification methods. Unlike changes in the membership functions, there are some instances where the rankings are changed. The first noticeable change is that there are values which became equal. This is apparent in all the defuzzification methods across all composite indicators. There are even three values which are equal in the MOM method. The most notable changes in the rankings are when the state of being sustainable of a service is affected. The first one is on the LOM of SLCA. Originally, traditional taxis are socially sustainable but, in the LOM, it has a lower value than its sustainable counterpart. Another instance is on the MOM of LCA, where the MC taxi is deemed not environmentally sustainable due to it being behind in value by 0.005. This is a relatively small difference. Another one is on the SOM of LCA where both the RH taxi and traditional taxi became sustainable by having a higher value than their sustainable counterpart. Lastly, in the COM of LCSA, RH taxi is deemed more sustainable by outranking the ST taxi. It is also observable that LOM, MOM, and SOM defuzzification methods has less accurate values or decimal places. Most of their values can reach 1.00. Based on the different defuzzification methods, COA has a more accurate result for it has more diverse values with more decimals.

Table 15. Ranking of the Taxi Services Alternatives using different defuzzification method

Assessment Type	**Defuzzification Method**	**Taxi Service**				
LCC	COA	1. SMC taxi (0.916)	2. MC taxi (0.778)	3. ST taxi (0.750)	4. Trad taxi (0.333)	5. RH taxi (0.0897)
	Bisector	1. SMC taxi (0.930)	2. MC taxi (0.790)	3. ST taxi (0.750)	4. Trad taxi (0.333)	5. RH taxi (0.080)
	LOM	1. SMC taxi (1.000)	1. MC taxi (1.000)	3. ST taxi (0.750)	4. Trad taxi (0.120)	5. RH taxi (0.090)
	MOM	1. SMC taxi (0.975)	2. MC taxi (0.940)	3. ST taxi (0.750)	4. Trad taxi (0.060)	5. RH taxi (0.045)
	SOM	1. SMC taxi (0.950)	2. MC taxi (0.880)	3. ST taxi (0.750)	4.Trad taxi (0.000)	4. RH taxi (0.000)
SLCA	COA	1. RH taxi (0.920)	2. Trad taxi (0.638)	3. SMC taxi (0.618)	3. ST taxi (0.618)	5. MC taxi (0.249)
	Bisector	1. RH taxi (0.930)	2. Trad taxi (0.630)	3. SMC taxi (0.600)	3. ST taxi (0.600)	5. MC taxi (0.250)
	LOM	1. RH taxi (1.000)	2. SMC taxi (0.620)	2. ST taxi (0.620)	4. Trad taxi (0.610)	5. MC taxi (0.260)
	MOM	1. RH taxi (1.000)	2. Trad taxi (0.500)	2. SMC taxi (0.500)	2. ST taxi (0.500)	5. MC taxi (0.250)

	SOM	1. RH taxi (1.000)	2. Trad taxi (0.390)	3. SMC taxi (0.380)	3. ST taxi (0.380)	5. MC taxi (0.240)
LCA	COA	1. MC taxi (0.823)	2. SMC taxi (0.787)	3. ST taxi (0.313)	4. RH taxi (0.272)	5. Trad taxi (0.247)
	Bisector	1. MC taxi (0.860)	2. SMC taxi (0.790)	3. ST taxi (0.290)	4. RH taxi (0.260)	5. Trad taxi (0.250)
	LOM	1. MC taxi (1.000)	1. SMC taxi (1.000)	3. ST taxi (0.360)	4. RH taxi (0.310)	5. Trad taxi (0.290)
	MOM	1. SMC taxi (0.945)	2. MC taxi (0.940)	3. ST taxi (0.250)	3. RH taxi (0.250)	3. Trad taxi (0.250)
	SOM	1. SMC taxi (0.890)	2. MC taxi (0.880)	3. Trad taxi (0.210)	4. RH taxi (0.190)	5. ST taxi (0.14)
LCSA	COA	1. SMC taxi (0.779)	2. ST taxi (0.584)	3. MC taxi (0.582)	4. RH taxi (0.410)	5. Trad taxi (0.385)
	Bisector	1. SMC taxi (0.770)	2. MC taxi (0.600)	3. ST taxi (0.530)	4. RH taxi (0.450)	5. Trad taxi (0.380)
	LOM	1. SMC taxi (1.000)	2. MC taxi (0.760)	3. ST taxi (0.620)	4. RH taxi (0.590)	5. Trad taxi (0.370)
	MOM	1. SMC taxi (0.975)	2. MC taxi (0.750)	3. ST taxi (0.500)	3. RH taxi (0.500)	5. Trad taxi (0.250)
	SOM	1. SMC taxi (0.880)	2. MC taxi (0.630)	3. RH taxi (0.440)	4. ST taxi (0.380)	5. Trad taxi (0.140)

4. CONCLUSION AND RECOMMENDATION

SA is a complex evaluation which has recently gained popularity due to the emerging sense of sustainable development across the globe. This is a useful tool allows decision makers to choose the best solution through concrete assessments.

Based on the LCC indicator and SLCA indicator, the MC taxi is not sustainable. Economically, MC taxi only has a favorable value for capital costs against the sustainability threshold, while having less favorable in the other four (4) indicators. This resulted in the SMC taxi (0.916) having a higher crisp value than the MC taxi (0.778). Although the MC taxi is cheap and fast, average commute prices and travel times are slightly better. In the case of the SLCA indicator, SMC taxi (0.618) has a higher crisp value than MC taxi (0.249). One of the weaknesses of the motorcycle service is the inclusivity factor, which involves being PWD and children friendly. For the LCA indicator, the MC taxi (0.823) has a higher crisp value than the SMC taxi (0.779), which denotes that is environmentally sustainable. Considering all the composite indicators, MC taxi is not sustainable based on the sustainability thresholds. MC taxi is only sustainable in the environmental dimension but not in the other two.

In the case of passenger cars, the ST taxi is (0.750) better in 4 out of the 5 indicators so its value is higher than the RH taxi (0.0897) and the traditional taxi (0.333). Both the RH and traditional taxi are not economically sustainable. Contrary to the economic dimension, both the RH taxi (0.920) and the traditional taxi (0.638) have higher values than the ST taxi (0.618). In terms of the LCA indicator, both RH taxi (0.272) and traditional taxi (0.247) is not sustainable because ST taxi (0.313) has the highest value. Considering all the composite indicators, RH taxi (0.41) and traditional taxi (0.385) had smaller crisp values than the ST taxi (0.584). This denotes that RH taxi and traditional taxi are not sustainable based on the sustainability thresholds.

Overall, the MC, RH, and traditional taxis are not sustainable with respect to the set sustainability thresholds. Based on the results, the MC taxi's main weakness lies in the social aspect of inclusivity. The service, currently, does not cater well to PWDs and children. One of the efforts that the MC taxi service can focus on is developing ways to

cater to PWDs through technology or other ways. In terms of children's travel, the main concern is their safety so there might need to be major technological advances or design changes before they can travel alone in MC taxi. In terms of economy, it is very close to the sustainability threshold. In the case of RH taxi, its main disadvantage is its price. For a more sustainable service, one approach they can focus on is to develop a better program or system which can minimize the travel time of the passengers which will reduce its price. Traditional taxis can also benefit with the adaptation of more advanced technologies to traverse the roads efficiently.

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