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A fuzzy approach to rebust Social Sustainability Assessment(ISSA)

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Abstract: Social sustainability has been increasingly recognized as a fundamental component of sustainable development in recent years. It is still challenging to measure social sustainability in comparison to other dimensions of sustainability (environmental and economic). The current study enhances the authors' proposed approach to assessing and quantifying social sustainability; Integrated Social Sustainabilit Assessment (ISSA). Fuzzy set theory was incorporated into the multi-criteria decision-making (MCDM) level in order to model the uncertainties associated with expert responses. To define uncertainty and construct fuzzy sets based on expert opinion, a novel approach has been developed. The same data from the available case study was used to evaluate the enhanced framework. The results show considerable change in the weight of some indicators and consequently in the social sustainability index. According to the results, the weight of some indicators and the social sustainability index have changed significantly. Fuzzy social assessment frameworks have been shown to be robust to responses from experts with acceptable levels of accuracy.

Keywords: social sustainability, framework, fuzzy, neighborhood, AHP

1. INTRODUCTION

The term social sustainability refers to a wide range of disciplines including natural sciences, social sciences, and humanities. Among other disciplines, it encompasses public health, social work, sociology, architecture, environmental studies, etc. (Dillard et al., 2008). In order to explain the trend of social sustainability through history, two theories assert that social sustainability studies have generally focused on macro-scales (cities and regions); in recent years, however, the focus has shifted to micro-scales (neighborhoods and communities) (Hemani et al., 2017). Furthermore, traditional "hard" indicators of sustainability for social development (such as employment and poverty reduction) are giving way to more intangible and "soft" indicators (Colantonio, 2010). It is important to have a clear definition of social sustainability since this study aims to develop a framework for assessing social sustainability. Akbarinejad (2022) comprehensively reviewed different definitions of social sustainability.

Over 70 percent of global carbon emissions and 60 percent of resources are emitted by buildings and urban areas ('Goal 11: Make Cities Inclusive, Safe, Resilient and Sustainable', 2022). There is a need for more research on this topic to better understand our environment, particularly the built environment. The intense urbanization of the past century has resulted in almost 75% of the European population living in urban areas in 2015 (*Urban Europe — Statistics on Cities, Towns and Suburbs*, 2016). Additionally, the urban population is expected to continue to grow even faster in the future and the average life expectancy is increasing throughout the world, and most people will reach the age of 60 (*Fact Sheet on Ageing and Health*, 2022). While the expansion of opportunities and services contributes to such growth, it adversely impacts urban residents' health and well-being. In order to reverse their negative effects, it is imperative to carefully evaluate and design urban spaces.

To create convenient and healthful environments for transferred communities from difficult areas, many community-based urban development projects are being established. These new developments may, however, adversely affect these communities and the indigenous populations surrounding them, which may lead to further social deterioration, or even to the abandonment of these new projects altogether (Gammaz & Hagras, 2020). This raises the question of how important it is to study the social impact of urban development projects from the start to help with decisions. In order to ensure sustainable urban development, it is essential to use effective planning tools. By addressing social changes resulting from planned interventions, the Social Impact Assessment (SIA) has demonstrated that it contributes to a more sustainable and physical environment (Vanclay et al., 2015).

To address opportunities and perceived problems, cities are now referred to as green, sustainable, healthy, smart, multicultural, and creative. (Barrett et al., 2016). Therefore, cities must promote health and well-being in urban environments by taking into account the complex interaction between people's health and the built environment. When designing sustainable urban places, it is imperative to consider the health and well-being of citizens. In society, well-being is

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an important measure of progress. The well-being of an individual is a complex combination of physical, mental, emotional, and social factors. In context of An "urban" facility manager, through integration of multiple disciplines in a human-centre approach, It can become the enabler and implementer of sustainable urban ecosystem, i.e. balancing social, economic and environmental pillars.(Temeljotov Salaj et al., 2020)

As a first step towards achieving the aforementioned goals and targets, it is essential to measure social sustainability. The present study employs fuzzy set theory to enhance the previously proposed social assessment tool and increase the robustness of the framework. Possibilistic approaches such as fuzzy set theory are many applications that cover the weaknesses of probabilistic approaches to quantify the model uncertainties (Barahmand & Eikeland, 2022a, 2022b). The main social sustainability criteria and indicators have been weighted based on expert opinion collected through a pair-wise questionnaire and fed into the Analytic hierarchy process (AHP). In this study, fuzzy set theory was applied to AHP in order to model the uncertainties associated with expert opinions. A novel approach was developed to define fuzzy numbers based on expert responses to achieve a greater level of robustness. Lastly, we compared the case study data with this framework to make a comparison with the previous model.

2. BACKGROUND

This section provides a brief overview of the methodology of the Integrated Social Sustainability Assessment (ISSA) framework. As Akbarinejad (2022) described, this novel approach integrates qualitative and quantitative methods and incorporates expert opinion as well as residents' satisfaction levels concerning social sustainability. As shown in Figure 1, this framework consists of three main steps, which are as follows:

1) Selecting social sustainability variables (criteria and indicators)
2) Weighting variables (criteria and indicators)
3) Data collection from citizens and calculating social sustainability index

AHP, developed by Saaty (1987), is one of the most popular and widely used methods in the field of multi-criteria decision-making (MCDM). As part of the technique, a set of alternatives is ranked or a set of alternatives is selected according to their merits (Ramanathan, 2004). Four steps are included in the AHP decision-making process (Saaty, 1990): (1) developing the hierarchical structure of the decision problem, (2) applying the AHP fundamental scale to collect expert opinions (see Table 1), in which numbers are chosen and assigned by experts. Next, an evaluation matrix with a 1–9 point scale is then prepared for pair-wise comparison, (3) calculates the Consistency Index (CI). During the third phase, the consistency of the pair-wise comparison matrix is computed using CI as follows:

$$CI = \frac{\lambda_m - N}{N - 1} \quad (1)$$

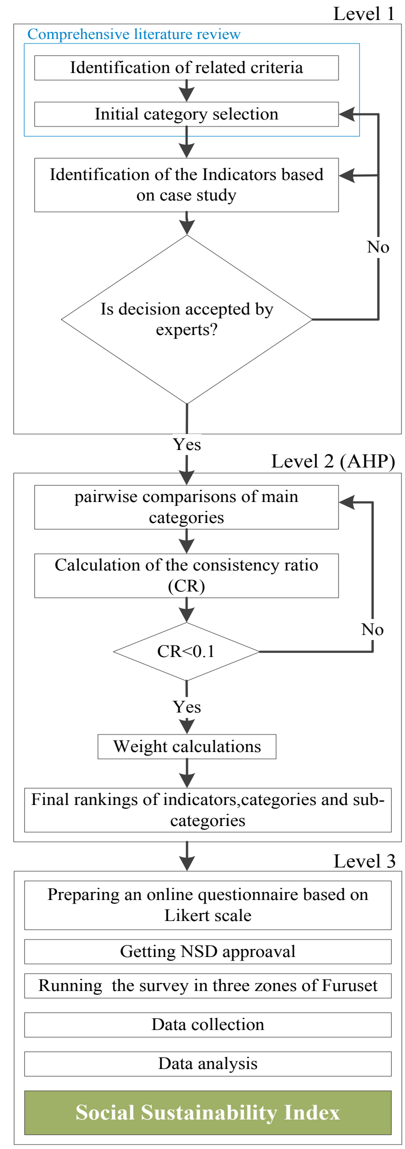

Figure 1. ISSA framework flow diagram described in (Akbarinejad, 2022)

Here, λ_m is the eigenvalue, and N denotes the number of major criteria.

Table 1. The AHP scale (Intensity of importance in variables)

Numeric	Linguistic
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between scale values

(4) calculating the consistency ratio (CR) (Franek & Kresta, 2014).

$$CR = CI.RI^{-1} \quad (2)$$

where, RI is the Random Index obtained from Table 2 (Hummel et al., 2014).

Table 2. Random Index (RI)

n	RI	n	RI	n	RI
1	0.00	4	0.90	7	1.32
2	0.00	5	1.12	8	1.41
3	0.058	6	1.24	9	1.45

After calculating the weights of all criteria and indicators based on the aggregation of expert opinions, residents should be surveyed on the basis of the categories and indicators identified for social sustainability. A six-point Likert scale was used to construct the questionnaire (strongly disagree, disagree, partly disagree, partly agree, agree, strongly agree). Residents were asked questions regarding each indicator in this questionnaire. In order to obtain the final scale of 0-100, a measuring scale of 0-5 was used. To quantify the results of the present study, the central tendency approach was used. Central tendency is a measure used to characterize a data set by identifying its center (Manikandan, 2011). The proposed social sustainability index (Akbarinejad, 2022) can be calculated using (1).

$$\mathbf{SSI} = \sum_{i=1}^{34} \mathbf{W_i \times I_i \times 20} \tag{3}$$

where, $\boldsymbol{SSI}$ is the proposed ISSA's social sustainability index, $\boldsymbol{W_i}$ is the each indicator's calculated weight in the AHP process, $\boldsymbol{I_i}$ is the Likert scale index which can be calculated by (2).

$$\boldsymbol{I_i} = \frac{\sum_{k=0}^{5} \boldsymbol{n_j \times k}}{\sum_{k=0}^{5} \boldsymbol{n_j}} \tag{4}$$

where, $\boldsymbol{n_j}$ is number of received responses from citizens to each Likert scale question, and $\boldsymbol{k}$ is the relative measuring scale from 0 to 5.

3. BASICS OF FUZZY-AHP

There are some limitations to AHP, as with all other methods. AHP utilizes accurate qualities for human judgments and it poses a challenge to aggregating opinions. The AHP can be participated in by a small group of individuals or by a large group of individuals. Weights can be accumulated either compensatory or non-compensatory among the group performing the performance rating (Arrington et al., 1982). Many scholars have attempted to resolve these limitations by extending Saaty's priority theory in the fuzzy extension (Chan & Kumar, 2007; Kahraman et al., 2004; Pourghasemi et al., 2012; Wang et al., 2008).

Due to the necessity for dealing with information derived from the computational perception that is uncertain, imprecise, vague, ambiguous, or lacking specific limits, Zadeh (1965) first proposed a mathematical technique dubbed fuzzy set theory (Balaman, 2019). This section introduces the basic concepts and definitions of fuzzy sets theory to facilitate uncertainty in anaerobic digestion modeling.

This section uses the notation and concepts introduced by (Carlsson & Fullér, 2001), (Fullér & Majlender, 2003), and (Zimmermann, 1985). There are some important definitions below (Barahmand et al., 2021):

Definition 1. fuzzy set A ($\tilde{A}$) is characterized by a Membership Function (MF) $\mu_{\tilde{A}}(x)$, where $x \in X$.

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) | x \in \tilde{A}\} \ , \quad \mu_{\tilde{A}}(x): X \to \{0,1\} \tag{5}$$

Where, $\mu_{\tilde{A}}(x)$ is the degree of membership of X in $\tilde{A}$. The closer the value of $\mu_{\tilde{A}}(x)$ is to 1, the more x belongs to $\tilde{A}$ and conversely for 0.

Definition 1. A triangular fuzzy number $\tilde{A} = [a_1, a_2, a_3, h(A)]_{(m,n)}$ is defined as a generalized triangular fuzzy number (Figure 2) with orders of m and n (GTFN) if the membership function is:

$$\boldsymbol{\mu_{\tilde{A}}(x)} = \begin{cases} \mathbf{0} & \boldsymbol{x \le a_1} \\ \boldsymbol{h(A)\left(\frac{x-a_1}{a_2-a_1}\right)^m} & \boldsymbol{a_1 \le x \le a_2} \\ \boldsymbol{h(A)\left(\frac{x-a_3}{a_2-a_3}\right)^n} & \boldsymbol{a_2 \le x \le a_3} \\ \mathbf{0} & \boldsymbol{x \ge a_3} \end{cases} \tag{6}$$

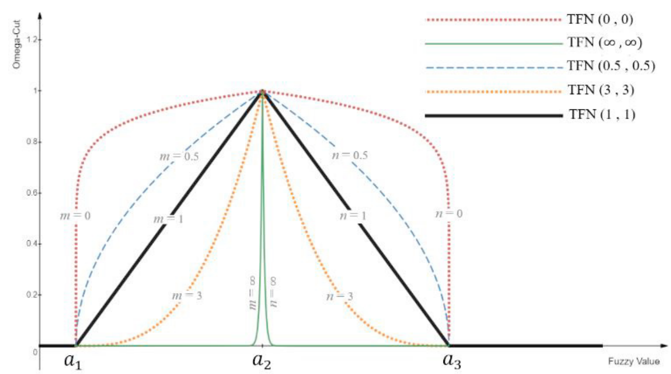

Figure 2. The generalized triangular fuzzy number for different orders

Definition 3. Considering linear (m=n=1) triangular fuzzy numbers $\tilde{A} = (a_1.a_2.a_3)$ and $\tilde{B} = (b_1.b_2.b_3)$, some fuzzy arithmetic operations can be defined as:

$$\tilde{A} + \tilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \tag{7}$$

$$\tilde{A}.\tilde{B} = (a_1 b_1, a_2 b_2, a_3 b_3) \tag{8}$$

$$\lambda\tilde{A} = (\lambda a_1, \lambda a_2, \lambda a_3) \tag{9}$$

$$\tilde{A}^{1-} = ({}^1/_{a_3}, {}^1/_{a_2}, {}^1/_{a_1}) \tag{10}$$

Definition 4. The possibility degree $\tilde{A} \ge \tilde{B}$ is defined as:

$$PD(\tilde{A} \ge \tilde{B}) = \sup_{x \ge y}[min(\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(y))] \tag{11}$$

$$PD(\tilde{A} \ge \tilde{B}) = \begin{cases} 1 & a_2 \ge b_2 \\ 0 & b_1 \ge a_3 \\ \frac{b_1 - a_3}{(a_2 - a_3) - (b_2 - b_1)} & otherwise \end{cases} \tag{12}$$

3. RESULTS AND DISCUSSION

Based on the fuzzy-AHP method introduced in (Chang, 1996) and the case study implemented in (Akbarinejad, 2022), the fuzzy weights of social sustainability in the context of Norway were calculated. A comparison matrix of four experts' responses to the main social sustainability categories can be seen in Figure 3. The letters A-F indicate the six main social sustainability criteria selected for Norway. These criteria are social equity (A), environmental awareness (B), social cohesion (C), health and safety (D), accessibility and satisfaction (E), and cultural value (F).

Previously, the aggregation of opinions was based on the geometric mean for each matrix cell. Instead, in this study, a fuzzy number was defined based on the opinions. Fizzy numbers can be defined in a variety of ways based on the information provided by the problem. Using this novel approach, four values were sorted from low to high for each cell. A trapezoidal fuzzy number could be represented by the four digits associated with each cell.

	A	B	C	D	E	F
A	1	5	1	1	1	1
B	0.20	1	0.33	0.33	0.33	0.33
C	1	3	1	1	1	1
D	1	3	1	1	1	1
E	1	3	1	1	1	1
F	1	3	1	1	1	1

Expert 1 (Academia)

	A	B	C	D	E	F
A	1	7	1	5	1	1
B	0.14	1	1	5	1	1
C	1	1	1	5	1	1
D	0.20	0.20	0.20	1	0.33	0.33
E	1	1	1	3	1	1
F	1	1	1	3	1	1

Expert 2 (Alna Minicipality)

	A	B	C	D	E	F
A	1	5	3	3	3	3
B	0.20	1	0.33	0.33	1	3
C	0.33	3	1	0.33	5	1
D	0.33	3	3	1	5	5
E	0.33	1	0.20	0.20	1	0.33
F	0.33	0.33	1	0.20	3	1

Expert 3 (Alna Municipality)

	A	B	C	D	E	F
A	1	5	0.20	0.33	5	5
B	0.20	1	0.25	0.20	0.33	3
C	5	4	1	5	5	1
D	3	5	0.20	1	4	5
E	0.20	3	0.20	0.25	1	7
F	0.20	0.33	1	0.20	0.14	1

Expert 4 (Academia)

Figure 3. Pair-wise comparisons of the main criteria based on experts' responses (adopted from (Akbarinejad, 2022))

A triangular fuzzy number was created by averaging two middle values for simplicity and to demonstrate the model structure. Figure 4 shows the fuzzy matrix created based on the experts' responses. It is important to note that the upper triangular matrix consists of expert opinions, while the lower triangular matrix is the inverse of each element in the upper triangular matrix.Consequently, to create triangular fuzzy numbers, first, the averages of the two middle values were calculated, then based on (8) the inverse of each fuzzy number was calculated and placed in the corresponding cell of the lower triangular matrix. In continuation of the procedure described in (Chang, 1996), fuzzy weights can be calculated for each criterion as shown in Table 3.

Table 3. Fuzzy weights of social sustainability criteria

Criteria		Fuzzy Weight
Social Equity	W1	(0.077, 0.257, 1.113)
Environmental Awareness	W2	(0.02, 0.092, 0.48)
Social Cohesion	W3	(0.042, 0.253, 0.871)
Health and Safety	W4	(0.02, 0.212, 0.971)
Accessibility and Satisfaction	W5	(0.026, 0.96, 0.714)
Cultural Value	W6	(0.026, 0.090, 0.557)

In the next step, using definition 4 and equations (9) and (10), defuzzified weights (*DWi*) can be calculated

The final step is to normalize these calculated deterministic weights (see Table 4).

Table 4. Final normalized deterministic weights (FNW) of social sustainability criteria

Criteria		Normalized Fuzzy Weight
Social Equity	FNW1	0.24
Environmental Awareness	FNW2	0.10
Social Cohesion	FNW3	0.18
Health and Safety	FNW4	0.20
Accessibility and Satisfaction	FNW5	0.16
Cultural Value	FNW6	0.12

As discussed earlier, ISSA framework is a citizen-driven framework considering experts' opinion on the context. It has two quantification levels. First level weights the selected indicators based on a multi-criteria descision-making method and second level quantifies the citizen's level of satisfaction and calculates the social sustainability index by (3)
However, one of the unique characteristics of the ISSA framework is its visualization. Akbarinejad (2022) describes how this method illustrates both levels and details od social sustainability indices at a single glance.

Figure 5 shows the social sustainability measure in one of the case studies (Gamble Furuset) discussed in (Akbarinejad, 2022). In Furuset, Gamle Furuset and Nordre Furuset are the oldest parts. The Gamle area is characterized by detached houses built in the early 1920s, with gardens and vulnerable areas, such as old hayfields and streams

It has caused serious problems in the municipality that many detached houses on old Furuset have been converted into small dormitories. According to the ISSA framework (Figure 5), social sustainability criteria are considerably lower in this zone and require greater attention. A number of issues are related to social equity, health and safety, and cultural values. A person living here has fewer chances and opportunities to find a decent job and to enjoy facilities than a person living in another part of the toe. They feel that they do not have a voice in local government.

Additionally, they reported experiencing anxiety and depression. As well as the lack of natural lighting in their home, they are not confident about the resilience of their house in the event of a disaster. Their building is also unsatisfactory, and they have difficulty interacting with their neighbors on an international level. As shown in Table 5, the calculated weights of the main criteria in this section are compared with those in the previous study.

The biggest variation belongs to social equity and accessibility and satisfaction. Cultural value did not change among all criteria. Table 6 shows the results of applying new fuzzy weights and using (3) to calculate the social sustainability index for the case study.

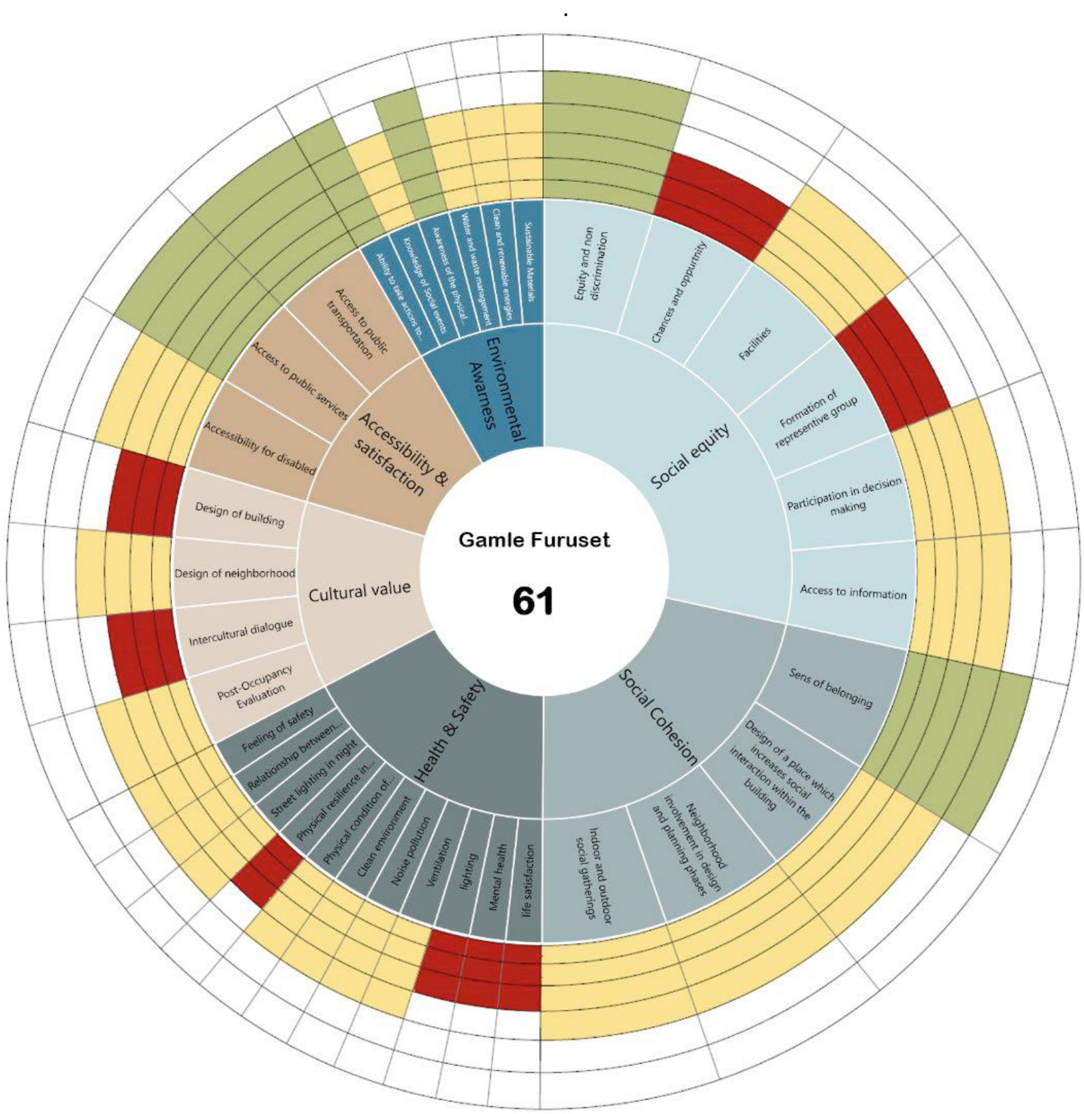

Figure 4. Gamble Furuset social sustainability result and overall social sustainability index

Table 5. Gamble Furuset social sustainability Indices

Index	Previous	Fuzzy	%Δ
Social Equity	13.31	14.22	6%
Environmental Awareness	6.66	7.55	12%
Social Cohesion	10.97	12.03	9%
Health and Safety	11.62	15.18	23%
Access and Satisfaction	11.81	12.75	7%
Cultural Value	7.21	7.94	9%
Overall Index	61.58	69.67	12%

The overall social sustainability index of Gamble Furuset experiences a significant increase (12 percent). Moreover, there are significant changes in all other sub-indices. Among the sub-indices, health and safety have experienced the greatest increase by 23 percent, while social cohesion has experienced the lowest rise by 6 percent. The most important subindex was subsequently changed from social equity to health and safety in the new approach. These changes may affect the decision making process. Using a fuzzy AHP may result in a more reliable aggregation of expert opinions, particularly when there is a significant difference between the responses. The change in social sustainability indices may not follow the pattern of the change in criteria weights as the social sustainability is calculated based on residence responses and their satisfaction levels. Therefore, in the further studies, uncertainty approach can also be applied to the calculation of the social sustainability index within the ISSA framework. As an another limitation, using broader expert panel with more diverse background may result in more trustable results.

6. CONCLUSIONS

This paper presents a fuzzy approach to existing framework based on author's proposal on Integrated Social sustainability Assessment (ISSA) and prepare a comparison of the results between AHP and Fuzzy approaches. There was no unified method that be able to measure the social sustainability performance in neighborhood scale and considering extensive attributes for obtaining the final social sustainability index, the proposed model is elaborated to overcome this gap by integrating critical attributes as a benchmark for evaluating social sustainability. Hence, this model provided a three-stage step by step hierarchical procedure to obtain social sustainability index of neighborhoods.

The main contribution of the study are summarized:

- Similar to all methods, there are some limitations to AHP, which utilizes accurate qualities for human judgments and it poses a challenge to aggregating opinions. The AHP can be participated in by a small group of individuals or by a large group of individuals.
- Many scholars have attempted to resolve these limitations by extending Saaty's priority theory in the fuzzy extension
- Using a fuzzy AHP may result in a more reliable aggregation of expert opinions, particularly when there is a significant difference between the responses.
- More than the AHP or Fuzzy approach, using broader expert panel with more diverse background may result in more trustable results.

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