Supplier sustainability performance evaluation and selection: A framework and methodology

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Abstract –This study proposes a supplier sustainability performance evaluation framework for evaluating and selecting suppliers based on their sustainability performance. An integrated model which uses fuzzy-Shannon Entropy to determine the sustainability criteria weights and fuzzy-Inference system to prioritize suppliers from the individual sustainability dimensions perspective is proposed to aid in the evaluation and selection. A Pakistan manufacturing company is used to exemplify the applicability and usefulness of the proposed suppliers' sustainability performance evaluation decision framework. The results show that amongst the economic, environmental and social sustainability dimensions, three criteria, namely: 'Quality' (10.87%), 'Cleaner Technology Implementation' (11.51%) and 'Information Disclosure' (13.75%), respectively, are the topmost ranked criteria. Across the triple-sustainability dimensions, suppliers 3 was ranked the topmost suppliers overall. This means that, to improve the sustainability of the company's supply chain, supplier 3 is most appropriate and recommended amongst the four suppliers for partnership. Managerial implications, limitations and further research directions are discussed.

*Keywords***:** sustainability; sustainable supplier performance evaluation; sustainable supplier selection, fuzzy Shannon entropy; fuzzy inference system.

1. Introduction

Due to the growing global pressures for industries to become more sustainable (Sarkis, 2018), organizations have started to implement sustainable business practices not only in their internal operations, but also in their external operations/partners for achieving this goal (Bai and Sarkis 2010; Bai and Sarkis 2014; Luthra et al. 2017). One important decision that affects the overall sustainability performance of organizations is the selection of sustainable suppliers through competitive bidding processes for partnering. Working with a supplier/partner that shares similar dream of meeting and exceeding environmental standards, is a partner worth having. A critical challenge facing purchasing managers is how to evaluate and select the most efficient suppliers that meet their sustainability standards (Amindoust et al., 2012). Sustainable supplier selection is indeed one of the critical decisions in industrial supply chains for helping organizations transitioning towards (Bai and Sarkis, 2014; Grimm et al., 2014). Thus, overall sustainability of manufacturing supply chains can potentially be achieved once inputs (e.g. raw materials and parts/components) received from suppliers into production/manufacturing adheres to the sustainability requirements and standards (Sarkis and Dhavale, 2015). Supplier selection is a strategic decision and organizations overall supply chain performance heavily depends on the

supplier's performance (Luthra et al. 2017). Therefore, appropriate supplier's selection and bidding process is required for organizations to remain highly competitive in the market and deliver products to customers on a timely basis (Kusi-Sarpong et al., 2018a).

Sustainability has become an emerging subject of research and many scholars have discussed it in the past 2-3 decades (Bai et al., 2017) with many of the thematic focusing on sustainability oriented supplier selection including sustainable supplier selection (Jain and Khan, 2016; V Jain and Khan, 2017) environmental and social criteria consideration in supplier selection (Winter and Lasch, 2016); sustainable supplier selection and evaluation (Luthra et al. 2017); sustainable supplier performance scoring (Ghadimi and Heavey, 2014); decision framework for effective offshore outsourcing adoption (Yadav et al., 2018); supplier selection by considering sustainability aspects (Kannan et al., 2014; Orji and Wei, 2015); performance evaluation and a flow allocation in sustainable supply chain (Jakhar, 2015); adopting environmental requirements in the supplier selection process (Jabbour and Jabbour, 2009). Although the sustainability supplier selection studies have seen an increasing growth over the period; nonetheless the field is still merging and more studies are needed within this context, especially from emerging economies to advance the understanding of the supplier selection in particular and sustainability concept in general.

To select the right supplier, various criteria should be considered and evaluated with respect to each supplier's attribute. Therefore, supplier selection is considered a multi-criteria decision making (MCDM) problem (Cheaitou and Khan, 2015; Khan, 2018; Khan et al., 2018, 2016; Yu et al., 2013). In sustainable supplier selection, the problem becomes more aggravated due to the many and conflicting criteria involved such as cost of the product, quality of products, delivery lead-time, flexibility, environmental requirement of the suppliers, etc. Such decisions require the support of MCDM tools. Many MCDM methods have been proposed and utilized in sustainable supplier selection and evaluation decisions such as FANP (Büyüközkan and Çifçi, 2011); DEMATEL (Chiou et al., 2011); FAHP (Chiouy et al., 2011); FIS (Amindoust et al., 2012) ; TOPSIS (Govindan et al., 2013); TOPSIS-QFD (Jain and Khan, 2016) ; DEA (Azadi et al., 2015; Shi et al., 2015), AHP-QFD (Dai and Blackhurst, 2012), FAHP (Azadnia et al., 2012; Büyüközkan and Çifçi, 2011; Lee et al., 2009); Fuzzy-TOPSIS (Kannan et al., 2014); Neurofuzzy TOPSIS

(Chaharsooghi and Ashrafi, 2014), AHP (Jain and Khan 2017); AHP-TOPSIS (Grover et al., 2016).

In this study, we introduce and combine for the first time fuzzy Shannon Entropy (FSE) and fuzzy inference system (FIS) for aiding the sustainable supplier selection in the automobile manufacturing industry from an emerging economy. FSE is the number or quality of information obtained from decision-making units which is used to determine the accuracy and reliability of decision-making problem (Song et al., 2017; Wu et al., 2011). Similarly FIS helps quantify decisions/information by using modeling of if-then rule base. Details of FSE and FIS can be found later in section 4 of this article. The integration of these tools is a novel methodology that is able to make accurate and reliable computation with relatively less data. In selecting the most sustainable supplier, two key important elements are required and necessary. These include sustainability performance criteria importance weights and performance evaluation and selection of suppliers with respect to the sustainability performance criteria. FIS was selected to aid in the evaluation and selection of sustainable suppliers due to its ability to handle and mimic the actual conditions in decision making process by incorporating decision makers' knowledge and experience in developing knowledgebase system as against other method such as TOPSIS, TODIM, and VIKOR (Kumar et al., 2017; Kusi-Sarpong et al., 2015). However, FIS has the limitation of requiring additional information about the criteria weights. FSE was then selected to overcome FIS method limitation to solve MCDM problems. FSE was selected over other methods such as FAHP/FANP, FDEMATEL (Kusi-Sarpong et al., 2016a, b) to determine these criteria weights due to its capability of eliminating the assumption of averaging when determining the criteria weights as against the other techniques, minimizing information losses (Romero-Troncoso et al., 2011). FSE relative weighs are then integrated into FIS to determine supplier's sustainability performance and selection. These analytical tools provide complementary avenues to rank/select preferred sustainable suppliers using expert judgments.

This study focused on the Pakistan manufacturing industry because it is the second largest contributor in terms of government taxes and revenues (contributes more than 12 billion rupees to the GDP) in addition to approximately 32%~35% of taxes paid by the car showrooms in Pakistan (FBR Report, 2017). The automotive sector is one of the rising sectors in Pakistan and use up to 70% locally produced parts as per global quality standards (Sector, 2012). Automotive sector in

Pakistan provides employment to more than 3 million people (directly and indirectly) in more than 200 million populations (https://propakistani.pk)[1]. However the industrial growth is not matching with the advancement in technology, organizational practices, and innovation in sustainability. In addition to that, it is essential for Pakistan automotive sector to enhance their overall sustainability standards to match with global sustainable standards, and the key starting point is from the suppliers perspective, especially since major of them are locally based with less sustainability orientation.

The general objective of this research is to investigate and prioritize suppliers based on their overall sustainability performance using industrial case experts' opinions.

More specifically, this paper will address the following objectives:

a) To identify the sustainable supplier performance evaluation criteria (social, environmental, economic dimensions) with the aim to evaluate supplier performance in terms of social, environmental, and economical performance.

b) To proposed novel hybrid Fuzzy Shannon Entropy (FSE) and fuzzy inference system (FIS) methodology to support the evaluation of supplier sustainability performance.

c) To implement the proposed novel hybrid methodology in selecting the most efficient sustainable supplier amongst a set of alternative suppliers for a case company.

This study addresses these objectives by taking the following steps. An initial literature review to identify the sustainable supplier selection evaluation criteria is conducted. Thereafter, a novel integrated multi-criteria decision-making method (MCDM) composed of Shannon Entropy and inference system under fuzzy environmental is proposed. We then combine the sustainable supplier selection evaluation criteria and the novel fuzzy MCDM methodology to investigate and prioritize sustainable suppliers according to the case company experts' opinions. Based on the study, managerial and practical implications will be presented.

This paper offers three main contributions that span the sustainable supplier selection literature and decision making application and are as follows:

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[1]   https://propakistani.pk/2015/08/12/automotive-industrys-contribution-to-pakistan-infographic   (Assessed: 20/08/2018)

a) Identifying multi-levels supplier sustainability performance evaluation framework using literature and experts inputs;

b) Develop a novel hybrid FSE and FIS based methodology that can use this framework to aid in evaluating supplier sustainability performance;

c) Case investigation to evaluate sustainability performance of suppliers in a cascaded approach (thus, social, environmental, and economical performance separately) using an emerging economy case company's experts' inputs.

The rest of the paper is structured as follows. In section 2, literature background is presented on sustainable supply chain management, sustainable supplier performance evaluation, sustainable supplier selection, and literature roundup and research gaps. The identification of potential sustainability supplier performance evaluation and selection criteria is completed in section 3. Methodological background of fuzzy set and fuzzy numbers, Shannon Entropy and Inference System are discussed in section 4. In section 5, a novel hybrid MCDM methodology is proposed. Real world application of the sustainable supplier performance criteria framework aided by the proposed novel hybrid MCDM methodology is provided along with results and discussion in section 6. Finally, conclusion, implications and future research is presented in section 7.

2. Literature Background

2.1 Sustainable supply chain management

Sustainability management and actions take into account an organization's environmental and social factors with their linkage with predictable economic performance (Sarkis and Dhavale, 2015). Sustainability supply chain management also focuses on improving environmental and social performance of firms in the supply chains (Seuring and Müller, 2008). Today's business operations are becoming responsible by promoting sustainability and being conscious of the fact that environmental, economic and social issues impact organizations actions and activities (Elkington, 1998). SSCM seeks to address sustainability risk issues and the opportunities as well as trade-offs from the perspective of industry and value chain. The subject of sustainable supply chain has become topical because customers, governmental agencies, regulatory bodies and employees have become increasingly aware of the environmental and social issues that impact the operations of firms (Moktadir et al., 2018). It is evident that supply chain executives are better placed to impact negatively or positive on the performance of the organization in terms of

environmental and social issues (Carter and Easton 2011). Sustainability measurement and its management is essential for SC management as determining the sustainability of SC is challenging (Qorri et al., 2018). The concept of sustainability allows the supply chain manager to think beyond the present position of the organization. Literature has shown that along with other factors that influence the sustainability implementation in SC, the most critical one is managerial orientation towards sustainability (Silvestre et al., 2018). Issues of how and what will make the organization thrive beyond 1 year, 5 years, 10 years and beyond becomes paramount. As a result it creates the opportunity for the supply chain manager to take corrective actions to ensure the sustainability of the organization (Carter and Easton 2011). It is concluded by many researcher in literature that to develop sustainable SC models, all factors of sustainability which includes economic, social, and environmental must be considered (Gómez-Luciano et al., 2018). It is against this backdrop that sustainable supply chain has become very crucial for the survival of the 21st century organizations. Upon this premise that the evaluation of supplier performance has become so crucial in sustaining supply chain activities in today's challenging business environment.

2.2 Sustainable supplier performance evaluation

The evaluation of supplier performance is crucial to the survival of the organizational supply chains (Ageron et al., 2012; Asadabadi, 2016). While the traditional criteria of selecting suppliers (e.g. price, quality etc.) are still crucial to the evaluation of supplier performance (Kusi-Sarpong. et al., 2018a), recent evaluation criteria due to the pressing need for organizations to become sustainable, embraces more broader sustainability oriented focused efficient factors (Bai and Sarkis, 2010; Bai and Sarkis, 2014; Büyüközkan and Çifçi, 2011). Organization are therefore considering supplier performance evaluation through the lens of sustainable policies. This takes into account the triple bottom line concept which considers social, environmental and economic issues in evaluation suppliers' sustainable performance (Chaharsooghi and Ashrafi, 2014). Carter (2011) argued that, sustainable supplier performance evaluation takes into account other factors such as risk management, organizational culture, transparency and strategy. Earlier research studies have mentioned and laid emphasis on factors such as responsiveness, cost, reliability, safety and environmental issue. Yet recent studies have identified attributes that go beyond these factors which are more comprehensive in nature. The triple bottom line approach which considers transparency as one of the factors, talks about openness to the organization's stakeholders. The triple bottom line also looks at strategy and culture. A sustainable supplier performance evaluation

must combine strategy and culture in evaluating the supplier's performance. According to Carter and Rogers (2008) the triple bottom line concept considers risk management as sustainable supplier performance evaluation process. Organizations in evaluating supplier performance must not only consider financial risk within the short term, rather other factors like worker and public safety, environmental waste, harm associated with products must also be considered. Natural disasters are risks that can affect the supply chain. These can take the form of poor coordination of demand requirements across the supply chain, poor demand planning and forecasting, fluctuation in the prices of raw materials, poor supplier quality, etc. (Carter and Rogers 2008). Several approaches have been identified by other literatures as supplier performance criteria have been deduced in diverse ways. This has however created some gaps that researchers need to fill.

2.3 Sustainable supplier selection

Organizations in recent times have become more reliant on suppliers and as a result selecting the right supplier must be based on sustainability criteria. Sustainable supplier selection has an effect on overall performance of sustainable SC which results in becoming an important issue in SSCM(Gören, 2018). According to Mohammed et al., (2018) sustainable supplier selection is now become an essential milestone is designing a robust SSC. Firms are increasing depending on purchased materials and outsourcing of production to third parties (Egels-Zandén et al., 2015). The roles these suppliers play in supply chain management and their impacts on organizational and sustainable performance require that their evaluation and selection be rigorous and robust (Ageron et al., 2012; Asadabadi, 2016). With the emergence of sustainable supply chain management, the selection process could be based on extended criteria from the tipple bottom line framework. Supplier selection and its development become complex task by adding sustainability in making decisions (Trapp and Sarkis, 2016). Sarkis and Dhavale (2015) argued that, the tipple bottom line approach takes into consideration three key elements, people, planet and profit. Many studies have identified the importance of integrating socio-environmental attributes into the conventional economic-based supplier selection decisions (Bai and Sarkis, 2010; Song et al., 2017; Zhu et al., 2007). Numerous studies on sustainable supplier evaluation and selection have emerged (see e.g.(Amindoust et al., 2012; Azadnia et al., 2012; Badri Ahmadi et al., 2017a; Bai and Sarkis, 2010; Genovese et al., 2010; Govindan et al., 2013; Maestrini et al., 2017; Sarkis and Dhavale, 2015). Several decision making processes come into play when considering supplier sustainability selection. Cost implication, quality of product, product delivery lead time, terms of

purchase/agreement, payment terms, supplier social responsibility, environmental factors, social factors, etc. (Chaharsooghi and Ashrafi, 2014). Helping organizations make efficient trade-offs among these many conflicting criteria is important thing that managers and decision-maker are much concern with and is the focus of this study.

2.4 Literature roundup and research gaps

Even though sustainable supply chain management has gained heavy attention in recent times, many scholars have argued that there have been limited studies on the Asian perspective (Gugler and Shi, 2009). The review of literature depicts that there's a growing interest and focus on suppliers sustainability performance as the sources and starting points for manufacturing organizations to achieve and improve their sustainability. Firms have therefore started to evaluate their suppliers' sustainability performances to identify areas of weaknesses and to propose possible solutions, directions and approaches to remedy them. It is against this background that this paper takes a critical look at the supplier sustainability performance evaluation and selection in the manufacturing industry from an emerging economy of Asia, the Pakistan perspective. This research work seeks to contribute to the advancement of the body of knowledge within the sustainable supply chain management literature in general and sustainable supplier selection in specific, mostly especially from the emerging economies.

3. Identification of Potential Sustainable Supplier Performance Evaluation and Selection Criteria

In guiding decisions such as supplier performance evaluation and selection, there is the need for a set of performance criteria for helping organizations evaluate the performance of each supplier against them. These criteria formation and composition depends on the kind of decision undertaken. Traditionally, supplier performance evaluation and selection decisions are mainly based on economic aspects. However, due to globalization, pressure for organizations to transit toward sustainability, and high competition, it is essential for organizations to evaluate and select their supplier considering all pillars of sustainability including social, environmental, and economic dimensions. Thus, it is important for organizations to integrate social and environmental performance criteria dimensions to the traditional criteria such as cost, quality, and delivery etc, to achieve a truly sustainable operation (Badri Ahmadi et al., 2017b). In this study, after a thorough literature search in all three dimensions of sustainability (social, environmental, and economic

dimensions) that potentially guide sustainable supplier performance evaluation and selection, Table A (see appendix) summarizes the sustainable supplier performance evaluation criteria along with their sources. The keywords that has been used to summarizes potential criteria for sustainable supplier evaluation are "supplier selection", sustainable supplier selection", supplier performance evaluation", supplier social performance criteria", supplier economic performance criteria", and supplier environmental performance criteria" from Scopus, science direct, and web of science.

Table 'A' combined widely used sustainable supplier performance evaluation criteria from literature, hence considered comprehensive in nature. However, these supplier performance evaluation criteria would be subject to review by a case company's expert group and the refined criteria framework will be further utilized alongside a proposed MCDM methodology for guiding the sustainable supplier selection decision-making in the case company.

4. Methodological Background

The case study approach is adopted in this study. Shannon Entropy (SE) and Inference System (IS) under fuzzy environment are integrated as a unified tool to be utilized in supporting the competitive sustainable supplier selection and bidding evaluation of the case. Since our proposed novel hybrid methodology is based on fuzzy set and fuzzy numbers, SE and IS, it is essential for readers to have an overview of these three techniques. Therefore in this section, we will provide some brief theoretical information of fuzzy set and fuzzy numbers, SE and IS, respectively.

4.1 Fuzzy set and fuzzy numbers

Fuzzy sets were introduced by Zadeh in 1965 to represent data and information possessing non-statistical uncertainties. It was specifically designed to mathematically represent uncertainty and vagueness and, provide formalized tools for dealing with the imprecision intrinsic in many problems. Fuzzy logic provides an inference morphology that enables approximate human reasoning capabilities to be applied to knowledge-based systems. Fuzzy theory provides a mathematical system to capture the uncertainties associated with human cognitive processes (Zadeh 1988; Zadeh 1975; Zadeh 1965). Fuzzy numbers have been introduced by Zadeh in order to deal with imprecise numerical quantities in a practical way (Dijkman et al., 1983). Since then, several authors have investigated properties and proposed applications of fuzzy numbers. In these applications, fuzzy numbers are used to indicate a real number, not to describe just one real

number. In general one can choose different real numbers which neither contradict nor agree completely with the notion one has about a fuzzy number, example "about seven". The extent to which some real number answers to the given description of the fuzzy number in question is represented by the membership value, i.e., the value of the membership function (MF) at that real number (Dijkman et al., 1983). MF is a curve that defines the exact degree of belongings of imprecise information to the corresponding value. Usually its interval is between [0, 1]. Figure 1 represents the standard membership function curve. The horizontal axis represents an input variable x, and the vertical axis defines the corresponding membership value $\mu(X)$ of the input variable X.
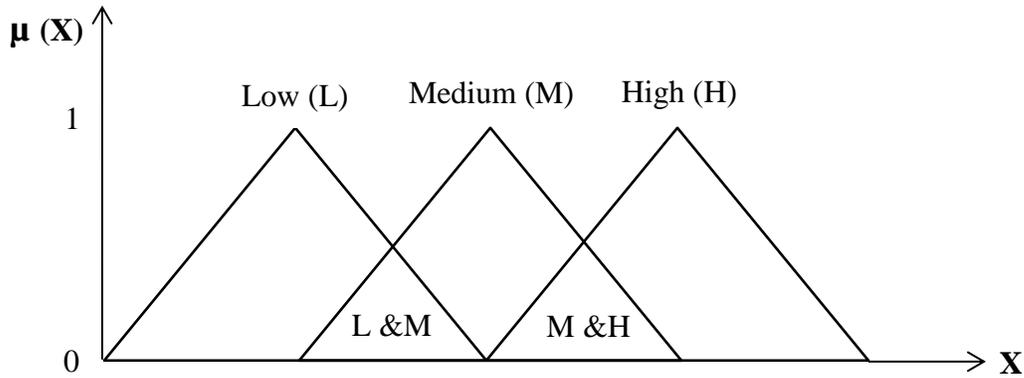

Figure 1: Standard Membership Function

4.2 SE (Shannon Entropy)

The entropy weighting scheme was first introduced from thermodynamics to information systems by Claude Shannon in his paper of *A Mathematical Theory of Communication* (Shannon 1948; Shannon 2001) After its introduction, it has been widely used in many fields such as engineering, management etc. Shannon entropy is an effective concept in the field of information theory, which is very useful and employable as a measure of uncertainty. The uncertainty in communication process signals is known as "information entropy" (Liang et al., 2006). Information entropy is the number or quality of information obtained from decision-making units which is used to determine the accuracy and reliability of decision-making problem (Song et al., 2017; Wu and Barnes, 2011). The higher is the information entropy, the lower the weight and vice versa.

4.3 IS (Inference System)

Inference system (IS) helps quantify decisions/information by using modeling of if-then rule base. There are basically three kinds of IS that has been used successfully in literature which are Sugeno, Mamdani and Tsukamoto inference. These types of IS differ in terms of outputs. There are many names that have been used for IS such as "rule-based systems", "expert systems", "modeling", "logic controllers", and simply "systems". For more details of IS, readers are referred to (Mendel 1995; Zadeh 1965; Dijkman et al. 1983).

5. Proposed Novel Hybrid MCDM Methodology

To aid in the sustainable supplier selection decision-making, we propose a novel MCDM model that integrates FSE and FIS. In designing the proposed novel hybrid MCDM methodology, some basic concepts of FSE and FIS are presented. These concepts are discussed in the next sub-section with a step by step approach of the methodology detailed at the end of the discussion.

5.1 Fuzzy Shannon Entropy in the Proposed Hybrid Model

5.1.1 Fuzzy Membership Functions for Determining Criteria Importance Weights

A systematic approach to extend the Shannon entropy method under fuzzy environmental is proposed. In order to overcome the issue of imprecise data, uncertainty and vagueness when populating the decision matrix, a 5-point linguistic scale has been developed. The 5-point linguistics terms include, "Weakly Importance", Low Importance", "Moderately Importance", Highly Importance and Strongly Importance" and are used by the decision-makers to populate the decision matrix. This linguistic scale and its equivalent to fuzzy numbers on numeric scale 0-1 as shown in Table 1 and Figure 2.

Table 1: Linguistic Terms for Supplier Performance Evaluation Criteria Weights

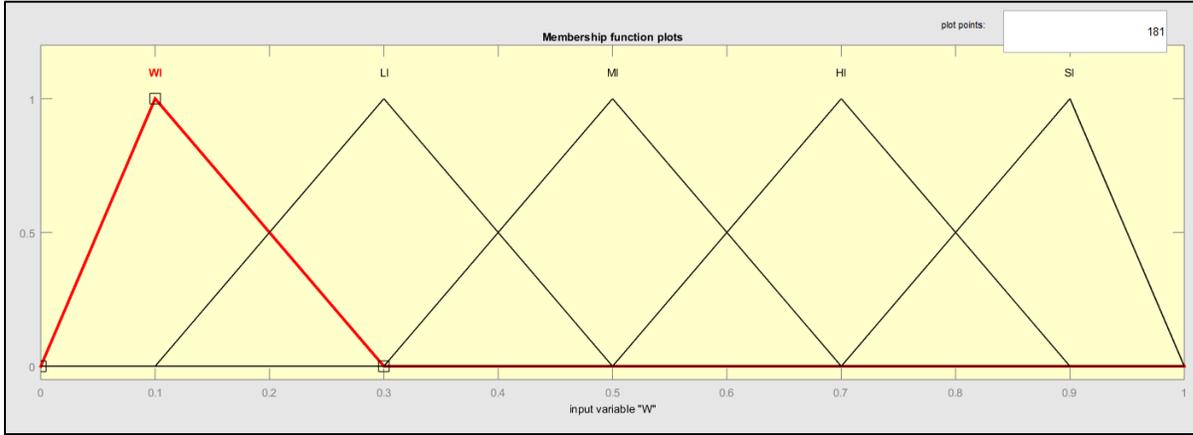|	
Weakly Important (WI)	(0, 0.1, 0.3)
Low Important (LI)	(0.1, 0.3, 0.5)
Moderately Important (MI)	(0.3, 0.5, 0.7)
Highly Important (HI)	(0.5, 0.7, 0.9)
Strongly Important (SI)	(0.7, 0.9, 1.0)

Figure 2: Triangular Membership Function

5.1.2 Determine decision matrix

Assuming there are m evaluation criteria to be rated by K expert groups (decision maker groups). The linguistic performance value rating by k expert groups with respect to i evaluation criteria is obtained from decision-maker perceptions and is denoted by f_{ki} . The final output is an $m \, x \, k$ initial linguistic decision matrix of the evaluation, $D = (f_{ki})_{mxk}$, with $1 \leq k \leq K$.

5.1.3 Defuzzify decision matrix

The initial linguistic decision matrix is first transformed into a triangular fuzzy numbers decision matrix, using Table 2. Let $f_{ki} = (l_{ki}, m_{ki}, u_{ki})$, be the corresponding triangular fuzzy number for the level of performance of i evaluation criteria for k expert group rating with $1 \leq k \leq K$. Then, the center of area (COA) defuzzification method, using Eq. (1) is applied to get crisp data x_{ki} (crisp numbers decision matrix).

$$x_{ki} = \frac{[(u_{ki}-l_{ki})+(m_{ki}-l_{ki})]}{3} + l_{ki} \tag{1}$$

5.1.4 Normalize crisp decision matrix

The crisp decision matrix is then converted into a normalized decision matrix P_{ki} using Eq. (2):

$$P_{ki} = \frac{x_{ki}}{\sum_{k=1}^{K} x_{ki}} \tag{2}$$

5.1.5 Determine the information entropy for each criterion

The determination of the information entropy E_j for each criterion is completed using Eq. (3):

$$E_i = -[ln(K)]^{-1} \sum_{k=1}^{K} P_{ki} ln \, P_{ki} \tag{3}$$

13

5.1.6 Compute the weight for each criterion

The weight w_i for each criterion is computed by using Eq. (4):

$$w_i = \frac{(1-E_i)}{(m - \sum_{i=1}^{m} E_i)} \tag{4}$$

Where $0 \leq w_i \leq 1$ and $\sum_{i=1}^{m} w_i = 1$

5.2 FIS in the Proposed Hybrid Model

5.2.1 Fuzzy Membership Functions for Performance Evaluation Criteria

In this aspect of the proposed novel hybrid methodology, the degree of importance of the inputs (performance evaluation criteria) is implemented on the basis of experts' opinions. Therefore, we developed a membership function to identify the performance criteria as mentioned in Table 3. It is noted that the membership function is applied in the triangular form in this paper. We have selected triangular membership function as it is most widely used function in literature. For determining sustainable supplier performance evaluation criteria, three fuzzy sets membership functions are applied. These fuzzy sets are in the form of linguistic rating variables that includes "low", "medium", and "high" as shown in Figure 3. We have used three points scale because of ease of data collection and as recommended by the experts. These variables are equivalent to fuzzy numbers on numeric scale 0-1 as shown in Table 2.

Table 2: Linguistic Terms for Supplier Performance Evaluation Criteria

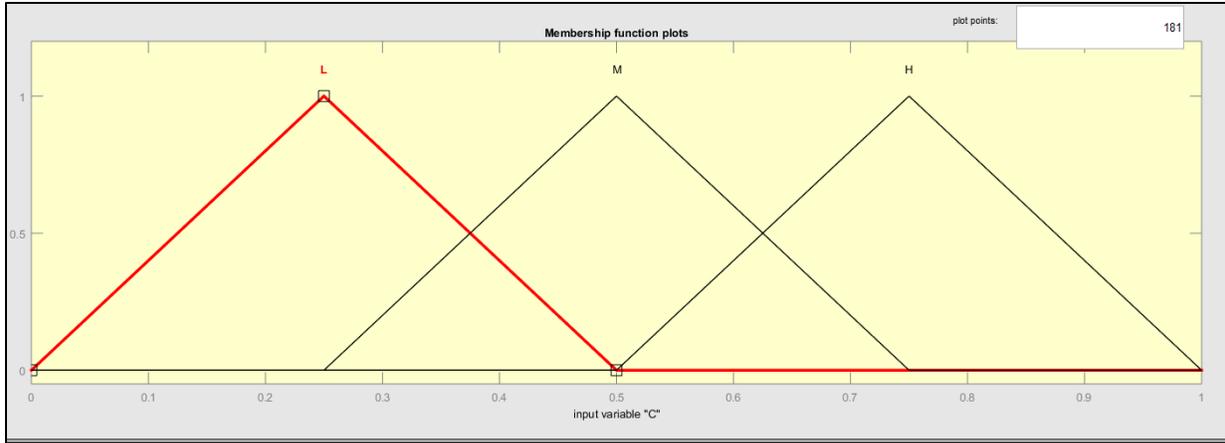| Low (L)	(0, 0.25, 0.5)
Medium (M)	(0.25, 0.50, 0.75)
High (H)	(0.50, 0.75, 1.0)

Figure 3: Triangular Membership Function

5.2.2 Fuzzy Membership Functions for the Supplier Performance

In determining the sustainable performance of suppliers in terms of social, environmental, and economical, we consider five fuzzy sets of membership functions. The fuzzy sets are in the form of linguistic rating variables that includes "weakly important", "low important", "moderately important", highly important, and "strongly important" as shown in Figure 4. We have used five points scale to capture the small changes in the input parameters. These variables are equivalent to fuzzy numbers on numeric scale 0-1 as same as shown in Table 3.

Table 3: Linguistic Terms for Supplier Performance Evaluation Criteria Weights

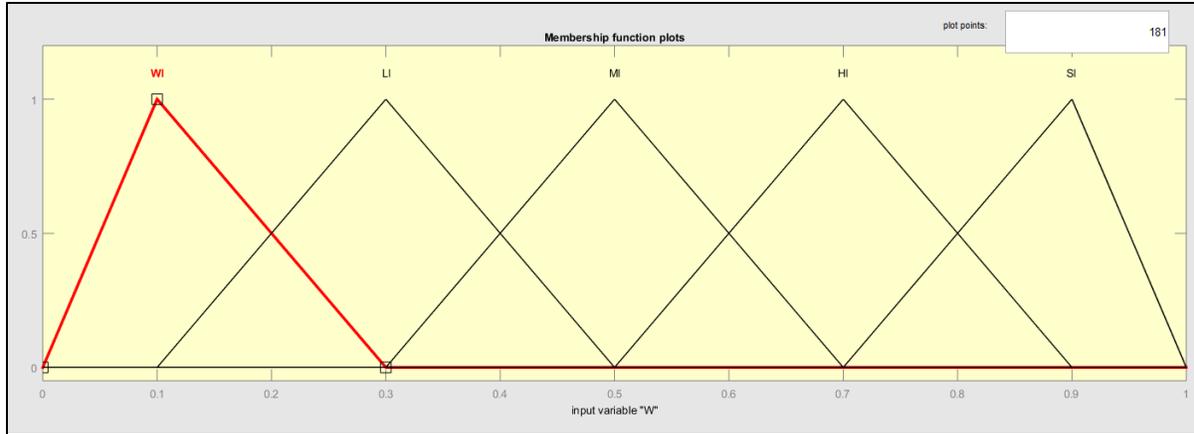|	
Weakly Important (WI)	(0, 0.1, 0.3)
Low Important (LI)	(0.1, 0.3, 0.5)
Moderately Important (MI)	(0.3, 0.5, 0.7)
Highly Important (HI)	(0.5, 0.7, 0.9)
Strongly Important (SI)	(0.7, 0.9, 1.0)

Figure 4: Triangular Membership Function

5.2.3 Applied Fuzzy Rules (if-then) in the Proposed Model

In our proposed methodology, fuzzy if-then rules are based on experts' opinion and their knowledge. Since we have to evaluate sustainable supplier performance in terms of social, environmental, and economical, we used the cascaded approach and considered the criteria that were considered relevant to each aspect of sustainability dimensions after the refinement by industrial experts. The appropriateness of criteria that must be considered at each perspective of sustainability was selected by experts. These refined and selected criteria are used to develop fuzzy linguistic rule base (if-then rules) to evaluate the social, environmental, and economic sustainability performance of suppliers.

5.2.4 Defuzzification

A fuzzy number must be defuzzified to get the crisp value. We used the center of area (COA) method at this stage.

6. Real world application

To exemplify the applicability and usefulness of the proposed sustainable supplier performance evaluation framework aided by the proposed novel hybrid FSE-FIS model, a case study of an automobile manufacturing company from an emerging economy is utilized. The step-by-step approach to implementing this methodology is detailed in Figure 5 below.
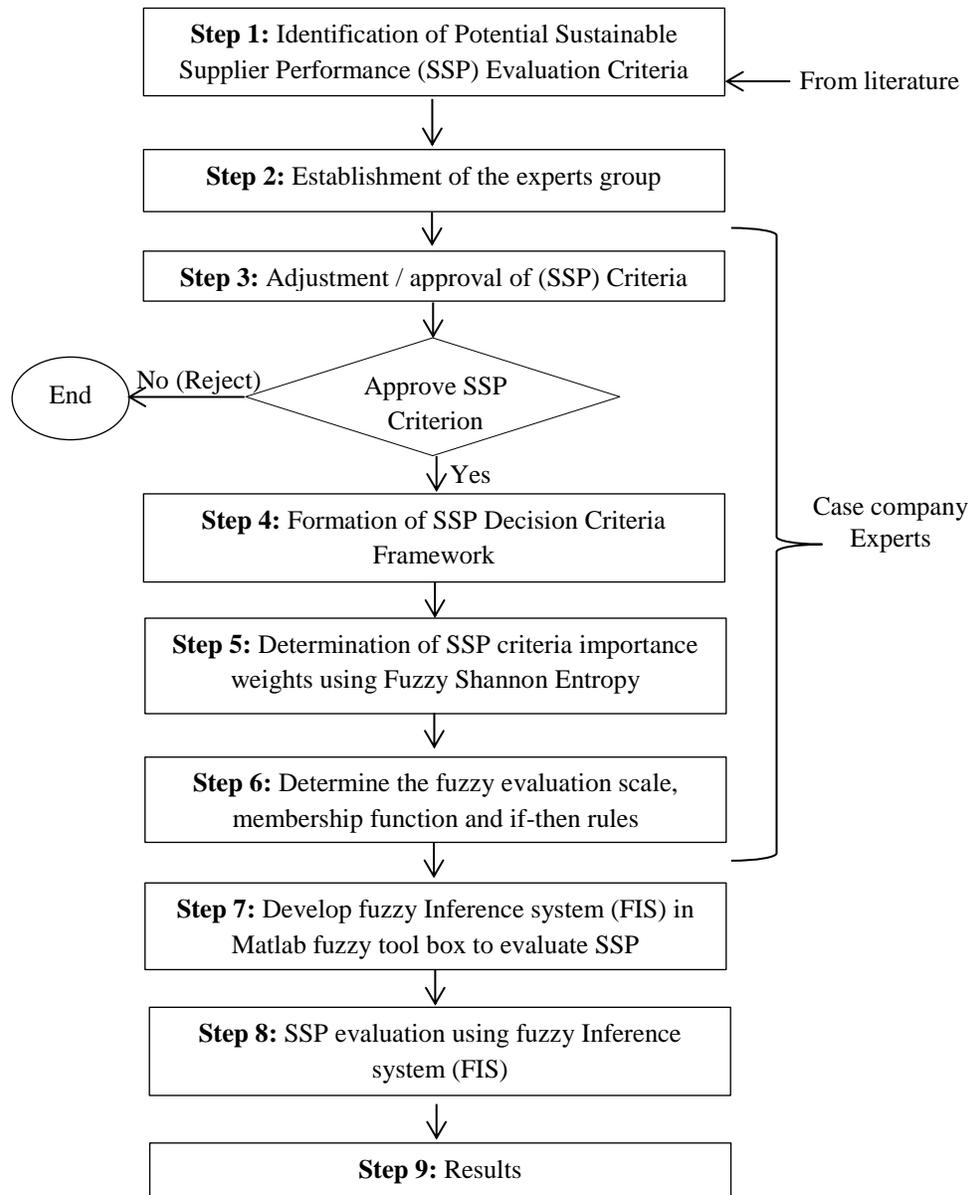
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┌─────────────────────────────────────────┐
│ Step 1: Identification of Potential     │ ◄──── From literature
│ Sustainable                             │
│ Supplier Performance (SSP) Evaluation   │
│ Criteria                                │
└─────────────────────────────────────────┘
                    │
                    ▼
┌─────────────────────────────────────────┐
│ Step 2: Establishment of the experts    │
│ group                                   │
└─────────────────────────────────────────┘
                    │
                    ▼
┌─────────────────────────────────────────┐
│ Step 3: Adjustment / approval of (SSP)  │
│ Criteria                                │
└─────────────────────────────────────────┘
                    │
                    ▼
       No (Reject)  ◇ Approve SSP ◇
  End ◄──────────── ◇  Criterion  ◇
                    │ Yes
                    ▼
┌─────────────────────────────────────────┐
│ Step 4: Formation of SSP Decision       │
│ Criteria Framework                      │
└─────────────────────────────────────────┘
                    │
                    ▼
┌─────────────────────────────────────────┐       Case company
│ Step 5: Determination of SSP criteria   │          Experts
│ importance weights using Fuzzy Shannon  │
│ Entropy                                 │
└─────────────────────────────────────────┘
                    │
                    ▼
┌─────────────────────────────────────────┐
│ Step 6: Determine the fuzzy evaluation  │
│ scale, membership function and if-then  │
│ rules                                   │
└─────────────────────────────────────────┘
                    │
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┌─────────────────────────────────────────┐
│ Step 7: Develop fuzzy Inference system  │
│ (FIS) in Matlab fuzzy tool box to       │
│ evaluate SSP                            │
└─────────────────────────────────────────┘
                    │
                    ▼
┌─────────────────────────────────────────┐
│ Step 8: SSP evaluation using fuzzy      │
│ Inference system (FIS)                  │
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│ Step 9: Results                         │
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Figure 5: Proposed Step-by Step Approach

Our proposed step-by step approach can be executed for any number of suppliers and there is no limitation. We have selected automotive cars Assembly Company as a case for our study's proposed methodology implementation from an emerging economy of Pakistan. The company is responsible of producing passenger car, light commercial vehicles, and Sports Utility Vehicle. So far case company has produced around 700,000 CBU/CKD vehicles (Rehman et al., 2018). It has more than 2600 employees consists of management staff and work force. They have more than

125 supplier in which they successfully transferred technology to over 55 suppliers (Rehman et al., 2018). Due to confidentiality, the identity of the case company cannot be reveal. Therefore, for the rest of the paper we will refer to the selected case company as XYZ Company. The XYZ Company wanted to evaluate, rank and identify the optimal supplier among four suppliers in terms of their overall sustainability performance. These suppliers are referred to as supplier 1, supplier 2, supplier 3, and supplier 4.

6.1 Criteria determination and refinement

Step 1: *Identification of potential sustainable supplier performance evaluation criteria*

Potential sustainable supplier performance evaluation criteria were identified through a survey of the literature and are summarized in Table A (see appendix).

Step 2: *Formation of expert groups*

Expert groups consisting of 2 procurement managers (8 and 9 years of experience), 3 procurement executives (2, 4, and 5 years of experience), 2 procurement supervisors (10 years of experience each), and 4 senior procurement executives (7 years of experience each) was formed. Members in the expert groups are responsible for XYZ company entire procurement decisions. To make it simple and effective during data collection, we divided the experts into four groups. Expert groupings were based on positions and job titles. For example, in the procurement managers group, all experts whose designation were managers and directly or indirectly related to procurement process were gathered. The first group consisted of 2 procurement managers referred to as expert group 1 (EG1), second group consisted of 3 procurement executives and referred to as expert group 2 (EG2), third group consisted of 4 senior procurement executives and referred to as expert group 3 (EG3), and last group consisted of 2 procurement supervisors and referred to as expert group 4 (EG4). The established expert groups were briefed about the objectives and purpose of this study. Some clarifications were requested by a few members of some expert groups and were clarified during group discussion.

Step 3: *Refinement of the potential sustainable supplier performance evaluation criteria*

The identified potential sustainable supplier performance evaluation criteria was tabulated (as shown in Table B (see appendix) and distributed amongst the groups and were asked to tick either "Yes" or "No" indicating whether or not the criteria listed are relevant to their company's sustainable supplier competitive bidding decision. We agreed with the four expert groups that any criterion that receives three or more "Yeses", at the end of the analysis, will indicate an affirmative

vote (acceptance) and so would be maintained on the listing otherwise deleted. The experts were also asked to suggest/add additional criteria they deemed essential but weren't captured through the literature survey under each of the three sustainability dimensions. At the end of the evaluation by the expert group and analysis, 4 criteria received less than three "Yes", and so were deleted from the listing. No additions or suggestions were made. The final listings together with their brief description and reference sources can be found in Table C (see appendix).

6.2 Application of fuzzy Shannon entropy aspect of the hybrid model

Step 4: *Determine decision matrix*

Each expert group was asked to rate each sustainable supplier performance evaluation criterion using linguistic variables. All the 4 expert groups linguistics response 17 x1 matrices were put together to form a 17 x 4 decision matrix and were transformed into triangular fuzzy numbers matrix using Table 4. The initial linguistic ratings and corresponding fuzzy number of the identified sustainable supplier performance evaluation criteria are as shown in Table 4 below.

Table 4: Group Opinions for Sustainable Supplier (SS) Performance Evaluation Criteria

Sustainability Aspect	Criteria	Expert Groups			
		EG1	EG2	EG3	EG4
Economic	C	HI (0.5, 0.7, 0.9)	HI (0.5, 0.7, 0.9)	SI (0.7, 0.9, 1.0)	MI (0.5, 0.5, 0.7)
	Q	SI (0.7, 0.9, 1.0)	MI (0.5, 0.5, 0.7)	MI (0.5, 0.5, 0.7)	SI (0.7, 0.9, 1.0)
	D	HI (0.5, 0.7, 0.9)	MI (0.5, 0.5, 0.7)	HI (0.5, 0.7, 0.9)	SI (0.7, 0.9, 1.0)
	SR	HI (0.5, 0.7, 0.9)	HI (0.5, 0.7, 0.9)	SI (0.7, 0.9, 1.0)	HI (0.5, 0.7, 0.9)
	F	MI (0.5, 0.5, 0.7)	MI (0.5, 0.5, 0.7)	MI (0.5, 0.5, 0.7)	HI (0.5, 0.7, 0.9)
	FC	MI (0.5, 0.5, 0.7)	HI (0.5, 0.7, 0.9)	HI (0.5, 0.7, 0.9)	MI (0.5, 0.5, 0.7)
Environmental	E	HI (0.5, 0.7, 0.9)	SI (0.7, 0.9, 1.0)	HI (0.5, 0.7, 0.9)	HI (0.5, 0.7, 0.9)
	RC	MI (0.5, 0.5, 0.7)	MI (0.5, 0.5, 0.7)	SI (0.7, 0.9, 1.0)	MI (0.5, 0.5, 0.7)
	ES	HI (0.5, 0.7, 0.9)	HI (0.5, 0.7, 0.9)	MI (0.5, 0.5, 0.7)	MI (0.5, 0.5, 0.7)
	FM	SI (0.7, 0.9, 1.0)	HI (0.5, 0.7, 0.9)	SI (0.7, 0.9, 1.0)	SI (0.7, 0.9, 1.0)
	CT	MI (0.5, 0.5, 0.7)	SI (0.7, 0.9, 1.0)	HI (0.5, 0.7, 0.9)	MI (0.5, 0.5, 0.7)
	RM	HI (0.5, 0.7, 0.9)	MI (0.5, 0.5, 0.7)	HI (0.5, 0.7, 0.9)	MI (0.5, 0.5, 0.7)
Social	EP	MI (0.5, 0.5, 0.7)	HI (0.5, 0.7, 0.9)	MI (0.5, 0.5, 0.7)	HI (0.5, 0.7, 0.9)
	HS	MI (0.5, 0.5, 0.7)	SI (0.7, 0.9, 1.0)	MI (0.5, 0.5, 0.7)	HI (0.5, 0.7, 0.9)
	ER	HI (0.5, 0.7, 0.9)	HI (0.5, 0.7, 0.9)	MI (0.5, 0.5, 0.7)	HI (0.5, 0.7, 0.9)
	ID	SI (0.7, 0.9, 1.0)	HI (0.5, 0.7, 0.9)	MI (0.5, 0.5, 0.7)	MI (0.5, 0.5, 0.7)
	SC	MI (0.5, 0.5, 0.7)	SI (0.7, 0.9, 1.0)	HI (0.5, 0.7, 0.9)	SI (0.7, 0.9, 1.0)

Step 5: *Defuzzification of decision matrix*

The triangular fuzzy decision matrix was defuzzify using center of area (COA) defuzzification method (Eq. (1)) into crisp data decision matrix. The final decision matrix is shown in Table D (see appendix).

Step 6: *Normalize crisp decision matrix*

The crisp decision matrix is converted into a normalized decision matrix using Eq (2) and is shown in columns 3-6 of Table 9.

Step 7: *Determine the information entropy of each criterion*

The information entropy for each criterion is determined by using Eq. (3) and is also shown in column 7 of Table 5.

Step 8: *Computer the criteria weights*

The criteria weights are computed using Eq. (4) and are shown in column 8 of Table 5 as the final result of fuzzy Shannon Entropy.

Table 5: Normalized, Information Entropy and Weights of SS Performance Evaluation Criteria

Sustainability Aspect	Criteria	Expert Groups				Information Entropy	Importance Weights
		EG1	**EG2**	**EG3**	**EG4**		
Economic	C	0.273	0.273	0.252	0.201	0.9948	0.0303
	Q	0.305	0.179	0.210	0.305	0.9813	0.1087
	D	0.251	0.184	0.251	0.314	0.9877	0.0714
	SR	0.252	0.252	0.245	0.252	1.0000	0.0003
	F	0.229	0.229	0.229	0.312	0.9930	0.0405
	FC	0.224	0.304	0.248	0.224	0.9940	0.0349
Environmental	E	0.242	0.303	0.213	0.242	0.9938	0.0357
	RC	0.235	0.235	0.295	0.235	0.9963	0.0216
	ES	0.295	0.295	0.193	0.217	0.9878	0.0709
	FM	0.272	0.217	0.239	0.272	0.9968	0.0184
	CT	0.208	0.354	0.230	0.208	0.9802	0.1151
	RM	0.304	0.224	0.248	0.224	0.9940	0.0349
Social	EP	0.212	0.288	0.212	0.288	0.9916	0.0486
	HS	0.198	0.336	0.198	0.268	0.9812	0.1088
	ER	0.268	0.268	0.197	0.268	0.9943	0.0331

| | ID | 0.344 | 0.274 | 0.180 | 0.202 | 0.9763 | 0.1375 |
| | SC | 0.173 | 0.295 | 0.236 | 0.295 | 0.9846 | 0.0893 |

6.3 Application of fuzzy inference system aspect of the hybrid model

Step 9: *FIS Model Building in Matlab*

The same membership functions for inputs (supplier performance evaluation criteria) and their importance weights as mentioned in section 5.2.1, was considered. Similarly, same membership functions for output (sustainable supplier performance evaluation) as mentioned in section 5.2.2, and fuzzy if-then rules as mentioned in section 5.2.3 are also considered.

Step 10: *Performance Evaluation Models*

FIS models were developed using Matlab software to evaluate SS Performance. Figures 6 shows a sample of the FIS models for evaluating the SS Performance in terms of supplier social performance. The supplier environmental and economic performance FIS models are modeled the same way but are not shown here.
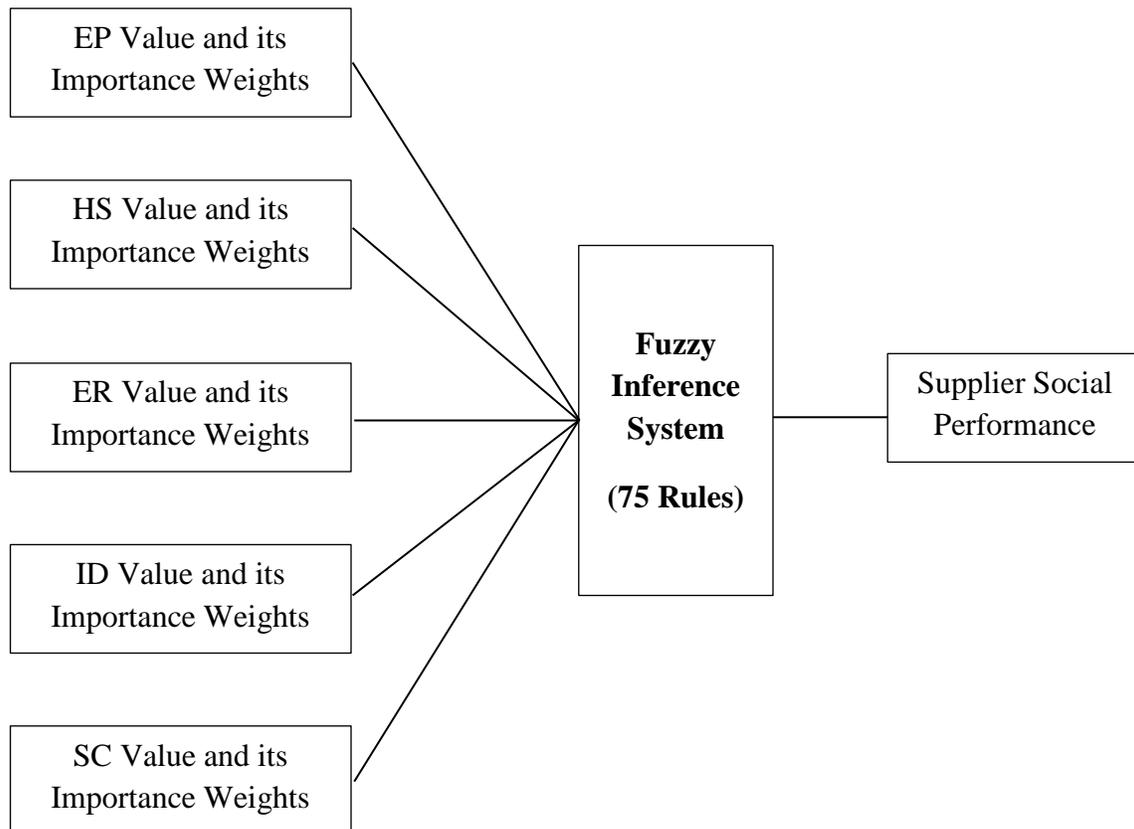
Figure 6: FIS Model for Supplier Social Performance Evaluation

Step 11: *Supplier Performance Evaluation in terms of Sustainability Dimensions*

The obtained performance criteria values and their importance weights were entered into the FIS models. The economic criteria performance ratings for each of the four suppliers (data from case company), their criteria importance weights (calculated in step 8 and mentioned in Table 5), and supplier's economic performance percentages (outputs) are shown in Table 6, with Tables 7 and 8 for environmental and social performances respectively. The FIS system were guided by some rules which were different across all three sustainability dimensions. The sample of rules are as follows:

"If cost is "low" and its importance weight is "weakly important", then supplier economic performance will be "moderately important"

If supplier financial capability is "high" and its importance weight is ""highly important", then supplier economic performance will be "strongly important".

Table 6: Supplier's economic criteria performance values, criteria importance weights and percentages

Economic Performance Criteria	Criteria Importance Weights	Supplier 1 Value	Supplier 2 Value	Supplier 3 Value	Supplier 4 Value
C	0.0303	0.600	0.600	0.900	0.300
Q	0.1087	0.900	0.900	0.900	0.600
D	0.0714	0.900	0.600	0.900	0.600
SR	0.0003	0.600	0.900	0.600	0.300
F	0.0405	0.900	0.900	0.900	0.600
FC	0.0349	0.600	0.600	0.900	0.300
Suppliers Economic Performance		**46.0%**	**43.7%**	**47.7%**	**43.2%**

Table 9: Supplier's environmental criteria performance values, criteria importance weights and percentages

Environmental Performance Criteria	Criteria Importance Weights	Supplier 1 Value	Supplier 2 Value	Supplier 3 Value	Supplier 4 Value
E	0.0357	0.600	0.300	0.600	0.900
RC	0.0216	0.600	0.900	0.900	0.600
ES	0.0709	0.900	0.600	0.900	0.300

FM	0.0184	0.600	0.600	0.900	0.300
CT	0.1151	0.300	0.300	0.600	0.300
RM	0.0349	0.600	0.600	0.300	0.900
Suppliers Environmental Performance		**37.0%**	**38.5%**	**42.5%**	**36.4%**

Table 8: Supplier' social criteria performance values, criteria importance weights and

percentages

Social Performance Criteria	Criteria Importance Weights	Supplier 1 Value	Supplier 2 Value	Supplier 3 Value	Supplier 4 Value
EP	0.0487	0.600	0.600	0.900	0.300
HS	0.1088	0.600	0.600	0.600	0.600
ER	0.0331	0.600	0.300	0.900	0.600
ID	0.1375	0.300	0.300	0.600	0.600
SC	0.0893	0.300	0.600	0.600	0.600
Suppliers Social Performance		**39.5%**	**40.6%**	**43.1%**	**43.1%**

6.4 Results analysis and discussion

XYZ company's suppliers' performances in terms of social, environmental, and economic sustainability perspectives are shown in Figure 7 and Table 9 below.
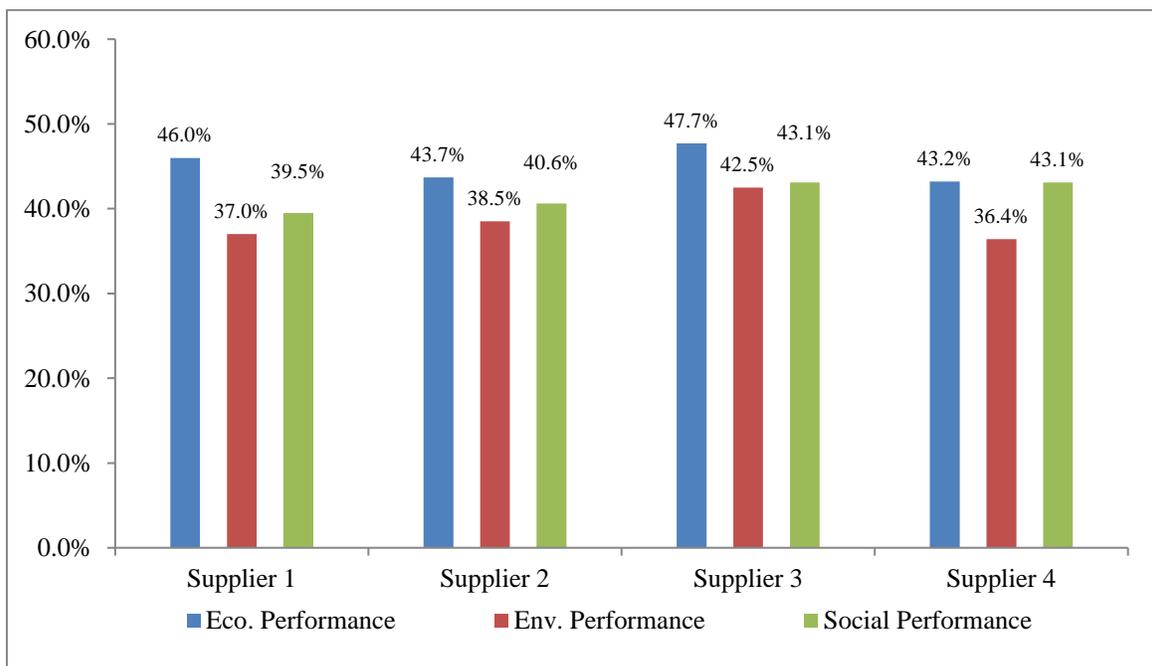
Figure 7: XYZ Company Supplier Performance

Table 9: Supplier's sustainability dimensions rankings

Suppliers	Economic Rank	Environmental Rank	Social Rank
Supplier 1	2	3	4
Supplier 2	3	2	3
Supplier 3	*1*	*1*	*1*
Supplier 4	4	4	*1*

From Figure 7 and Table 9, it clearly shows that in terms of economical sustainability perspective, supplier 3 performance is ranked the topmost (47.7%) with supplier 4 performance ranked the lowest (43.2%). From environmental sustainability perspective, supplier 3 performance again is ranked the topmost (42.5%) with two suppliers 4 performance ranked as the lowest (36.4%). Finally, in terms of social sustainability perspective, two suppliers (suppliers 3 and 4) performance are ranked the topmost (43.1% each) with supplier 1 performance ranked as the lowest (39.5%). It is also important to note from Figure 7 that within each supplier sustainability performance dimension, economic sustainability performance dimension contributions the most amongst the three followed by social and environmental sustainability performances, hence the economic sustainability performance dimension is considered the most influential sustainable performance dimension amongst the three sustainability dimensions. This findings is in support of a recent study conducted by Kusi-Sarpong et al. (2018b) that concluded that 'financial availability for innovation' of sustainability, is an important initiative that may need to be present to support other initiatives. Therefore economic performance is indeed an imperative dimension that needs the topmost priority when organization are aiming to be sustainable. This may mean that, the economic dimension of the sustainability performance may drive the sustainability goal during sustainable supplier performance decision making and program in the manufacturing industry. It may further mean that for manufacturing companies to attain higher social sustainability and subsequently superior environmental performance, economic concerns should take a center stage of their sustainability supplier decisions (Basiago, 1999; Nations et al., 2015; Seghezzo, 2009).

The results also show that, within the *economic sustainability dimension*, the three most contributing criteria to the improvement of suppliers performance include: quality (Q: 0.1087), delivery (D: 0.0714) and flexibility (F: 0.0405); within the *environmental sustainability dimension*

include: cleaner technology implementation (CT: 0.1151), environmental management systems (ES: 0.0709), air/water land emission (E: 0.0357); and within the *social sustainability dimension* include: information disclosure (ID: 0.1375), health and safety (HS: 0.1088), and social commitment (SC: 0.0893). What this mean is that, the supplier company would need to put in more efforts and resources to improve these top ranked criteria within each sustainability dimension so as to improve the dimensions' contributions to the overall sustainability.

The top three ranked criteria overall amongst the top three ranked criteria within each of the three sustainability dimensions that most improve supplier's sustainability performance include: information disclosure (ID: 0.1375), cleaner technology implementation (CT: 0.1151), and health & safety (HS: 0.1088) respectively. Among these three top criteria are two social dimension criteria reaffirm that fact that social sustainability are really an emerging concern for the manufacturing industry, especially from the emerging economies (Badri Ahmadi et al., 2017b; Mani et al., 2016a, b). "Cleaner technology implementation" stands out as a critical environmental initiative that could lead in pushing the environmental dimension of sustainability to speed (Bhupendra and Sangle, 2015). What this result means is that, if the case company decides to improve their sustainability performances in terms of economic, environmental and social perspective separately, or even aggregated, then, *suppliers 3* is preferable and recommended. Thus, supplier 3 is more appropriate for the case company to partner with in order to boost their overall sustainability (economic, environmental and social dimension) capabilities and competencies.

7. Conclusion and Future Research

7.1 Summary of findings

In the era of global pressure from diverse stakeholder groups for sustainability, industries and companies are finding ways to meet this ever increasing demand to remain highly competitive. One of the strategic ways to go and probably the starting point is to partner and work with sustainable suppliers. A sustainable supplier plays an important role in building a good organizational image for buying firms. Therefore, suppliers' sustainability performance evaluation is essential in determining and selecting the right suppliers. Supplier sustainability performance aids in enhancing over organizational supply chain sustainability performance. Yet, evaluating sustainability performance of suppliers is a challenging task. This may be partly due to the many

sustainability conflicting criteria available to these organizations. Therefore, it is essential for an organization to have appropriate sustainability tools and frameworks that incorporate all required criteria and their associated sub-criteria to measure, analyze and evaluate suppliers' sustainability performance.

In this paper, we proposed supplier performance evaluation criteria (framework) in terms of sustainability aspects (economic, social, and environmental). Literature review initially identified seven (7) economic criteria, nine (9) environmental criteria, and six (6) social criteria. These criteria were reviewed and practically validated using an automobile manufacturing industry managers' from Pakistan, an important Southeastern Asia emerging economy country. This review resulted in a final set of six (6) economic criteria, six (6) environmental criteria and five (5) social criteria. This framework was further implemented in the automobile manufacturing company to evaluate four of their key suppliers' sustainability performance in terms of the triple sustainability dimensions and ranked these suppliers. This evaluation was aided by a novel hybrid FSE and FIS based methodology. The results of the evaluation show that in terms of economic, environmental and social sustainability dimensions, *Quality*, *Cleaner Technology Implementation, Information Disclosure,* respectively are the most contributing criteria. However, overall, supplier 3 was ranked the topmost suppliers in all three sustainability dimensions, reinforcing it appropriateness as the best supplier for the case company to partner and work with should they want to boost their overall sustainability.

7.2 Implications for theory and methodology on cleaner production/sustainability

This study has implications for theory and practice on cleaner production/sustainability, which are discussed in this section.

Theoretically, this study posited a new typology of production and sustainability factors. This typology was validated and developed using inputs from Pakistani manufacturing industry managers. Although theoretically, these factors seemed to be appropriate for this subset of Pakistani manufacturers, a broader theoretical investigation is required to extend it to a broader Pakistani manufacturing and non-manufacturing setting. Additionally, given Pakistan's emerging nation status, the theoretical applicability of this typology to a broader emerging nation population is an important and needed theoretical and empirical investigation.

One of the important theoretical issues was whether previous theoretical and empirical suppositions on social sustainability's relatively lessened attention amongst the broad

26

sustainability dimensions. Unlike some previous literature (see e.g., Zhu and Sarkis, 2004; Zhu et al., 2005), the Pakistani case showed that environmental sustainability issues seemed to have less importance. Some critics of sustainability have also stated that sustainability is 'bad for the environment' (Banerjee, 2003; Esty, 2001; Sarkis, 2007). Although the literature has focused on environmental sustainability as a major emphasis in modeling and perspective, general sustainability, in practice will favor economic and other anthropocentric factors. Environmental issues, as posited by these critics, will be tertiary to the other two sustainability dimensions. In Pakistan, and arguably many emerging economy nations, the economic and social dimensions will be favored, to the detriment of the environmental issues due to issues related to poverty, joblessness, and limited social programs that could be supported through economic growth. One theoretical issues is whether this relationship will maintain as Pakistan and other emerging economy nations become more developed. This outcome of this study alters slightly our understanding of the sustainability phenomena in the literature and calls for the need for more studies, especially from the underrepresented emerging economies.

From a methodological perspective, theoretically, the integration of the tools and the outcome of the theoretical model showed that it is beneficial. This expounds on the issue of theoretically, multiple criteria approaches are valuable when considering sustainability concerns. That evidence of the need for these types of models is further supports theoretical modeling development. Although practical studies related to longitudinal results, how well these theoretical models contributed to the success of the organization, is needed.

7.3 Managerial and practical implications

The proposed framework is general in nature and can be applied in any sector regardless of their business. In addition, the methodology is capable of handling uncertainty and incorporates qualitative and vague information. Integrating these capabilities, we believe our proposed methodology is comprehensive and able to evaluate supplier sustainability performance effectively and efficiently. The proposed framework and methodology therefore can be used by managers to assess other strategic decisions such as broader business and organizational processes performance evaluation. Thus, there is flexibility in the application of both the framework and methodology. Managers and decision makers in the manufacturing industry now have a means to evaluate and rank their suppliers performance in terms of sustainability. It is a critical business decision for managers to engage the right suppliers based on sustainability in recent times. In line with the

results, industrial managers are empowered to engage the right suppliers that are reliable and responsive. This study and resulting framework allows managers in manufacturing industries the opportunities to develop and make thoughtful decisions on supplier partnerships based on the triple dimension of social, environmental and economic criteria. The practical applicability of the methodological framework provides managers in the manufacturing industry and by extension, other industries with practical and better understanding of the complete decision-making process, thereby making a more informed decision regarding sustainability.

From a practical perspective, this study have shown that, more efforts will be required for pushing the idea of sustainability into the Pakistan manufacturing sector for achieving cleaner production and sustainability even though there are some elements of motivation in there, as the economic performance was central to the sustainability performance. This higher economic performance motivation may be used as the starting point for educating and pushing practitioners about the need to put in much more efforts towards implementing sustainability initiatives as they stand to achieve more economic gains. A sector though very lucrative but lacks the necessary structures and systems for implementing cleaner production and sustainability. This study serves as an enabler for promoting and advancing their understanding and stressing the importance of the need for sustainability initiative to practitioners in the Pakistan manufacturing sector and providing them with the necessary tools for aiding and supporting the implementation of their sustainability. This promotion and motivation will help them to see sustainability initiatives as a very prudent initiative that is central to their organizational success. It was also observed that "Cleaner technology implementation" as an initiative within the environmental dimension, was the topmost and critical initiative that could lead to pushing the environmental dimension of sustainability up to speed. Practitioner may therefore channel much efforts and resources towards this initiatives as their improvement may lead to the improvement of the other environmental dimension criteria, and hence the overall sustainability

7.3 Limitations and further study

This study results are not possible without some limitations and additional research is needed. These limitations provide some rooms for improvement and provide useful basis for future research in sustainable supplier selection in particular and sustainable supply chain in general. For example, the comprehensiveness of the framework for the automobile manufacturing industry requires additional empirical investigation. Given that only a handful of managers from a single

automobile company were involved and asked their opinion, a more careful scientific evaluation considering broader respondents and organizations within this industry and region are necessitated to help determine how much of these sustainability criteria are required or practiced. Another limitation is that, the results of the study are based on a single evaluation framework (fuzzy-based Shannon Entropy-Inference System); hence, the findings are sensitive to the assumptions of these tools for the case company's suppliers' sustainability performance evaluation and selection. More tools can be applied in this case and the results compared for a final decision to be made.

Acknowledgements

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Appendix

Table A: Potential Sustainable Supplier Evaluation Criteria complied from Literature

Sustainability Aspects	Criteria	References
Economical	Cost	(Pandey, Shah, and Gajjar 2017; Badri Ahmadi et al. 2017b; De Boer, Labro, and Morlacchi 2001; Ho, Xu, and Dey 2010; Sarkar and Mohapatra 2006; Demirtas and Üstün 2008).
	Quality	(Ahmadi, Kusi-Sarpong, and Rezaei 2017b; Pandey, Shah, and Gajjar 2017; Park, Hartley, and Wilson 2001; Shu and Wu 2009; Bevilacqua, Ciarapica, and Giacchetta 2006; Jain and Khan 2017b)
	Delivery	(Pandey, Shah, and Gajjar 2017; Badri Ahmadi et al. 2017b; De Boer, Labro, and Morlacchi 2001; Aissaoui, Haouari, and Hassini 2007)
	Service Reliability	(Oliveira and Lourenço 2002; Badri Ahmadi et al. 2017b; Katsikeas, Paparoidamis, and Katsikea 2004; Yu and Tsai 2008)
	Capacity	(Badri Ahmadi et al., 2017)
	Flexibility	(Johnsen 2009; Verma and Pullman 1998; Dabhilkar et al. 2009; Ahmadi, Kusi-Sarpong, and Rezaei 2017)
	Financial Capability	(Dulmin and Mininno 2003; Berger, Gerstenfeld, and Zeng 2004; Badri Ahmadi et al. 2017b)
Environmental	Air / Water / Land Emission	(Amindoust et al., 2012; Bai and Sarkis, 2010; Lee et al., 2009)
	Resource Consumption	(Hsu and Hu, 2009; Lee et al., 2009)
	Environmental Management System	(Hsu and Hu, 2009; Seuring and Müller, 2008)
	Use of environment friendly material	(Amindoust et al., 2012)
	Cleaner Technology Availability	(Hsu and Hu, 2009; Lee et al., 2009; Pandey et al., 2017)
	Recycled Material	(Amindoust et al., 2012; Pandey et al., 2017)
	Green Packaging	(Ahmadi et al., 2017)
	Green Policy	(V Jain and Khan, 2017)
Social	Employment Practice	(Bai and Sarkis, 2010; Govindan et al., 2013)
	Health and Safety	(Amindoust et al., 2012; Bai and Sarkis, 2010)
	Employer Rights	(Matos and Hall, 2007)
	Information Disclosure	(Luthra, Govindan, and Mangla 2017)
	Social Commitment	(Hutchins and Sutherland, 2008; Matos and Hall, 2007)
	Business Ethics	(V Jain and Khan, 2017)

Table B: Potential Criteria Validation Questionnaire

Sustainability Aspect	Criteria	Brief Description	Relevant?	
			Yes	No
Economic	Cost	Cost of the product / raw materials to be purchased		
	Quality	Meeting quality requirements		
	Delivery	Delivering of products within an agreed lead time		
	Service Reliability	Delivering right product at right time		
	Flexibility	Ability to cope up with variability		
	Capacity	Capacity of supplier to cope up with future demand increase		
	Financial Capability	Financial condition and stability		
Environmental	Air / Water / Land Emission	Amount of CO_2 emission during manufacturing and delivery		
	Resource Consumption	Amount of resources consumed		
	Environmental Management System	Environmental policy and certifications		
	Use of environment friendly material	Percentage of recyclable material used during manufacturing process		
	Cleaner Technology Availability	Equipment or technology available for minimizing carbon emission during manufacturing process		
	Recycled Material	Amount of recycled material used		
	Green Packaging	Supplier behavior in promoting green recyclable material		
	Green Policy	Commitment of suppliers towards green policy		
Social	Employment Practice	Fair policy for employers and following labor laws		
	Health and Safety	Safety and health policy for employer and worker		
	Employer Rights	All employers know their rights and responsibilities and have freedom to practice their professional career		
	Information Disclosure	Companies and organizations are providing information to their customers and users about the material used, and carbon emission during manufacturing process		
	Social Commitment	Community engagement and volunteer works		
	Business Ethics	Perception of supplier in market in terms of ethics.		

Table C: Final Sustainable Supplier Evaluation Criteria Listing after Refinement by Experts

Sustainability Aspects	Criteria	Symbol	Brief Description	References
Economic	Cost	C	Cost of the product / raw materials to be purchased	(Pandey, Shah, and Gajjar 2017; Ahmadi, Kusi-Sarpong, and Rezaei 2017; De Boer, Labro, and Morlacchi 2001; Ho, Xu, and Dey 2010; Sarkar and Mohapatra 2006; Demirtas and Üstün 2008)
	Quality	Q	Meeting quality requirements	(Ahmadi, Kusi-Sarpong, and Rezaei 2017; Pandey, Shah, and Gajjar 2017; Park, Hartley, and Wilson 2001; Shu and Wu 2009; Bevilacqua, Ciarapica, and Giacchetta 2006; Jain and Khan 2017b)
	Delivery	D	Delivering of products within an agreed lead time	(Pandey, Shah, and Gajjar 2017;Ahmadi, Kusi-Sarpong, and Rezaei 2017; De Boer, Labro, and Morlacchi 2001; Aissaoui, Haouari, and Hassini 2007)
	Service Reliability	SR	Delivering right product at right time	(Oliveira and Lourenço 2002; Badri Ahmadi, Kusi-Sarpong, and Rezaei 2017; Katsikeas, Paparoidamis, and Katsikea 2004; Yu and Tsai 2008)
	Flexibility	F	Ability to cope up with variability	(Johnsen 2009; Verma and Pullman 1998; Dabhilkar et al. 2009; Ahmadi, Kusi-Sarpong, and Rezaei 2017)
	Financial Capability	FC	Financial condition and stability	(Dulmin and Mininno 2003; Berger, Gerstenfeld, and Zeng 2004;Ahmadi, Kusi-Sarpong, and Rezaei 2017)
Environmental	Air / Water / Land Emission	E	Amount of CO_2 emission during manufacturing and delivery	(Amindoust et al., 2012; Bai and Sarkis, 2010; Lee et al., 2009)
	Resource Consumption	RC	Amount of resources consumed	(Hsu and Hu, 2009; Lee et al., 2009)
	Environmental Management System	ES	Environmental policy and certifications	(Hsu and Hu, 2009; Seuring and Müller, 2008)
	Use of environment friendly material	FM	Percentage of recyclable material used during manufacturing process	(Amindoust et al., 2012)
	Cleaner Technology Availability	CT	Equipment or technology available for minimizing carbon emission during manufacturing process	(Hsu and Hu, 2009; Lee et al., 2009; Pandey et al., 2017)
	Recycled Material	RM	Amount of recycled material used	(Amindoust et al., 2012; Pandey et al., 2017)
Social	Employment Practice	EP	Fair policy for employers and following labor laws	(Bai and Sarkis, 2010; Govindan et al., 2013)
	Health and Safety	HS	Safety and health policy for employer and worker	(Amindoust et al., 2012; Bai and Sarkis, 2010)
	Employer Rights	ER	All employers knows their rights and responsibility	(Matos and Hall, 2007)

		and have freedom to practice their professional career	
Information Disclosure	ID	Companies and organizations are providing information to their customers and users about the material used, and carbon emission during manufacturing process	(S. Luthra et al., 2017)
Social Commitment	SC	Community engagement and volunteer works	(Hutchins and Sutherland, 2008; Matos and Hall, 2007)

Table D: Group Crisp Decision Matrix of SS Performance Evaluation Criteria

Sustainability Aspect	Criteria	Expert Groups			
		EG1	EG2	EG3	EG4
Economic	C	0.696	0.696	0.642	0.512
	Q	0.872	0.512	0.599	0.872
	D	0.696	0.512	0.696	0.872
	SR	0.696	0.696	0.678	0.696
	F	0.512	0.512	0.512	0.696
	FC	0.512	0.696	0.567	0.512
Environmental	E	0.696	0.872	0.611	0.696
	RC	0.512	0.512	0.642	0.512
	ES	0.696	0.696	0.456	0.512
	FM	0.872	0.696	0.767	0.872
	CT	0.512	0.872	0.567	0.512
	RM	0.696	0.512	0.567	0.512
Social	EP	0.512	0.696	0.512	0.696
	HS	0.512	0.872	0.512	0.696
	ER	0.696	0.696	0.512	0.696
	ID	0.872	0.696	0.456	0.512
	SC	0.512	0.872	0.696	0.872