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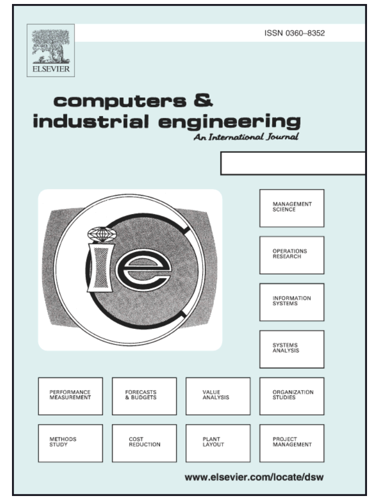

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Alireza Fallahpour, Ezutah Udoncy Olugu, Siti Nurmaya Musa, Kuan Yew Wong, Samira Noori

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A decision support model for sustainable supplier selection in sustainable supply chain management

Full author names: Alireza Fallahpour*[1], Ezutah Udoncy Olugu[1], Siti Nurmaya Musa[1], Kuan Yew Wong[2], Samira Noori[1]

Full institutional mailing addresses: [1]Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia.

[2]Department of Manufacturing and Industrial Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Malaysia.

Alireza Fallahpour: alirezafallahpour@siswa.um.edu.my; Fallahpour.a@gmail.com; +60173274393; +989030522113

Ezutah Udoncy Olugu: olugu@um.edu.my ; +603-79675330

Siti Nurmaya Musa: nurmaya@um.edu.my ; +603-79675317

Kuan Yew Wong: wongky@mail.fkm.utm.my ; +60 7-5534691

Samira Noori: n.samira326@gmail.com

Abstract

This study is aimed at developing the most important and applicable criteria and their corresponding sub-criteria for sustainable supplier selection through a questionnaire-based survey. In addition, a hybrid model is proposed to identify the most sustainable supplier with respect to the determined attributes using an Iranian textile manufacturing company as case study. The first contribution of the research is developing a comprehensive list of sustainability criteria and sub-criteria and incorporating them into a questionnaire and distributing the questionnaire to academics and practitioners for establishing the importance and applicability of these criteria and sub-criteria. In order to demonstrate the robustness of the data obtained from the questionnaire, different established statistical tests (Cronbach's alpha and Mann-Withney U-Test) were applied. The results show that economic aspect is still the most essential aspect, followed by environmental aspect and finally social aspect. The second contribution is the development of a new hybrid model by integrating fuzzy preference programing, as one of the newest and most accurate fuzzy modification of Analytical Hierarchy Process, with Fuzzy

Technique for Order of Preference by Similarity to Ideal Solution. Fuzzy Preference Programming overcomes the shortcomings of the previous methods for obtaining the weight and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution prioritizes the suppliers and finds the best one under uncertainty. Generally, the developed list provides a basis that is helpful in improving suppliers' performance in terms of sustainability which leads to improvement in sustainable supply chain management performance. In addition, the developed hybrid model can deal with inconsistency, uncertainty and calculation complexity. Generally, the framework (including the first and second objectives) can be applied by managers to evaluate and determine their appropriate suppliers in the presence of uncertainty.

Key words: *sustainable supplier selection; questionnaire-based survey; Importance and applicability; Fuzzy Preference Programming.*

1. Introduction

Supply chain management (SCM) comprises all the activities related to the transformation and flow of goods and services, including their attendant information flows, from the sources of the materials to the end users (Büyüközkan et al., 2011). Efficient SCM has been identified as beneficial to organizations through improvement in competitive advantage, reduction in supply chain risk, reduced production risk, increased revenue, improved customer service, optimized inventory level, and increased customer satisfaction and profitability (Boran et al., 2009; Chang et al., 2011). In the past two decades, environmental and social concerns have received significant attention as part of sustainable development initiative. Hence, sustainability has become very important to organizations (Govindan et al., 2013a; Chiarini, 2012). As an extremely important issue for business, SSCM can be regarded as an approach that includes the management of material, information and capital flows, as well as cooperation among companies along the supply chain, while taking into account the goals from all three dimensions (economic, environmental and social) of sustainable development derived from customer and stakeholder requirements (Amindoust et al., 2012); Büyüközkan et al., 2011).

Suppliers selection has been identified as one of the most critical issues in SSCM (Sarkis et al., 2014; Maria Vanalle and Blanco Santos, 2014). Tseng et al. (2009) stated that selecting suitable supplier is a very difficult issue in the field of SCM because it includes criteria and decision making methods which are characterized with complexity and uncertainty. Generally, it has been reported in literature that there are two main issues in supplier selection which are determining the most suitable criteria and their corresponding sub-criteria, and developing appropriate and accurate model for performance evaluation and ranking (selection). Many studies have been carried out for proposing solo or hybrid models for sustainability assessment and prioritization. Also, there are some studies for providing an appropriate list of sustainability attributes using different methods. However, there is a lack of focus on both developing a comprehensive list of sustainability criteria and sub-criteria as well as measuring their importance and applicability and proposing a robust and integrated model for suppliers' performance evaluation and selection. Therefore, the research questions of this study are:

i) Which set of criteria and sub-criteria is most important and applicable in the evaluation of suppliers' sustainability performance?

ii) How an integrated model can be developed to weigh and evaluate the sustainability performance of suppliers in the presence of uncertainty?

Providing a list of suitable sustainable criteria and their corresponding sub-criteria is an issue which needs more attention in this regard. Generally the literature on supplier selection reports that few studies have been conducted to determine the most important attributes for evaluating and/or ranking suppliers' performance (Dickson, 1996; Weber et al., 1991). However, there is dearth of research specifying the most important and applicable sustainable criteria and their-corresponding sub-criteria. Thus, the first contribution of this research is to determine the importance and applicability of the sustainable attributes through a questionnaire-based survey as a systematic method. This is followed by the demonstration of the robustness of the data obtained from the questionnaire using established statistical tests such as Cronbach's alpha and Mann-Withney U-Test. Since sustainable supplier selection comprises ambiguity and fuzziness in real life, hence fuzzy-based decision making models would be necessary to deal with imprecision and vagueness for selecting the best suppliers in a real life case study. Moreover, the literature shows that the relative weights of sustainability criteria were not considered in most of the methods (Singh et al., 2015b).

It has been shown in the literature that there are two categories for deriving weights. The methods in the first category provide a set of fuzzy weights from a fuzzy pairwise comparison matrix. These includes geometric mean method, fuzzy logarithmic least-squares method (LLSM) and Lambda–Max method. On the other hand, the second category provides a set of crisp weights from a fuzzy pairwise comparison matrix. Examples include extent analysis and fuzzy preference programming (FPP). The methods in the first category have their advantages as well as their disadvantages. For example, the computational process of geometric mean method is tremendous (Bozbura et al., 2007). In LLSM, the calculation process is tremendous and only triangular fuzzy numbers are used Büyüközkan et al.(2004). Lambda–Max method gives a series of non-normalized interval eigenvector weight estimates through an iterative solution process and needs to transform a fuzzy comparison matrix into a series of interval comparison matrices using α-level sets and the extension principle and therefore needs the solution of a series of eigenvalue problems (Wang et al., 2006).

In general as the fuzzy weights derived from the methods in the first category are not as easy to calculate as the methods in the second category, most of the researchers prefer to use the simple extent analysis method proposed by Wang et al. (2011) for fuzzy AHP weight derivation due to its simplicity. However, Wang et al.(2008) stated that the weights of the attributes and the alternatives calculated by this method are invalid. In contrast, the weights derived from the FPP method are more accurate, its computation process is easy and this method has a natural consistency indicator (Mikhailov, 2004).

Furthermore, various ranking methods have been developed for supplier selection. Nowadays, managers/decision makers attempt to use those models which are applicable and able to deal with uncertainty and ambiguity. In this paper, FTOPSIS is applied for supplier selection because it distinguishes between benefit (the more the better) and cost (the less the better) category attributes and chooses solutions that are close to the positive ideal solutions and far from the negative ideal solutions. In addition, as compared to TOPSIS, FTOPSIS is used for prioritization because it enables managers to incorporate uncertainty in their assessments and the calculation process is not tremendous. Moreover, it can be said that although FAHP and FANP are the two most widely used alternatives for ranking and selection, extra pairwise comparison matrixes are needed for alternative selection in both methods. Therefore, FTOPSIS is more practical when compared with these models.

The second contribution of this research is to develop an integrated MCDM model using a combination of FPP with FTOPSIS. For this objective, a real case study is selected. The suppliers of the company are evaluated on the basis of the determined attributes (in the first objective of this study). The relative weight of each attribute is calculated using FPP. Afterward, the best suppliers ranked by applying FTOPSIS. Also, the validity of the model is investigated to show the robustness of the model.

The remainder of this study is as follows: The literature review is presented in the second section. The methodology including the questionnaire-based survey for measuring the importance and applicability of the developed list of sustainable criteria and proposed FPP-FTOPSIS model (including overview of the FPP and FTOPSIS, aggregation method and model) is presented in the third section. In section four, the real case study, results of the implementation of the model, validity of the model and result analysis are presented. In the next section, the managerial implications are shown. The study culminated with a conclusion.

2. Literature

This section consists of three sub-sections. The first presents a brief overview of SSCM. The second presents a brief overview of supplier selection models and application of FPP in decision making while in the third the most important sustainable criteria are presented.

2.1. A brief overview of SSCM

SSCM is defined as the management of material and information flows as well as cooperation among organizations along the supply chain network while taking into account the economic, environmental and social criteria into account Govindan et al.(2013a); Lin et al.(2016). By controlling sustainability factors, a firm takes a responsible position on economic prosperity, environmental quality, and social justice (Bai et al. (2010). Therefore, many researchers have recently investigated SSCM Azadi et al. (2015); Azadnia et al. (2012); Ghadimi et al. (2014); Sarkis et al. (2014); Tseng et al. (2015).

Although various approaches have been adopted in the study of SSCM, it is obvious that the social aspect of sustainability has not received the desired attention (Seuring, 2013). On the environmental aspect, life-cycle assessment based approaches and impact attributes clearly dominate the research conducted so far. For a complete review of SSCM, see Hassini et al. (2012), Seuring (2013) and Seuring et al. (2008).

2.2. MCDM techniques in supplier selection and application of FPP in decision making

Since suppliers can be assessed from several different viewpoints, various MCDM models have been proposed for supplier selection (Fallahpour et al., 2016; Fallahpour et al. 2015); Kazemi et al. 2014); Kazemi et al. , 2015); Lin et al. , 2010); Tavana et al., 2016); Tseng ,2011); Vahdani et al., 2012) . Some of the latest research pertaining to the supplier selection are listed in this section.

Dobos et al. (2014) used Data Envelopment Analysis (DEA) to assess the performance of suppliers on the basis of environmental criteria. Roshandel et al.(2013) proposed a Hierarchy FTOPSIS (HFTOPSIS) to assess and rank suppliers. The proposed model was used to rank and select the best one based on 25 influential attributes. Wu (2009) integrated DEA with Artificial Neural Networks (ANN) to propose a predictive model for determining the suppliers' efficiency score. In that model, after collecting a data set, the efficiency score of each alternative was evaluated using DEA. Then, a Multi-Layer Perceptron (MLP) ANN-based model was provided to predict the suppliers' efficiency.

Fallahpour et al. (2015) proposed a hybrid model for supplier selection based on the green attributes. In that study, DEA was combined with Genetic Programming (GP) to both introduce GP as a new robust predictive model in the field of supplier selection and solve the black box problem of ANN in this regard. In that model, after determining suitable environmental attributes, the data set was collected using triangular fuzzy number. Afterwards, the suppliers' environmental efficiency was assessed using the Kourosh and Arash Method (KAM) (as a new model of DEA). Then, using GP, a mathematical model was derived for the suppliers' efficiency based on the determined criteria. In order to demonstrate the validity of the model, the results were compared with the results obtained by DEA-ANFIS. Dou et al. (2014) proposed a grey ANP method to determine green supplier development programs that would improve suppliers' performance. The approach used ANP to determine the weights of attributes and prioritize the green supplier development programs. Afterward, the grey aggregation method was performed to assess the suppliers' involvement propensity in different green supplier development programs.

Büyüközkan et al. (2011) proposed a framework by combining fuzzy logic and ANP to prioritize sustainable suppliers. The model not only evaluated the suppliers' performance, but also maintained the consistency level of the assessment. Kang et al.(2012) proposed a FANP model to assess various aspects of suppliers. In that research, the criteria weight and the ranking of the suppliers were obtained using FANP. Amindoust et al. (2012) proposed a Fuzzy Inference System (FIS) for sustainable supplier selection. First the evaluation criteria based on the literature were determined. Then, using MATLAB software, the FIS rules were developed for evaluating the suppliers' performance. Carrera et al. (2008) developed a FIS structure for assessing the supplier selection process.

From the literature, it has been reported that AHP is one of the most well-known and common techniques used in this area. In supplier selection, AHP has been used for both criteria weight determination and performance evaluation. For instance, Kannan et al. (2013) combined FAHP with TOPSIS to rank suppliers' with respect to environmental attributes. Then, they proposed a linear model for order allocation. They stated that their model is the first model to consider green supplier selection and order allocation. Mani et al. (2014) concentrated on socially sustainable supplier selection through social factors using AHP in decision making. Shaw et al. (2012) proposed an integrated supplier selection model for developing a low carbon supply chain. In this model, the weights of the factors were calculated by FAHP. Then, the weights were applied in fuzzy multi-objective linear programming for supplier selection and quota allocation. The proposed model can help decision makers with uncertain information.

The AHP-based models for supplier selection are very useful in decision making. However the findings show that AHP eigenvalue prioritization technique cannot be used when the managers encounter a complicated and uncertain problem and express their comparison judgments as uncertain ratios, such as ''about two times more important'', ''between two and four times less important'', etc (Mikhailov et al. 2004); Wang et al. 2010). Thus, the conventional AHP is not very useful in the presence of uncertainty. In this study, FPP as a fuzzy modification of AHP is used to achieve the relative weights of criteria and then the FTOPSIS is performed to prioritize the suppliers. The following paragraph presents the application of FPP in decision making. FPP has been applied in different areas for decision making. Mikhailov and Tsvetinov (2004) used FPP to evaluate the service process. Price, delivery and service quality were determined as the evaluating criteria. After gathering the data set, the best alternative was selected using FPP. Mikhailov (2002) and Kaur et al. (2010) applied FPP in the same way to rank and choose the best partnership in the formation of virtual enterprises and vendor selection, respectively. Chamodrakas et al. (2010) modified the FPP to select appropriate suppliers. They implemented their FPP-based model in an electronic company.

2.3. Supplier selection criteria

One of the main challenges in the supplier evaluation process is to choose the right criteria. The criteria in sustainable supplier selection are determined based on the three aspects known as economic, environmental and social. In economic aspect, literature reports that different criteria have been used for supplier selection. Dickson (1966) was the first to identify 23 attributes that purchasing agents and managers in the United States and Canada preferred to use for evaluating suppliers' performance.Weber et al. (1991) conducted a review of 74 articles published from 1966 to 1990. The authors highlighted that Cost/Price, Delivery and Quality were the most important criteria in assessing suppliers. Ho et al. (2010) suggested that the most widely adopted criteria for supplier selection were quality, delivery, price (or cost), manufacturing capability, service, management, technology, research and development, finance, flexibility, reputation, relationship, risk, and safety and environment respectively. In terms of environmental aspect, Govindan et al. (2013b) carried out a literature review survey and showed that environmental management system is the widely used environmental criterion followed by green image, environmental performance, design for environment, green competencies, environmental improvement cost, ISO 1400, green product and so on. In terms of social aspect, numbers of criteria have been determined which can be summarized as discrimination, long working hours, human rights, health and safety, information disclosure, the rights of stakeholders, employment practices (Amindoust et al., 2012; Azadi et al., 2015; Ghadimi et al. (2014); Goebel et al. (2012); Govindan et al. (2013a); Mani et al. (2014).

3. Methodology

This section contains two main sub-sections. The first sub-section is about the questionnaire-based survey for establishing the importance and applicability of the criteria and their corresponding sub-criteria. In the second sub-section, the developed MCDM model is clearly explained.

3.1. The sustainable supplier selection criteria

The first objective of this study is to develop a list of most important and applicable sustainability criteria (in each of the aspects of economic, environmental and social) and their correspondent sub-criteria for supplier selection. Figure 1 depicts the process. A list of the refined main criteria and their corresponding sub-criteria for each of the aspects are developed based on the literature and opinions of the panel of this study (it should be mentioned that based on the opinions of the experts panel, some criteria like Service and Delivery were combined together and introduced as Delivery & Service, and the sub-criteria of pollution control was considered in main criterion of Green Product. In addition, in economic aspect for criterion of Flexibility, new sub-criteria were defined according to the experts' opinions).

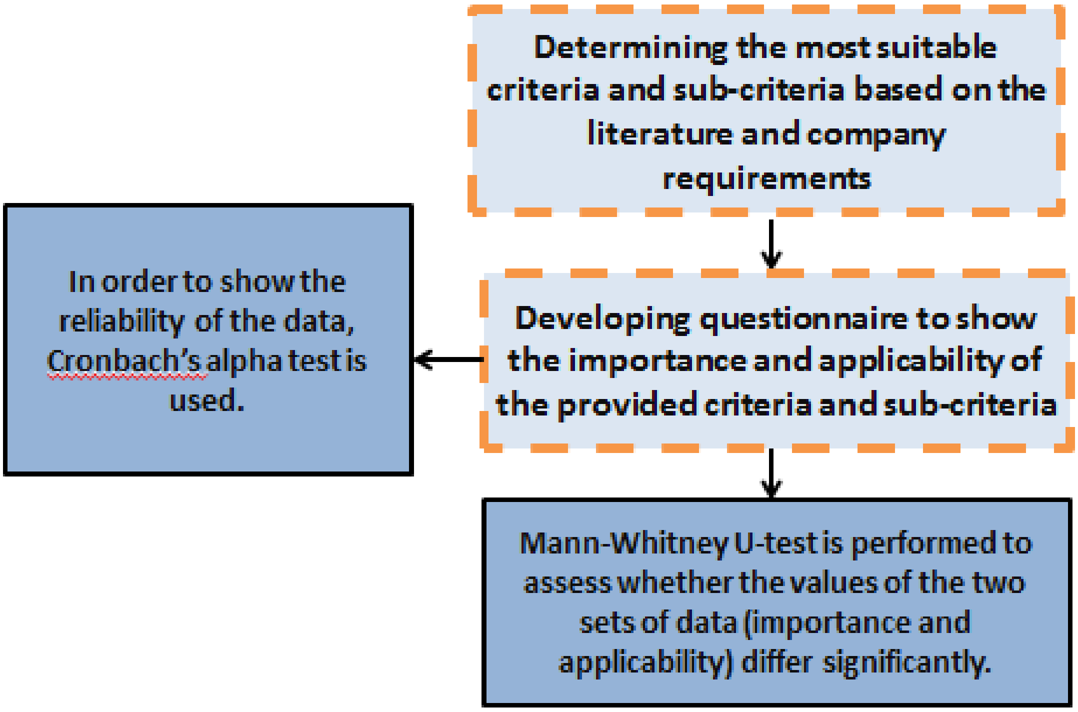

Figure 1.The process of developing the criteria and sub-criteria

In this research, 13 main criteria with 46 sub-criteria were selected for the 3 aspects (Amindoust et al., 2012; Azadi et al., 2015; Azadnia et al., 2012; Büyüközkan et al., 2011; Dobos et al. 2014; Govindan et al., 2013a; Kannan et al., 2015; Rostamzadeh et al., 2015; Sarkis et al., 2014; Shen et al., 2013). The following section defines all the main criteria and sub-criteria (Table A1[1] gives the definition of each sub criterion). It should be noted that in front of each sub-criterion, its effect (advantage/disadvantage or benefit /cost) on the evaluation is given.

3.1.1. The attributes of the economic aspect

In this research, four main criteria were selected as the economic attributes such as Cost (C), Quality (Q), Delivery & Service (DS) and Flexibility (F). The definition of each of the main criteria is given in the following section.

3.1.1.1. Cost (C_1): The factor that shows all the expenditures related to the materials (goods) supplied by supplier. The following sub-criteria were applied in this study for this criterion:

- Material cost ($C_{1,1}$) Fallahpour et al.(2015); Grisi et al. (2010) (disadvantage)
- Freight cost ($C_{1,2}$) FeyzioğLu et al. (2010); Kuo et al. (2010) (disadvantage)
- After sales service cost ($C_{1,3}$) (Yan (2009) (disadvantage)

[1] Please see appendix A

3.1.1.2. Quality(C_2): The excellence ability of supplied materials to meet or exceed purchasers' expectations (Fallahpour et al., 2015). The following sub-criteria were applied in this study for this criterion:

- Rejection Rate of the Product ($C_{2,1}$) FeyzioğLu et al. (2010) (disadvantage)
- Capability of Handling Abnormal Quality ($C_{2,2}$) Lee et al. (2009) (advantage)
- Process for Internal Quality Audit of Material ($C_{2,3}$) Grisi et al. (2010) (advantage)

3.1.1.3. Delivery & Service (C_3): The factor that shows the effort of supplier in delivering the needed material and solving the problems related to the supplied goods to the customer. The following sub-criteria were applied in this study for this criterion:

- Lead Time flexibility ($C_{3,1}$) (Yang et al. , 2008; Yuzhong et al. (2007) (advantage)
- After Sales Service ($C_{3,2}$) Yan (2009) (advantage)
- Time to Solve the Complaint ($C_{3,3}$) Yang et al. (2008); Yuzhong et al. (2007) (disadvantage)
- On-Time Delivery ($C_{3,4}$) (advantage)

3.1.1.4. Flexibility C_4: The factor that shows the level of the flexibility of supplier in supplying material, price of the supplied material, etc. The following sub-criteria were applied in this study for this criterion:

- Flexibility in Giving Discount ($\boldsymbol{C_{4,1}}$) (advantage)
- Flexibility of Delivery Time ($C_{4,2}$) (advantage)
- Flexibility in Ordering ($C_{4,3}$) (advantage)

3.1.2. The attributes of the environmental aspect

Over the past few decades, environmental issues have received much attention from governments, public and researchers. In this research, six main criteria were selected as the environmental attributes such as Environmental Management System (Env.M.S), Green Product (G.P), Green Warehousing (G.W), Eco-Design (Eco.D), Green Technology (G.Te) and Green Transportation (G.Tr). The definition of each of the main criterion is given in the following section.

3.1.2.1. Environmental Management System (Env.M.S) $(\boldsymbol{C_5})$**:** The factor that shows the effort of supplier in environment management (Tseng, 2011). The following sub-criteria were applied in this study for this criterion:

- ISO-14001 certification ($C_{5,1}$) Chen et al. (2010); Chiou et al. (2008); Humphreys et al. (2006); Lee et al. (2009) (advantage)
- Environmental Performance Evaluation ($C_{5,2}$) Thongchattu et al. (2010) (advantage)
- Eco-Labeling ($C_{5,3}$)(Chiou et al. , 2008; Mahmood et al., 2013) (advantage)
- Environment-Friendly Raw Materials ($C_{5,4}$) (Awasthi et al., 2010; Humphreys et al., 2006); Paul Humphreys et al., 2003; Yang et al., 2008) (advantage)

3.1.2.2. Green product $(\boldsymbol{C_6})$**:** The factor that shows the effort of supplier in producing green products. The following sub-criteria were applied in this study for this criterion:

- Green certification ($C_{6,1}$) Tseng (2011) (advantage)
- Reuse ($C_{6,2}$) (Büyüközkan et al. , 2011; Handfield et al. 2002; Humphreys et al. 2003; Humphreys et al. 2003) (advantage)
- Green Packaging ($C_{6,3}$) (Büyüközkan et al. 2011; Chiou et al. , 2008) (advantage)
- Air Emissions ($\boldsymbol{C_{6,4}}$) (Humphreys et al. , 2003; Humphreys et al.,2003; Lee et al. 2009; Noci, 1997) (disadvantage)
- Waste Water ($C_{6,5}$) (Humphreys et al, 2003; Humphreys et al., 2003; Noci, 1997) (disadvantage)
- Hazardous Wastes ($C_{6,6}$) (Kannan et al., 2015) (disadvantage)

3.1.2.3. Green warehousing $(\boldsymbol{C_7})$**:** This shows the effort of supplier to minimize costs and increase social responsibility by warehousing the raw materials and generally all the needed materials for the companies based on carbon footprint consideration (Rostamzadeh et al., 2015). The following sub-criteria were applied in this study for this criterion:

- Inventory of Non-Hazardous Substances ($C_{7,1}$) (advantage)
- Inventory of Substitute Material ($C_{7,2}$) Hsu et al. (2007, 2009) (advantage)
- Warehouse Management ($C_{7,3}$) Hsu et al. (2007, 2009) (advantage)

3.1.2.4. Eco-design $(\boldsymbol{C_8})$**:** This measures the effort of supplier to conduct activities that aim to minimize environmental impacts of products during their entire life cycle (Rostamzadeh et al. (2015). The following sub-criteria were applied in this study for this criterion:

- Recycle of Products when Design ($\boldsymbol{C_{8,1}}$) Bin et al. (2010); Kannan et al. (2015) (advantage)
- Re-Manufacturing of Products when Design ($C_{8,2}$**)** Handfield et al. (2002); Kannan et al. (2015) (advantage)
- Reduction of the use of Hazardous Materials when Design ($C_{8,3}$**)** Bin et al. (2010) (advantage)

3.1.2.5. Green Transportation (C_9): This factor shows the effort of supplier to minimize the environmental pollution while conveying the needed order. The following sub-criteria were applied in this study for this criterion:

- Using a Modern Eco-efficient Transportation fleet like energy efficient Vessels and high Euro norms for trucks ($C_{9,1}$) Rostamzadeh et al. (2015). (advantage)
- Using Green Fuels with low sulfur content, and alternative fuels like liquid natural gas ($C_{9,2}$) Rostamzadeh et al. (2015).(advantage)

3.1.2.6. Green Technology (C_{10}): The factor that shows the effort of supplier in producing green products (Lee et al., 2009). The following sub-criteria were applied in this study for this criterion:

- Materials Used in the Supplied Components that reduce the impact on natural resources ($\boldsymbol{C_{10,1}}$) Kannan et al. (2015); Lee et al. (2009) (advantage)
- Capability of R&D ($C_{10,2}$) Chen et al. (2010); Lee et al. (2009) (advantage)
- Ability to alter process and product for reducing the impact on natural resources ($C_{10,3}$) (Li et al. (2009) (advantage)

3.1.3. The attributes of the social aspect

In this research, the social attributes were divided into three parts including Workers' Rights (WR), Health and Safety at Work (HSW), and Supportive Activities for the Workers (SAW). The definition of each of the main criterion is given in the following section (Bai et al. (2010); Govindan et al. (2013a); Nikolaou et al. (2013) .

3.1.3.1. Workers' Rights (C_{11}): The factor that shows workers have rights at work. The following sub-criteria were applied in this study for this criterion:

- Workers' contract ($C_{11,1}$) (advantage)
- Employment insurance ($C_{11,2}$) (advantage)
- Employment compensation ($C_{11,3}$) (advantage)
- Standard working hours ($C_{11,4}$) (advantage)
- Overtime pay ($C_{11,5}$) (advantage)

3.13.2. Health and Safety at Work (C_{12})

This represents the effort of the suppliers to safeguard the health and safety of workers at work. The following sub-criteria were applied in this study for this criterion:

- Health Insurance at Work ($C_{12,1}$) (advantage)
- Training for Safety at Work ($C_{12,2}$) (advantage)
- Providing Appropriate Equipment at Work ($C_{12,3}$) (advantage)

3.1.3.3. Supportive Activities (C_{13})

This demonstrates the supplier's support and motivational activities at work. The following sub-criteria were applied in this study for this criterion:

- Discrimination ($C_{13,1}$) (disadvantage)
- Growth at Work ($C_{13,2}$)) (advantage)
- Wages ($C_{13,3}$) (advantage)
- Attention to Religious and Cultural Issues at Work (such as praying, fasting, etc.) ($C_{13,4}$)) (advantage)

3.1.4. Questionnaire development

After developing a comprehensive list of criteria and sub-criteria, a questionnaire is developed to show how much the criteria and sub-criteria are important and applicable. The questionnaire contained four sections. The first part includes questions for obtaining the background of the respondents. The second, third and fourth parts consist of the economic, environmental and social criteria and their sub-criteria, respectively. Importance level represents the degree of perceived importance placed on the sub-criteria, while applicability shows whether they can be applied or used in practice. A Likert scale from 0 to 5 was adopted ; where 0 = no idea, 1 = very low, 2 = low, 3 =moderate, 4 = high, and 5 = very high.

The questionnaire was sent to seven experts from academia and industry to conduct content validation to ensure that the content was correct and will be able to serve the desired purpose. The comments and feedback from the experts were applied to revise the questionnaire. After the revision, the questionnaires were sent back to the same experts and they all indicated their agreement.

Once the development of the questionnaire was completed, it was sent to 150 experts from academia (80 out of 150; 53.33%) and industry (70 out of 150; 46.67%) chosen as potential experts to evaluate sub-criteria. All the responses were received within 35 days from the starting date. Of the 150 questionnaires mailed, 23 were completed and returned (industry: 10 out of 23 (43.47%) and academia: 13 out of 23 (56.52%)). As the two ratios are relatively similar, and the completed and returned questionnaires represent 15.33% of the overall sample, it could be considered as a suitable level as can be observed from Gunasekaran et al. (2004) and Olugu et al. (2011). As earlier mentioned, the respondents were asked to evaluate the sub-criteria. Hence, an average mean value was used for each of the criteria to show their level of importance and applicability. The results are presented in the following paragraphs. Table 1 presents the mean values of importance and applicability of each criterion.

Table 1. The means values of importance and applicability of each criterion

Economic aspect							
Cost*		Quality*		Delivery and Service		Flexibility	
Imp	Appl	Imp	Appl	Imp	Appl	Imp	Appl
4.13	4.32	4.41	4.39	4.05	4.09	3.96	3.85

Environmental aspect					
Env.M.S		G*- Product		G-Warehousing	
Imp	Appl	Imp	Appl	Imp	Appl
3.81	3.81	3.5	3.73	3.38	3.52
Eco-Design		G- Transportation		G-Technology	
Imp	Appl	Imp	Appl	Imp	Appl
3.27	3.41	3.15	3.26	3.22	3.40

Social aspect					
Workers' rights		Health and safety		Supportive activities	
Imp	Appl	Imp	Appl	Imp	Appl
3.73	4.07	3.58	3.79	3.19	3.66

***=Imp: Importance; Appl: Applicability; G: Green**

It is worth noting that after gathering the data set, the reliability test was carried out to make sure that the instrument and data collected were reliable for further analysis. According to the literature, Cronbach's alpha is the most widely used test to demonstrate the internal reliability of indicators for a specific scale. Both importance and applicability have thirteen (13) criteria for economic, environmental, and social aspects. All criteria underwent an internal reliability assessment using Cronbach's internal reliability coefficient alpha. The test was run in two stages; the first stage was to test the reliability of the importance of the data set and second stage was carried out to test the reliability of the applicability of the data set.

In terms of importance of the data set, the results of running an internal reliability assessment test using Cronbach's alpha revealed all the 13 criteria to have an alpha value higher than the recommended value of 0.70 as suggested by Ferketich (1990). Applicability data set showed alpha values above the recommended value of 0.70. Table 2 shows the summary of results of alpha values for both importance and applicability data sets.

Table 2. Reliability Test (Cronbach's alpha values)

Economic aspect							
Cost		Quality		Delivery & Service		Flexibility	
Imp*	Appl*	Imp	Appl	Imp	Appl	Imp	Appl
0.817	0.793	0.801	0.823	0.814	0.846	0.843	0.861

Environmental aspect					
Env.M.S		G*- Product		G-Warehousing	
Imp	Appl	Imp	Appl	Imp	Appl
0.907	0.872	0.769	0.856	0.9	0.789
Eco-Design		G-transportation		G-Technology	
Imp	Appl	Imp	Appl	Imp	Appl
0.823	0.866	0.787	0.879	0.808	0.844

Social aspect					
Workers' rights		Health and safety		Supportive activities	
Imp	Appl	Imp	Appl	Imp	Appl
0.849	0.784	0.833	0.8	0.761	0.919

G: Green; Imp: Importance; Appl: Applicability

Another statistical analysis, Mann–Whitney U-test was conducted to assess whether the mean scores of the two sets of data (importance and applicability) differ significantly. SPSS software was applied to conduct this non-parametric test. Since the Mann–Whitney U-test is done on ranked scores, the data for the two groups do not have to be normally distributed Olugu et al. (2011). All the main criteria of the three aspects were assessed using this test and the p value of each of them was greater than 0.05 (if the p value is less than 0.05 it means there is a significant difference between the data sets). The results show that there is no significant difference between the mean scores of the two data sets. Therefore, it can be said that there is a strong correlation between the importance and applicability of the listed criteria.

3.2. The proposed FPP-FTOPSIS

This sub-section comprises four parts. In the first three parts, overviews of the FPP, FTOPSIS, and aggregation method are presented. In the last part, the proposed integrated model is described in detail.

3.2.1. FPP for determining the criteria weight

The FPP was developed as an accurate method for measuring the inconsistency of decision makers' judgments. Kaur et al (2010) stated that this method outperforms some of the existing prioritization techniques such as fuzzy geometric mean method, fuzzy logarithmic least square method, fuzzy arithmetic mean and so on. The following steps can summarize the procedure for applying FPP for calculating the weights (Wang et al., 2010):

1. Forming the problem like a hierarchy:

   This step is aimed at building a hierarchy comprising the goal, attributes and alternatives.

2. Providing the fuzzy judgment pairwise comparison matrix for the criteria:

   This step consists of providing comparison matrices for comparing the attributes.

$$A = \begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & \tilde{a}_{nn} \end{bmatrix} \quad (1)$$

Where $\tilde{a}_{ij}$ is a Triangular Fuzzy Number (TFN) to illustrate the decision makers' idea of i over j and $\tilde{a}_{ij}$ = 1/$\tilde{a}_{ij}$. In the following paragraphs definitions of TFN is given.

Definition 1. Assume $\tilde{A}$ is a fuzzy set in a universe of discourse X and membership function $\mu_{\tilde{A}}(x)$ describes it .This function is related to each element x, where $\mu_{\tilde{A}}(x)$ belongs to the interval [0, 1]. The function value $\mu_{\tilde{A}}(x)$ is termed as the degree of membership of x in $\tilde{A}$.

Definition 2. The fuzzy set $\tilde{A}$ is both normal and convex, which means that the ''Normality'' hints that;

$$\exists x \in X, \quad \mu_{\tilde{A}}(x) = 1 \tag{2}$$

And by convex it means;

$$\forall x_1 \in X, \ \forall x_2 \in X, \ \forall \alpha \in [0, 1],$$

$$\mu_{\tilde{A}}(\alpha x_1 + (1-\alpha)x_2) \geq min(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2)) \tag{3}$$

Definition 3.

N is defined to be a triangular fuzzy number represented by a triplet (l, m, u). Where, $l < m < u$, when its membership function is considered as:

$$\mu_N(x) = \begin{cases} \frac{x-l}{m-l}, & l \leq x \leq m, \\ \frac{u-x}{u-m} & m \leq x \leq u, \\ o, & Otherwise, \end{cases} \tag{4}$$

Where *l*, *m* and *u* are considered as the lower bound, modal bound and upper bound, respectively. The triangular fuzzy number $N$is often given as (*l*, *m*, *u*). In this research the TFNs shown in Figure 2 is performed for the comparisons. In addition, Table 3 a summary of the fuzzy linguistic variable set[2] with TFN for assisting comparisons has been proposed.

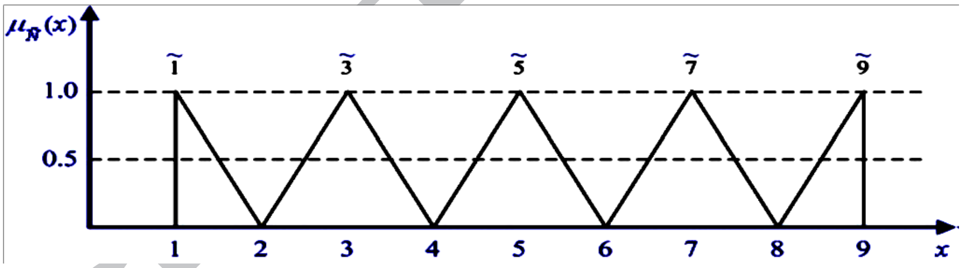

Figure 2. TFN for comparison

Table 3. Linguistic variables for importance of aspects and criteria for FAHP-FPP comparisons

Fuzzy Number	Linguistic variables	TFN
$\tilde{1}$	**Equally important**	(1,1,2)
$\tilde{3}$	**Moderately important**	(2,3,4)
$\tilde{5}$	**Essentially important**	(4,5,6)
$\tilde{7}$	**Very strongly important**	(6,7,8)
$\tilde{9}$	**Absolutely important**	(8,9,9)
$\tilde{2}, \tilde{4}, \tilde{6}, \tilde{8}$	**Intermediate value between two adjacent judgments**	

3. Deriving the crisp weights vector $W = (W_1, W_2, \ldots, W_n)^T$ using FPP. In this step, the purpose is to calculate the relative weight of the attributes $w = (W_1, W_2, \ldots, W_n)^T$such that the ratios W_i/W_j are

[2]This is a set whose values (namely linguistic values) have the form of phrases or sentences in a natural language (Tseng, 2010).

approximately within the scopes of the pair wise judgment $\tilde{a}_{ij}$, or equivalently Rezaei et al. (2013):

$$l_{ij} \lessapprox \frac{W_i}{W_j} \lessapprox u_{ij} \quad (5)$$

For any i and j, there may be many W_i and W_j that satisfies the inequality in equation (5). However, different ratios $\frac{W_i}{W_j}$ gives different decision makers' satisfaction that can be calculated by a membership function (Rezaei et al., 2013):

$$\mu_{ij}\left(\frac{W_i}{W_j}\right) = \begin{cases} \frac{\frac{W_i}{W_j}-l_{ij}}{m_{ij}-l_{ij}}, & \frac{W_i}{W_j} \leq m_{ij}, \\ \frac{u_{ij}-\frac{W_i}{W_j}}{u_{ij}-m_{ij}} & \frac{W_i}{W_j} \geq m_{ij}, \end{cases} \quad (6)$$

Since the judgments a_{ij} are ambiguous, $l_{ij} < m_{ij} < u_{ij}$ and consequently dividing by zero do not occur. The membership function (6) can be obtained as:

$$\mu_{ij}\left(\frac{W_i}{W_j}\right) \in (-\infty, 0), if\ \frac{W_i}{W_j} < l_{ij}\ or\ \frac{W_i}{W_j} > u_{ij} \quad (7)$$

$$\mu_{ij}\left(\frac{W_i}{W_j}\right) \in [0, 1], if\ l_{ij} \leq \frac{W_i}{W_j} \leq u_{ij} \quad (8)$$

If $\frac{W_i}{W_j} = m_{ij}$, then the membership function is 1.

The purpose of FPP is to obtain the optimal crisp priority vector W^* of the fuzzy feasible area Z on the *(n- 1)*-dimensional simplex Q^{n-1}

$$Q^{n-1} = \{W_i | \sum_{i=1}^{n} W_i\ ,\quad W_i > 0\} \quad (9)$$

With $\mu_Z(W)$ as the membership function.

$$\mu_Z(W) = min\{\mu_{ij}(W) | i = 1,2,, \ldots, n-1, j = 2,3, \ldots, n, j > i\} \quad (10)$$

As Mikhailov (2003) mentioned that maximum degree of membership of an optimum crisp priority vector is :

$$\lambda^* = \mu_Z(W^*) = \left(\begin{matrix} max \\ W \epsilon Q^{n-1} \end{matrix} \left(\begin{matrix} min\{\mu_{ij}(W)\} \\ ij \end{matrix} \right) \right) \quad (11)$$

By the maximin rule of Bellman and Zadeh, the equation (11) can be changed to the following equation:

$$\max \lambda \quad (12)$$
s.t.

$$\left(m_{ij}-l_{ij}\right)\lambda W_j - W_i + l_{ij}W_j \leq 0,$$
$$\left(u_{ij}-m_{ij}\right)\lambda W_j + W_i - u_{ij}W_j \leq 0,$$
$$\sum_{k=1}^{n} W_k = 1,$$
$$W_k > 0,$$
$$i = 1,2,,\dots,n-1, j = 2,3,\dots,n, \qquad k = 1,2,\dots,n$$

Solving the above problem, optimum priority vector W^* and λ^* are calculated.

3.2.2. Fuzzy TOPSIS (FTOPSIS)

TOPSIS is considered as one of the useful models in decision making. It is based on this concept that the best alternative should have both the least distance from the Positive Ideal Solution (PIS) and longest distance from the Negative Ideal Solution (NIS) at the same time. FTOPSIS is a fuzzy modification of TOPSIS to overcome its shortcoming in facing ambiguity and uncertainty. The FTOPSIS technique applied in this paper is as follows:

- Creating the fuzzy decision matrix. In this step, purpose is to evaluate the alternatives with respect to each sub-criterion. The scale used in this study is shown in Table 4.
- Obtaining normalized fuzzy decision matrix. It is as represented by R.

R= $\left[r_{ij}\right]_{m\times n}$ (13)

Where $i = 1,2,3,\dots,m$ and $r = 1,2,3,\dots,n$.

$r_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right)$, and $C_j^* = max\ c_{ij}$ (benefit criteria) (14)

$r_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right)$, and $a_j^- = min\ a_j^-$ (cost criteria) (15)

- Creating weighted normalized matrix by multiplying normalized matrix with the weights of the criteria.

  $V = \left[v_{ij}\right]_{m\times n}$, where $v_{ij} = r_{ij}.w_j$ and is the w_j weight of the *j*th attribute (w_j obtained by FPP in this research).

- Calculating the fuzzy positive ideal solution (FPIS, A^*) and fuzzy negative ideal solution(FNIS, A^-) as follows respectively:

  A^*=$(v_1^*, v_2^*, \dots, v_n^*)$ where v_j^* =$\{\max(v_{ij})$if j ∈ J; $\min(v_{ij})$if j ∈ $J'\}$ (16)

  A^-=$(v_1^-, v_2^-, \dots, v_n^-)$ where v_j^* =$\{\min(v_{ij})$if j ∈ J; $\max(v_{ij})$if j ∈ $J'\}$ (17)

- Determining the distance of each alternative from FPIS and FNIS as follows:

$d_i^* = \sum_{j=1}^{n} dv(\, v_{ij},\, v_j^*), i = 1,2,\dots,m$ (18)

$$d_i^- = \sum_{j=1}^{n} dv(v_{ij}, v_j^-), i = 1,2, \dots, m \tag{19}$$

- Calculating Closeness Coefficient (CC_i) of each alternative as bellow:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \tag{20}$$

- Ranking the alternatives. Alternative A_i is closer to the FPIS and farther from FNIS as CC_i approaches to 1 Kannan et al. (2013).

Table 4. Linguistic variables for measuring the performance

Linguistic Variables	Fuzzy Numbers
Very Low (VL)	**(1,2,3)**
Low (L)	**(2,3,4)**
Medium (M)	**(3,4,5)**
High (H)	**(4,5,6)**
Very High (VH)	**(5,6,7)**
Excellent (E)	**(6,7,8)**

3.2.3. Aggregation method

In the case of group decision making, the importance weights are needed to aggregate to achieve a single fuzzy number for each weight. In this research, the fuzzy numbers are aggregated by using the arithmetic mean operator Singh et al. (2015a). Assume $\tilde{I}_i = [(I_{il}, I_{im}, I_{iu})]$ is the relative importance rating of the *ith* attribute. The aggregated importance is calculated as:

$$I_{il} = \frac{1}{d}\sum_{k=1}^{d} I_{il}^k \quad , I_{im} = \frac{1}{d}\sum_{k=1}^{d} I_{im}^k \quad , I_{iu} = \frac{1}{d}\sum_{k=1}^{d} I_{iu}^k \tag{21}$$

Where d is the number of decision makers (DM) and $\tilde{I}_i^k = [(I_{il}^k, I_{im}^k, I_{iu}^k)]$ represents the *k*th DM's idea about the relative weight of *i*th criteria.

Assume $\tilde{x}_{i=}[(x_{il}, x_{im}, x_{iu})]$ is the aggregated performance rating of alternative based on *i*th criterion. It is as follows:

$$x_{il} = \frac{1}{d}\sum_{k=1}^{d} x_{il}^k \quad , x_{im} = \frac{1}{d}\sum_{k=1}^{d} x_{im}^k \quad , x_{iu} = \frac{1}{d}\sum_{k=1}^{d} x_{iu}^k \tag{22}$$

Where d is the number of decision makers (DM) and $\tilde{x}_i^k = [(x_{il}^k, x_{im}^k, x_{iu}^k)]$ represents the *k*th DM's idea about performance rating of organization based on *i*th criterion.

3.2.4. The proposed integrated model

This part proposes the fuzzy MCDM approach for sustainable supplier selection depicted in figure B1[3] . It includes the following steps (each step is described in detail in the following sub-sections):

- Collecting data set for determining the weights
- Calculating the criteria weights using FPP

[3] Please see appendix B

- Collecting data set for prioritizing the suppliers
- Ranking and selecting the best supplier using FTOPSIS.

In the first step, using Table 3, the opinions of the decision maker(s), as pairwise comparison, are collected and using Equation (21) the aggregated fuzzy comparison matrix is obtained for the aspects, criteria and sub-criteria. In the second step, the crisp weight of each sub-criterion is computed using FPP. It is worthy of note that the local weight of each aspect, criterion and sub-criterion is first calculated following which, the global weights of the sub-criterion is derived by multiplying the local weight of each aspect by the local weight of its criterion and the local weight of the related sub-criterion, the global weights of the sub-criterion is derived. For example, Economic aspect (local weight is 0.2), quality (local weight is 0.3) is one of the criteria in economic aspect and rejection rate is one of the sub-criteria of quality (local weight is 0.3). The global weight of rejection rate is 0.018 (0.2*0.3*0.3). In the third step, the aggregated (equation 22) fuzzy decision matrix is created based on the decision makers' opinion using the table of linguistic variables (Table 4). Lastly, the ranking is done by FTOPSIS.

4. Case study and Results

In order to evaluate the performance of the developed integrated method, this section presents the findings from its implementation in a real case company (the company' name is not disclosed for reasons of confidentiality). This company manufactures knitted fabric and includes staple spinning line, weaving line and sizing, dyeing and finishing line. The textile company requires different types of fibers, finishing and auxiliary materials as raw materials. This firm has more than 70 employees and monthly production capacities of 150,000kg of yarn and 120,000m woven fabric respectively. 10 suppliers work with this company to supply the needed raw materials.

4.1. Criteria for sustainable supplier selection and weigh calculation

As mentioned before, those criteria and sub-criteria determined in the first objective are used for evaluating the suppliers' performance and ranking. Figure C1[4] illustrates the hierarchical process of the sustainable supplier selection problem with 3 aspects, 13 main criteria and 46 sub-criteria.

The first step is to collect data set for obtaining the weights of each attributes. To this end, the two managers of the company who have a PhD in spinning (Textile engineering) and management

[4] Please see appendix C

(management in Textile engineering) (each of them has more than 15 years' experience in the textile industry) from the case company were asked to express their opinion (as the FAHP-FPP comparison matrix) about the aspect and criteria based on Table 3. Then, using the aggregation method (Equation 21), the final comparison matrix of each of them was obtained. In the second step, the optimum weight (global weight) of each sub-criterion should be computed using FPP. It is worth noting that in terms of inconsistency, the experts were asked to re-evaluate their opinions. Tables[5] D1 to D7 show the experts' opinion and the aggregated data of the aspects, criteria and sub-criteria. Since the numbers under the diagonal are reverse of the numbers above the diagonal, these numbers are not presented here. After collecting the aggregated comparison matrix, the crisp weights of the aspects and criteria (local weight) were computed using FPP[6]. Afterwards the local weight and global weight of each sub-criterion was calculated (see Table 5).

Table 5.The local and global weights of the aspects and their corresponding criteria

Aspects/Criteria	Local Weight	Global Weight of sub-criteria
Economic	**0.634**	
C	0.409	
$C_{1,1}$	0.657	**0.634*0.409*0.657=0.170**
$C_{1,2}$	0.248	**0.064**
$C_{1,3}$	0.095	**0.024**
Q	0.367	
$C_{2,1}$	0.580	**0.634*0.367*0.580=0.135**
$C_{2,2}$	0.259	**0.060**
$C_{2,3}$	0.209	**0.049**
DS	0.117	
$C_{3,1}$	0.548	**0.634*0.117*0.548=0.040**
$C_{3,2}$	0.126	**0.009**
$C_{3,3}$	0.126	**0.009**
$C_{3,4}$	0.163	**0.012**
F	0.105	
$C_{4,1}$	0.45	**0.634*0.105*0.45=0.029**
$C_{4,2}$	0.25	**0.016**
$C_{4,3}$	0.30	**0.020**
Environmental	**0.198**	
Env.M.S	0.231	
$C_{5,1}$	0.416	**0.198*0.231*0.416=0.019**
$C_{5,2}$	0.333	**0.015**
$C_{5,3}$	0.083	**0.003**
$C_{5,4}$	0.166	**0.007**
GP	0.206	
$C_{6,1}$	0.194	**0.198*0.206*0.194=0.008**
$C_{6,2}$	0.130	**0.005**
$C_{6,3}$	0.096	**0.003**
$C_{6,4}$	0.181	**0.007**
$C_{6,5}$	0.143	**0.006**
$C_{6,6}$	0.256	**0.010**
GW	0.160	

[5] Please see appendix D
[6] In this paper, LINGO 11 was used for solving the FPP problem.

	$C_{7,1}$	0.546	**0.198*0.160*0.546=0.017**
	$C_{7,2}$	0.126	**0.004**
	$C_{7,3}$	0.327	**0.010**
Eco-D		0.131	
	$C_{8,1}$	0.584	**0.198*0.131*0.584=0.015**
	$C_{8,2}$	0.23	**0.006**
	$C_{8,3}$	0.186	**0.004**
G.Tr		0.086	
	$C_{9,1}$	0.77	**0.198*0.086*0.77=0.013**
	$C_{9,2}$	0.23	**0.004**
G.Te		0.186	
	$C_{10,1}$	0.608	**0.198*0.186*0.608=0.022**
	$C_{10,2}$	0.309	**0.011**
	$C_{10,3}$	0.083	**0.003**
Social		**0.167**	
WR		0.538	
	$C_{11,1}$	0.357	**0.167*0.538*0.357=0.032**
	$C_{11,2}$	0.285	**0.025**
	$C_{11,3}$	0.071	**0.006**
	$C_{11,4}$	0.142	**0.012**
	$C_{11,5}$	0.142	**0.012**
HSW		0.170	
	$C_{12,1}$	0.661	**0.167*0.170*0.661=0.019**
	$C_{12,2}$	0.196	**0.005**
	$C_{12,3}$	0.142	**0.004**
SAW		0.292	
	$C_{13,1}$	0.370	**0.167*0.292*0.370=0.018**
	$C_{13,2}$	0.304	**0.014**
	$C_{13,3}$	0.135	**0.006**
	$C_{13,4}$	0.190	**0.009**

4.2. Evaluating the suppliers by FTOPSIS

After obtaining the weights, the third step is collecting data set using Table 4 for ranking. Finally, the suppliers were prioritized using FTOPSIS[7] to rank and select the best one. The following part gives the results of the steps of FTOPSIS.

Step1: Creating the fuzzy decision matrix. To this end, the two experts from the case company were asked to express their ideas about the performance of each criterion for each supplier with respect to Table 5 (see Table 6). Then, using Equation 22, the aggregated data set was obtained (Table 7). The following section presents the results of the steps of FTOPSIS. Note that in section three the advantage sub-criteria and dis-advantage sub-criteria were determined.

Table 6. The opinions of the two experts about the suppliers

	Economic				**Environmental**			**Social**		
	$C_{1,1}$	$C_{1,2}$	$C_{1,3}$	…	…	…	…	…	$C_{13,3}$	$C_{13,4}$
S1	VL,L	M,M	L,M	…	…	…	…	…	L,M	M,L
S2	H,E	E,E	M,M	…	…	…	…	…	L,VL	L,M
S3	VH,H	L,VL	E,E	…	…	…	…	…	H,M	M,M
S4	…	…	…	…	…	…	…	…	…	…
S5	…	…	…	…	…	…	…	…	…	…
S6	…	…	…	…	…	…	…	…	…	…

[7] In this research, **MATLAB 2011b** software was used for coding the algorithm of FTOPSIS.

S7	…	…	…	…	…	…	…	…	…	…
S8	…	…	…	…	…	…	…	…	…	…
S9	L,L	L,VL	M, L	…	…	…	…	…	L,M	E,E
S10	E,H	H,H	E,VH	…	…	…	…	…	M,H	H,H

Table 7. The aggregated data set

	Economic				Environmental			Social		
	$C_{1,1}$	$C_{1,2}$	$C_{1,3}$	…	…	…	…	…	$C_{13,3}$	$C_{13,4}$
S1	(1,2.5,4)	(3,4,5)	(2,3.5,5)	…	…	…	…	…	(2,3.5,5)	(2,3.5,5)
S2	(4,6,8)	(6,7,8)	(3,4,5)	…	…	…	…	…	(1,2.5,4)	(2,3.5,5)
S3	(5,6.5,8)	(1,2.5,4)	(6,7,8)	…	…	…	…	…	(3,4.5,6)	(3,4,5)
S4	…	…	…	…	…	…	…	…	…	…
S5	…	…	…	…	…	…	…	…	…	…
S6	…	…	…	…	…	…	…	…	…	…
S7	…	…	…	…	…	…	…	…	…	…
S8	…	…	…	…	…	…	…	…	…	…
S9	(2,3,4)	(1,2.5,4)	(2,3.5,5)	…	…	…	…	…	(2,3.5,5)	(6,7,8)
S10	(4,6,8)	(4,5,6)	(5,6.5,8)	…	…	…	…	…	(3,4.5,6)	(4,5,6)

Step2: Obtaining normalized fuzzy decision matrix. After collecting the aggregated data, it is normalized using equations 14 and 15. Table 8 shows the normalized data set.

Table 8. the normalized data set

	Economic			Environmental			Social		
	$C_{1,1}$	$C_{1,2}$	$C_{1,3}$	…	…	…	…	$C_{13,3}$	$C_{13,4}$
S1	(0.25,0.40,1)	(0.375,0.5,0.625)	(0.25,0.437,0.625)	…	…	…	…	(0.25,0.437,0.625)	(0.25,0.437,0.625)
S2	(0.125 0.167, 0.25)	(0.75,0.875,1)	(0.375,0.5,0.625)	…	…	…	…	(0.125,0.312,0.5)	(0.25,0.437,0.625)
S3	(0.125, 0.154,0.2)	(0.125,0.3125,0.5)	(0.75,0.875,1)	…	…	…	…	(0.375,0.562,0.75)	(0.375,0.5,0.625)
S4	…	…	…	…	…	…	…	…	…
S5	…	…	…	…	…	…	…	…	…
S6	…	…	…	…	…	…	…	…	…
S7	…	…	…	…	…	…	…	…	…
S8	…	…	…	…	…	…	…	…	…
S9	(0.25,0.333,0.5)	(0.125,0.3125,0.5)	(0.25,0.437,0.625)	…	…	…	…	(0.25,0.437,0.625)	(0.75,0.875,1)
S10	(0.125,0.167,0.25)	(0.5,0.625,0.75)	(0.625,0.8125,1)	…	…	…	…	(0.375,0.562,0.75)	(0.5,0.625,0.75)

Step3: Creating weighted normalized matrix. In this stage, the weights calculated by FPP are multiplied in the normalized table (see Table 9).

Table 9. the weighted normalized data set

	Economic			Environmental		Social		
	$C_{1,1}$	$C_{1,2}$	$C_{1,3}$	…	…	…	$C_{13,3}$	$C_{13,4}$
S1	(0.042,0.068,0.17)	(0.024,0.032,0.04)	(0.009,0.012,0.015)	…	…	…	(0.0015,0.0026,0.0037)	(0.0022,0.004,0.0056)
S2	(0.021 0.028, 0.042)	(0.048,0.056,0.064)	(0.018,0.026,0.024)	…	…	…	(0.0007,0.001,0.003)	(0.0022,0.004,0.0056)
S3	(0.021 0.026, 0.034)	(0.008,0.020,0.032)	(0.003,0.007,0.012)	…	…	…	(0.0022,0.0033,0.0045)	(0.0033,0.0045,0.0056)
S4	…	…	…	…	…	…	…	…
S5	…	…	…	…	…	…	…	…
S6	…	…	…	…	…	…	…	…
S7	…	…	…	…	…	…	…	…
S8	…	…	…	…	…	…	…	…
S9	(0.042 0.056, 0.085)	(0.008,0.020,0.032)	(0.003,0.007,0.012)	…	…	…	(0.0015,0.0026,0.0037)	(0.0067,0.0078,0.0090)
S10	(0.021 0.028, 0.042)	(0.032,0.04,0.048)	(0.012,0.015,0.018)	…	…	…	(0.0022,0.0033,0.0045)	(0.0045,0.0056,0.0067)

Step 4: Determining the distance of each alternative from FPIS and FNIS, calculating the CC_i and ranking (see table 10).

Table 10. Ranking the suppliers

Supplier	d_i^*	d_i^-	CC_i	Ranking
S1	0.087421969	0.066744258	0.432936963	4
S2	**0.062776261**	**0.099891089**	**0.614081985**	**1**
S3	0.106247461	0.049734272	0.318846774	8
S4	0.108267999	0.048220129	0.308139216	9
S5	0.095487134	0.053158546	0.357619177	6
S6	0.09579427	0.052639808	0.354634248	7
S7	0.068224757	0.085996032	0.557616342	3
S8	0.108549259	0.047742626	0.305470919	10
S9	0.088180632	0.065801511	0.427332091	5
S10	0.063237582	0.099632264	0.611729345	2

In general, the ranking of the suppliers has been carried out with respect to the 46 sustainability sub-criteria. The last column of table 10 shows the ranking of the suppliers. It can be observed that supplier 2 (S2) is the best supplier with CC_i = 0.614081985, while supplier 8 (S8) with CC_i = 0.305470919 is considered the weakest supplier in terms of sustainability. Generally, after supplier 2, this is followed by **S10** > **S7** > **S1** > **S9** > **S5** > **S6** > **S3** > **S4** > **S8**.

4.3. Validation of the model

The literature reports that there are three common methods to show the validity of the MCDM-based models including: 1) Consistency index (Rezaei et al., 2013); 2) Comparing with other models (Oztaysi, 2014) (In this study, we compare the results with TOPSIS); 3) Sensitivity analysis (Roshandel et al., 2013).

4.3.1. Consistency index

Mikhailov (2000) indicated that the values of λ (Eqn. (12)) represents the consistency index such that, for $\lambda < 0$ the initial judgments are inconsistent while for $0 \leq \lambda \leq 1$, the initial judgments are consistent. The values of λ for the aspects economic, environmental and social are 0.634, 0.198, and 0.167, respectively. In terms of economic aspect, the values of λ for its corresponding criteria (cost, quality service & delivery and flexibility) are 0.409, 0.367, 0.117, and 0.105, respectively. In terms of environmental aspect, the values of λ for its corresponding criteria (environmental management system, green product, green warehousing, eco-design, green transportation and green technology) are 0.231, 0.206, 0.16, 0.131, 0.086, and 0.186, respectively. And in terms of social aspect, the values of λ for its corresponding criteria (Workers' rights, Health and safety at work and, supportive activity at work) are 0.538, 0.170, and 0.292, respectively. As these numbers are positive, it can be concluded that the final weights are approximately consistent and satisfy the decision makers' opinion, and that the model is valid.

4.3.2. Comparing with TOPSIS

In this section, the results derived from the proposed method were compared with the results of classical TOPSIS (as one of the best techniques in decision making (Ertuğrul et al., 2008)). Furthermore, it can be said that comparing a decision making method with its classical method has been used in decision making literature (Oztaysi, 2014). In addition, it should be mentioned that in comparison with other existing methods such as AHP and ANP (as the two most widely used alternatives for ranking and selection), TOPSIS is less complicated and time consuming. Moreover, in AHP and ANP, extra pairwise comparison matrixes are needed for alternative selection. Therefore, TOPSIS is better for comparison when compared with these models.

In order to compare the FTOPSIS with its classical model (based on positive ideal solution and negative ideal solution) under crisp environment to show to what extent the results are consistent, the mean values in Table 10 were used for the purpose of calculations. The steps of TOPSIS are not shown here since the purpose of this part is to compare the results. The results show that the three best suppliers are still S2, S10 and S7, which are followed by S1 > S5 > S9 > S6 > S3 > S4 > S8. The changes are that between S9 and S5. The findings show that the results are consistent with each other.

4.3.3. Sensitivity analysis

In order to verify the validity of the derived results, a sensitivity analysis was conducted. The purpose of sensitivity analysis is to monitor the changes of the ranking when only one main attribute has the maximum weight whereas the others have the minimum weight (Roshandel et al., 2013). To this end, 46 states were considered. For example, for sub-criterion $C_{4,1}$, it is supposed that its weight is 0.17 (the maximum value) and the weights of the rest of the 45 sub-criteria are 0.003 (the minimum value) and this practice was continued for all the 46 sub-criteria. Afterwards, the FTOPSIS was applied for ranking. The result shows that suppliers 2, 10 and 7 are the best alternatives in any situations.

4.4. Result analysis of the developed MCDM model

A hybrid FPP-FTOPSIS was developed to evaluate and prioritize suppliers with respect to the sustainable criteria. In this stage, FPP as a new fuzzy programming method, was used to compute the weight of the attributes. At the end, FTOPSIS as one of the most widely used MCDM techniques, was applied to rank the alternatives. To show how much the FPP-FTOPSIS model is applicable, a real case study (the textile company) was selected and the 10 suppliers who work with this company were assessed based on specified attributes in the first objective (three aspects, 13 main criteria and 46 sub-criteria). The managers of the company were asked to provide their opinions about the weights (Tables D1-D7) and the performance of the attributes (Table 4).

Table 6 presents the results associated with the weights. As mentioned earlier, the criteria were categorized into three aspects. The results at the weighting stage (see figure 3) showed that economic aspect was the most important aspect with the weight of 0.634 for the experts. It was followed by environmental (0.198) and social (0.167). As it was observed that the ratios of economic aspect to the environmental and social aspects are 3.2 and 3.8, respectively while the ratio of environmental to social aspect is almost equal (1.18).

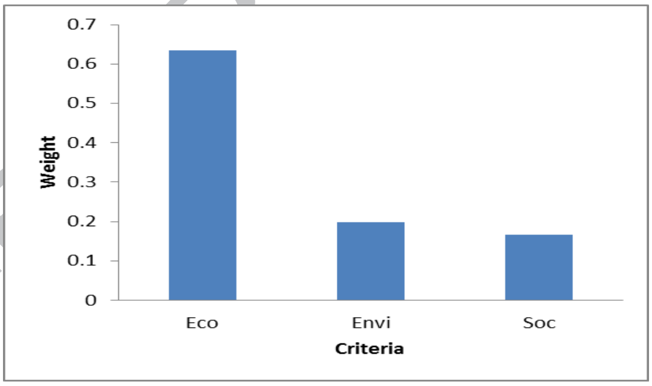

Figure 3. The comparison between the aspects

. In general, a comparison of all 46 sub-criteria showed that the most important sub-criterion is material cost, with priority of 0.17. Other results for the sub-criteria are rejection rate of the product (0.135), the freight cost (0.064), capability of handling abnormal quality (0.06) and process for internal audit quality of material (0.049), which took second, third, fourth and fifth respectively. Note that even though the model was to assess sustainable suppliers, it can be seen that many economic sub-criteria have relatively high priorities. This indicates that the selection of sustainable suppliers, economic criteria should be considered. After computing the weights, the ranking was done by implementing the FTOPSIS algorithm. The obtained results from various steps of FTOPSIS have been presented in Table

10. Determining the distance from positive ideal solution and negative ideal solution are the two main steps in this method, and the supplier with the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution is the best alternative. It can be seen from Table 10 that supplier 2 has both the maximum value in negative ideal solution and minimum value in the positive ideal solution. Therefore, this supplier is selected as the most preferred alternative, followed by supplier 10 and supplier 7. Meanwhile, supplier 8 with the longest distance from the positive ideal solution and shortest distance from the negative ideal solution is the weakest alternative based on the 46 sustainable sub-criteria.

5. Managerial implication

This research covered two main objectives which have several implications for those managers/decision makers who intend to assess their suppliers based on sustainability attributes. The first objective of this study was to develop a list of important and applicable sustainability criteria (in each of the aspects of economic, environmental and social) and their corresponding sub-criteria for supplier selection through a questionnaire-based survey and the second objective is to propose an integrated model for sustainable supplier selection.

Developing the list of sustainability attributes and measuring their importance and applicability provides managers with a better understanding of the concept of sustainability. Although the literature reports that there are some studies which have determined the related criteria and sub-criteria for suppliers' sustainability performance evaluation, they did not measure the importance and applicability of the criteria and sub-criteria through a questionnaire-based survey. Indeed, this list of 13 criteria and 46 sub-criteria, which has been evaluated by established statistical tests, provides a basis that is helpful in improving suppliers' performance in terms of sustainability which leads to improvement in SSCM performance.

The results show that economic aspect is still the most essential aspect, followed by environmental aspect and finally social aspect. Table 2 presents that in terms of importance and applicability, quality, cost and delivery and service are the most effective criteria that managers should focus in suppliers' performance assessment in real world. In addition to the economic-based criteria, environmental management system and workers' right are the two most effective attributes. That is, suppliers should focus on these environmental and social criteria and sub-criteria besides economic criteria if they want to get the managers' attention for long-term cooperation. Hence, the findings from the first objective are handy information for organizations that wish to improve their SSCM.

Besides the first objective, a new hybrid model by integrating FPP and FTOPSIS was developed to assess suppliers' sustainability in the presence of uncertainty. The proposed model was implemented in a real textile company and the best suppliers of the company were evaluated based on the 13 criteria and 46 corresponding sub-criteria determined in the first objective. Using FPP, the accurate weights of the criteria and sub-criteria were determined. By applying FTOPSIS, the suppliers were prioritized and the best supplier was determined. The case company can benefit from the hierarchical structure (Figure C1) developed in this research, which can be used to obtain the goals of the company in the field of SSCM. The results for the supplier assessment can be effective in increasing the quality of the product, decreasing the cost and toxic material in the supply chain, and increasing the rate of sale of the product. The results for the suppliers' evaluation can be useful for the suppliers to understand their weaknesses and improve their performance. Therefore, managers can make and develop a strong relation with their partners relying on their strength and take actions to reduce their weaknesses (Rostamzadeh et al., 2015). It is worthy to note that the findings have been discussed with the suppliers. They seem to accept the results of the study as a true evaluation tool for finding weaknesses and improving their performance.

6. Conclusion

This research has contributed specifically to sustainable supplier selection by: (i) Developing a comprehensive list of sustainability criteria and their corresponding sub-criteria and (ii) Proposing a hybrid hierarchical decision making model to select the optimal supplier using FPP and FTOPSIS.

In the field of sustainable supplier selection, two issues are very important. Firstly is the criteria and sub-criteria that should be used for performance evaluation, and secondly is the method that should be applied for selecting the best supplier. In this study, a comprehensive list of important and applicable sustainability attributes was developed using a questionnaire-based survey. A questionnaire was developed to evaluate the importance and applicability of the criteria and sub-criteria using experts from the academia and industry. Hence, an average mean value was obtained for each of the criteria to show their level of importance and applicability. The results derived from the Cronbach's alpha test showed that the collected data sets for importance and applicability are reliable and satisfactory. In addition, Mann–Whitney U-test was performed to evaluate whether the mean scores of the two sets of data (importance and applicability) differ significantly. The results show that there is no significant difference between them.

Furthermore, this study proposed an effective integrated MCDM model for determining the most appropriate supplier in SSCM. The presented model incorporated a hierarchical MCDM structure, FPP and FTOPSIS, wherein FPP was used to weigh the criteria and FTOPSIS was used for ranking the suppliers and determining the best one. FPP is the newest fuzzy modification of AHP which can deal with inconsistency, uncertainty and calculation complexity. Moreover, FTOPSIS as the fuzzy modification of TOPSIS not only works based on the concept that the best alternative should have both the least distance from the PIS and longest distance from the NIS at the same time, but also overcomes its shortcoming in facing ambiguity and uncertainty. Generally, the framework (including the first and second objectives) can be used by supply chain members to assess and determine their suitable suppliers in the presence of uncertainty.

Some important issues for future studies are given here under. Nowadays, carbon management has become very important to the managers of firms. Adding the carbon management criteria and their corresponding sub-criteria and measuring their importance and applicability, deserves further exploration. Also, a fuzzy-based questionnaire can be used for data collection in order to prevent information bias. Using FPP-ANP to study the dependence relationships of attributes, also deserves further exploration.

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Appendix A:

Table A1. The definition of the sub-criteria

		Economic aspect
Criterion	**Sub-criteria**	
Cost	Material cost	**The price of the material considering the quality of the material and other services provided by supplier. This attribute is counted as disadvantage (cost) because with increase in material cost, the customers' (managers of company) satisfaction decreases.**
	Freight cost	**The cost of transportation. This attribute is counted as disadvantage because with an increase in freight cost, the customers' satisfaction decreases.**
	After sales service cost	**The price of the after sales service. This attribute is counted as disadvantage because with an increase in after sales service cost, the customers' satisfaction decreases.**
Quality	Rejection rate of the product	**Number of rejected supplied goods detected by quality control. This attribute is counted as disadvantage because with increase rejection rate of the product, the customers' satisfaction decreases.**
	Capability of handling abnormal quality	**The capability of the supplier in handling abnormal quality problems ((Lee et al., 2009). This attribute is counted as advantage (benefit) because with increasing capability of handling abnormal quality, the customers' satisfaction increases.**
	Process for internal Quality Audit of Material	**One shall ensure that the supplier will make a reasonable number of audits on the quality level offered and is certified to ensure a maximum level of quality to prevent possible failures (Grisi et al., 2010). This attribute is counted as advantage because with increasing process for internal quality audit of material, the customers' satisfaction increases.**
Delivery & Service	Lead time flexibility	**Flexibility in time between the placement and arrival of order without compromising quality and cost ((Kannan et al., 2015). This attribute is counted as advantage because with increasing flexibility in lead time, the customers' satisfaction increases.**
	After sales service	**The level of service is given after delivering goods. This attribute is counted as advantage because with increasing after sales service, the customers' satisfaction increases.**
	Time to solve the complaint	**Time between notification to the supplier and resolution of complaints. This attribute is counted as disadvantage because with increase time to**

		resolve complaints, the customers' satisfaction decreases.
	On-time delivery	**The capability to follow the predefined delivery. This attribute is counted as advantage because delivering the goods on the right time helps to increase the customers' satisfaction.**
Flexibility	Flexibility in discount	**Rate of discount given by supplier to customer. This attribute is counted as advantage because flexibility in discount helps to increase the customers' satisfaction.**
	Flexibility of delivery time	**Level of flexibility of supplier in changing the time of delivery of the order. This attribute is counted as advantage because with increasing flexibility of delivery time, the customers' satisfaction increases.**
	Flexibility in ordering	**Level of the flexibility of supplier in changing the orders based on the request of the customer. Since this attribute reduces supply chain cost and increases the customer satisfaction, it should be counted as advantage.**
	Environmental	
Environmental Management System	ISO-14001 certification	**Whether the supplier has environment-related certification such as ISO1400. This criterion aids firms to improve their environmental management system. Thus, it should be considered as advantage.**
	Environmental Performance Evaluation	**Supplier should have environmental policies, planning of environmental objectives, checking and control of environmental activities ((Grisi et al., 2010). This factor aids firms to manage, monitor and control their environmental issues in a holistic manner. Therefore, it should be used as advantage.**
	Eco-Labeling	**Whether the supplier uses eco-labels for the products or not. This attribute encourages suppliers to have better environmental performance. So, this criterion should be counted as advantage.**
	Environment-friendly raw materials	**Supplier must use environment friendly materials and avoid the use of non-biodegradable materials. This criterion minimizes carbon foot print and greenhouse gas emission. Thus, in this research it is used as advantage.**
Green Products	Green certification	**Supplier must provide green related certification for products ((Kannan et al., 2015). This criterion helps organizations to improve their environmental performance. Thus, it should be considered as advantage.**
	Re-use	**Ability to re-utilize the used products and their related accessories (Kannan et al., 2015). This criterion helps organizations to improve their environmental performance. Thus, it should be considered as advantage.**
	Green packaging	**The level of green materials used in packaging ((Kannan et al., 2015; Lee et al., 2009). This criterion reduces the environmental impact and ecological footprint. Therefore, it should be used as advantage.**
	Air emissions	**The quantity control and treatment of hazardous emission, such as SO_2, NH3, CO and HCl (Lee et al., 2009). This attribute is counted as disadvantage**

		because with increase quantity of SO_2, NH_3, CO and HCl, the environmental performance of organizations decreases.
	Waste water	**The quantity control and the treatment of waste water ((Kannan et al., 2015). This criterion is considered as disadvantage, because with increase of quantity of waste water the environmental impact and ecological footprint increases.**
	Hazardous wastes	**Pollution minimization initiatives related to Hazardous wastes. This criterion is considered as disadvantage, because with increase of quantity of hazardous wastes, the environmental impact and ecological footprint increases.**
Green Warehousing	Inventory of non-hazardous substances	**Compliance with regulations of hazardous substances to prevent the products from containing excess in restricted substances (Kannan et al., 2015). This attribute directly reduces the quantity of hazardous material in final goods. Therefore, this should be counted as advantage.**
	Inventory of substitute material	**Supplier must transit their materials into green materials under a fixed deadline to make sure a currently used non green material is replaced by a green material of the same functions and specifications. This attribute is counted as advantage because by increasing this criterion the environmental performance level of organizations increases.**
	Warehouse management	**Level of warehouse management to prevent material mixing and maintain the quality of material. This attribute is counted as advantage because with increasing Warehouse management the environmental performance level of organizations increases.**
Eco-design	Recycle of products when design	**Ability to treat the used products or their accessories, to reprocess the materials, and to replace the required new materials when producing new products (Rostamzadeh et al., 2015). This attribute reduces the harmful waste we discard into the environment. Thus, it should be considered as advantage.**
	Re-manufacturing	**Detach certain accessories from waste products for future usage (Rostamzadeh et al., 2015). This reduces the pollution associated with manufacturing new products. Therefore, this criterion is used as advantage.**
	Reduction of the use of hazardous materials when design	**Supplier must try to decrease the rate of hazardous material when design. This criterion controls and reduces the quantity of hazardous material in products which helps to increase the environmental performance of organizations. So, it should be counted as advantage.**
Green Transportation	Using a modern eco-efficient transportation fleet	**Supplier should use eco-efficient transportation fleet like energy efficient Vessels and high Euro norms for trucks (Rostamzadeh et al., 2015). This reduces the pollution associated with product transportation. Therefore, this criterion is used as advantage.**
	Using Green fuels	**Supplier should use Green fuels with low sulfur content, and alternative fuels. This reduces the pollution associated with product transportation.**

		Therefore, this criterion is used as advantage.
Green Technology	Materials used in the supplied components that reduce the impact on natural resources	**The use of materials in the components that have a lower impact on the natural resources (Kannan et al., 2015; Lee et al., 2009). This attribute is counted as advantage because by increasing this factor the environmental performance of organizations increases.**
	Capability of R&D	**Capability of R&D of the supplier to meet current and future demand of the company. This factor helps to improve the quality of the existing products as well as reduce hazardous material when design. Therefore it should be counted as advantage.**
	Ability to alter process and product for reducing the impact on natural resources	**The ability of the supplier to alter the process and product design in order to reduce the impact on the natural resources (Kannan et al., 2015). Since this criterion helps to increase the level of environmental performance, it should be used as advantage.**
	Social	
Workers' Rights	Contract	**Supplier should have contract with their workers. This attribute is a supportive action for worker which increases workers' satisfaction. So, it is counted as advantage.**
	Employment insurance	**Supplier should provide employment insurance for their workers. Providing employment insurance increases the workers' satisfactory. So, it is counted as advantage.**
	Employment compensation	**Supplier should be responsible for their workers. This is a supportive activity which encourages workers to work with higher efficiency at work. So, this criterion should be counted as advantage.**
	Standard working hours	**Ordinary hours are a worker's normal and regular hours of work, which do not attract overtime rates. This is a supportive activity which encourages workers to work with higher efficiency at work. So, this criterion should be counted as advantage.**
	Overtime pay	**Supplier should pay the salary for the overtime. This is a supportive activity which is aimed at motivating workers. So, this criterion should be counted as advantage.**
Health and Safety at Work	Health insurance at work	**Supplier must cover the cost of workers' health insurance at work. This attribute is a supportive action for worker which increases workers' satisfaction. So, it is counted as advantage.**
	Training for safety at work	**To prevent accidents and protect the health of workers, they must be trained at work. This attribute increases the level of safety at work. Therefore it should be considered as advantage.**
	Providing appropriate equipment at work	**To prevent accidents and protect the health of workers, they must have appropriate equipment. This attribute increases the level of safety at work. Therefore it should be considered as advantage.**
	Discrimination	**There must not be any difference between men and women workers for growth at work. This attribute is counted as disadvantage, because the more discrimination, the more dissatisfaction.**

Supportive Activities	Growth at work	**Based on experience, skill workers' position should be encouraged. This attribute is a supportive action for workers which increases workers' satisfaction. Hence, it is counted as advantage.**
	Wages	**Workers must be paid based on work laws. Paying based on the work law causes workers to feel satisfactory. So, their performance increases at work. Therefore, this criterion should be counted as advantage.**
	Attention to religious and cultural issues at work (such as praying, etc.)	**Supplier must respect religious and cultural issues at work. This attribute is a supportive action for workers which increases workers' satisfaction. So, it is counted as advantage.**

(please note that the name of some sub-criteria has been shortened.)

Appendix B:

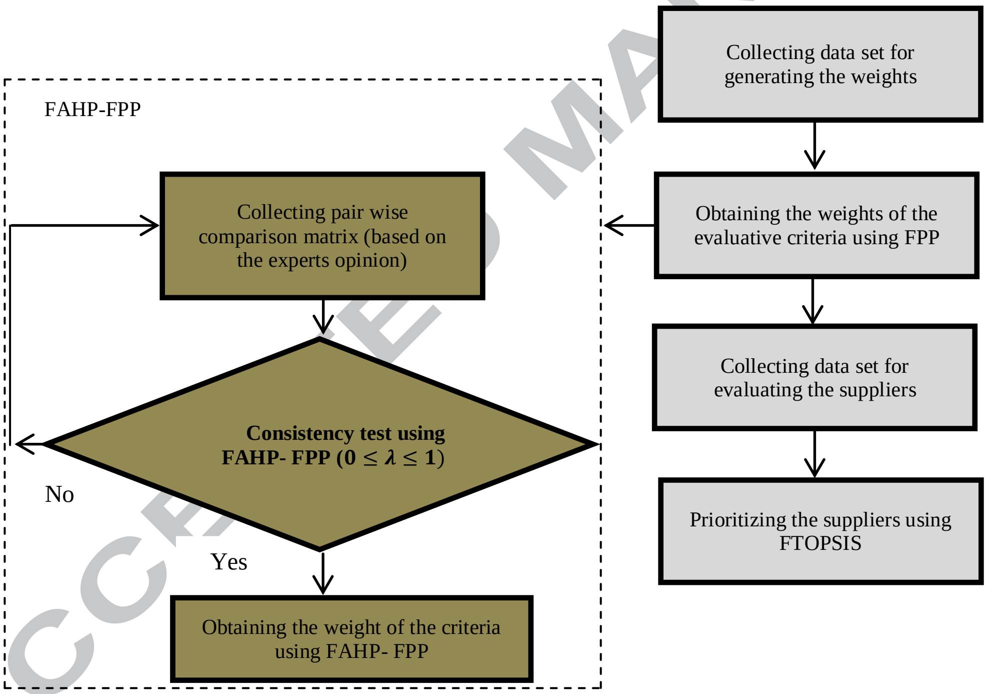

Figure B1. The proposed fuzzy-based framework for sustainable supplier selection

Appendix C

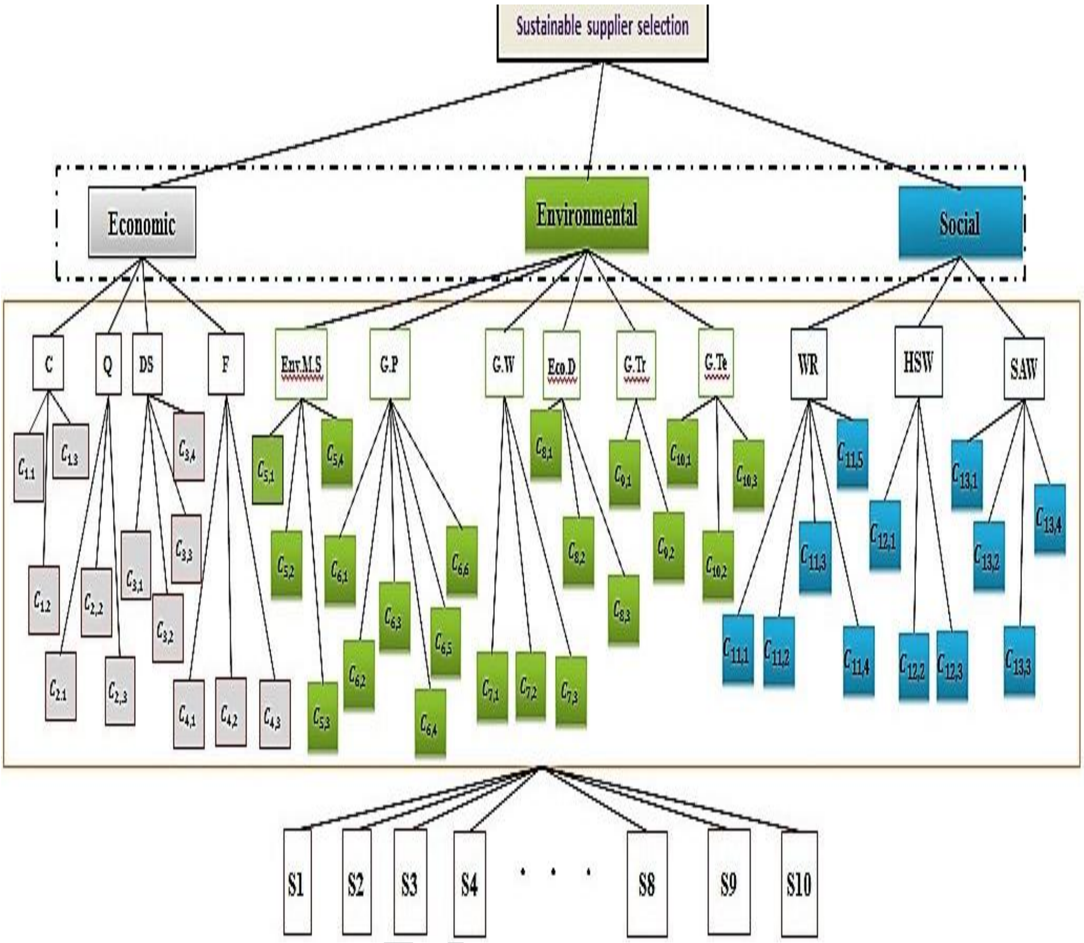

Figure C1. The hierarchical process of the problem

Appendix D:

Table D1. The data set related to the three aspects

	The opinions of the two experts			The aggregated data set		
	Economic	**Environmental**	**Social**	**Economic**	**Environmental**	**Social**
Economic	$\tilde{1}$	$\tilde{2},\tilde{4}$	$\tilde{3},\tilde{5}$	$\tilde{1}$		$(3,4,5)$
Environmental		$\tilde{1}$	$\tilde{2},\tilde{2}$		(2,3,4) $\tilde{1}$	$(1,2,3)$
Social			$\tilde{1}$			$\tilde{1}$

Table D2. The data set related to the economic criteria

	The opinions of the two experts				The aggregated data set			
	C	**Q**	**DS**	**F**	**C**	**Q**	**DS**	**F**
C	$\tilde{1}$	$\tilde{1},\tilde{1}$	$\tilde{4},\tilde{2}$	$\tilde{2},\tilde{4}$	$\tilde{1}$	$(1,1,2)$	$(2,3,4)$	(2,3,4)
Q		$\tilde{1}$	$\tilde{2},\tilde{6}$	$\tilde{3},\tilde{3}$		$\tilde{1}$	$(3,4,5)$	(2,3,4)
DS			$\tilde{1}$	$\tilde{1},\tilde{1}$			$\tilde{1}$	(1,1,2)
F				$\tilde{1}$				$\tilde{1}$

Table. D3. The aggregated data set related to the sub-criteria of cost, quality, delivery and service, and flexibility

	$C_{1,1}$	$C_{1,2}$	$C_{1,3}$
$C_{1,1}$	1	(3,4,5)	(5,6,7)
$C_{1,2}$		1	(2.5,3.5,4.5)
$C_{1,3}$			1

	$C_{2,1}$	$C_{2,2}$	$C_{2,3}$
$C_{2,1}$	1	(1,2,3)	(2,3,4)
$C_{2,2}$		1	(1,2,3)
$C_{2,3}$			1

	$C_{3,1}$	$C_{3,2}$	$C_{3,3}$	$C_{3,4}$
$C_{3,1}$	1	(1,2,3)	(3,4,5)	(1,2,3)
$C_{3,2}$		1	(2,3,4)	(2,3,4)
$C_{3,3}$			1	(0.25,0.33,0.5)
$C_{3,4}$				1

	$C_{4,1}$	$C_{4,2}$	$C_{4,3}$
$C_{4,1}$	1	(3,4,5)	(1,2,3)
$C_{4,2}$		1	(0.25,0.33,0.5)
$C_{4,3}$			1

Table D4.The data set related to environmental criteria.

	The opinions of the two experts					
	Env.M.S	GP	GW	Eco-D	G.Tr	G.Te
Env.M.S	$\check{1}$	$\check{4},\check{2}$	$\check{2},\check{6}$	$\check{2},\check{2}$	$\check{2},\check{3}$	$\check{3},\check{2}$
GP		$\check{1}$	$\check{2},\check{4}$	$\check{1},\check{1}$	$\check{2},\check{4}$	$\check{1},\check{2}$
GW			$\check{1}$	$(\check{2},\check{2})^{-1}$	$\check{2},\check{2}$	$\check{1},\check{1}$
Eco-D				$\check{1}$	$\check{2},\check{2}$	$\check{1},\check{1}$
G.Tr					$\check{1}$	$\check{2},\check{3}$
G.Te						$\check{1}$

	The aggregated data set					
	Env.M.S	GP	GW	Eco-D	G.Tr	G.Te
Env.M.S	$\check{1}$	(2,3,4)	(3,4,5)	(1,2,3)	(1.5,2.5,3.5)	(1.5,2.5,3.5)
GP		$\check{1}$	(2,3,4)	(1,1,2)	(2,3,4)	(1,1.5,2)
GW			$\check{1}$	(0.33,0.5,1)	(1,2,3)	(1,1,2)
Eco-D				$\check{1}$	(1,2,3)	(1,1,2)
G.Tr					$\check{1}$	(1.5,2.5,3.5)
G.Te						

Table D5. The aggregated dataset related to the sub-criteria of environmental management system, green product, green warehousing, Eco-design, green transportation, green technology

	$C_{5,1}$	$C_{5,2}$	$C_{5,3}$	$C_{5,4}$
$C_{5,1}$	1	(1,2,3)	(3,4,5)	(1,2,3)
$C_{5,2}$		1	(2,3,4)	(2,3,4)
$C_{5,3}$			1	(0.25,0.33,0.5)
$C_{5,4}$				1

	$C_{6,1}$	$C_{6,2}$	$C_{6,3}$	$C_{6,4}$	$C_{6,5}$	$C_{6,6}$
$C_{6,1}$	1	(1,2,3)	(1,2,3)	(1,1.5,2)	(1,1.5,2)	(0.28,0.4,0.66)
$C_{6,2}$		1	(1,1,2)	(0.28,0.4,0.66)	(0.28,0.4,0.66)	(0.28,0.4,0.66)
$C_{6,3}$			1	(0.22,0.28,0.4)	(0.22,0.28,0.4)	(0.22,0.28,0.4)
$C_{6,4}$				1	(1,1,2)	(1,1,2)
$C_{6,5}$					1	(1,1,2)
$C_{6,6}$						1

	$C_{7,1}$	$C_{7,2}$	$C_{7,3}$
$C_{7,1}$	1	(3,4,5)	(1,2,3)
$C_{7,2}$		1	(0.25,0.33,0.5)
			1

	$C_{8,1}$	$C_{8,2}$	$C_{8,3}$
$C_{8,1}$	1	(2,3,4)	(3.5,4.5,5.5)
$C_{8,2}$		1	(1.5,2.5,3.5)
$C_{8,3}$			1

	$C_{9,1}$	$C_{9,2}$
$C_{9,1}$	1	(2.5,3.5,4.5)

	$C_{10,1}$	$C_{10,2}$	$C_{10,3}$
$C_{9,2}$			1
$C_{10,1}$	1	(2.5,3.5,4.5)	(3,4,5)
$C_{10,2}$		1	(1.5,2.5,3.5)
$C_{10,3}$			1

Table D6. The data set related to social criteria.

	The opinions of the two experts			The aggregated data set		
	WR	HSW	SAW	WR	HSW	SAW
WR	$\breve{1}$	$\breve{2},\breve{2}$	$\breve{6},\breve{2}$	$\breve{1}$	$(\mathbf{1},\mathbf{2},\mathbf{3})$	$(\mathbf{3},\mathbf{4},\mathbf{5})$
HSW		$\breve{1}$	$\breve{3},\breve{3}$		$\breve{1}$	$(\mathbf{2},\mathbf{3},\mathbf{4})$
SA			$\breve{1}$			$\breve{1}$

Table D7. The aggregated dataset related to the sub-criteria of workers' rights, health and safety at work and supportive activities at work

	$\boldsymbol{C_{11,1}}$	$\boldsymbol{C_{11,2}}$	$\boldsymbol{C_{11,3}}$	$\boldsymbol{C_{11,4}}$	$\boldsymbol{C_{11,5}}$
$C_{11,1}$	1	(1,2,3)	(3,4,5)	(1,2,3)	(1,2,3)
$C_{11,2}$		1	(2,3,4)	(2,3,4)	(2,3,4)
$C_{11,3}$			1	(0.25,0.33,0.5)	(0.33,0.5,1)
$C_{11,4}$				1	(1,1,2)
$C_{11,5}$					1

	$C_{12,1}$	$C_{12,2}$	$C_{12,3}$
$C_{12,1}$	1	(3,4,5)	(3,4,5)
$C_{12,2}$		1	(1,2,3)
$C_{12,3}$			1

	$\boldsymbol{C_{13,1}}$	$\boldsymbol{C_{13,2}}$	$\boldsymbol{C_{13,3}}$	$\boldsymbol{C_{13,4}}$
$C_{13,1}$	1	(1,2,3)	(3,4,5)	(1,2,3)
$C_{13,2}$		1	(1.5,2.5,3.5)	(2,3,4)
$C_{13,3}$			1	(0.25,0.33,0.5)
$C_{13,4}$				1

- Selecting the most suitable sustainability criteria using questionnaire.
- Applying various statistical tests to validate the developed criteria.
- Developing an integrated FPP-FTOPSIS model for sustainable supplier selection.
- Calculating weights using FPP and ranking suppliers using FTOPSIS.
- Explaining the model using the real case study based on the developed criteria.

ACCEPTED MANUSCRIPT