**Business and Economics Research Journal**
Volume 5 Number 3 2014
pp. 129-147
ISSN: 1309-2448
www.berjournal.com

# Sustainable Supplier Selection with A Fuzzy Multi-Criteria Decision Making Method Based on Triple Bottom Line

**Burcu Avcı Öztürk**[a] **Funda Özçelik**[b]

**Abstract**: *To meet the demands of various stakeholders and to comply with environmental legislations, businesses started to look at their supply chain to enhance their overall sustainability profile. Supply chain operations with sustainability awareness have become an important issue in recent years and make the sustainable supplier performance evaluation and selection process as a central concept of sustainable supply chain management. In this study, supplier selection problem is modelled within the context of sustainable supply chain based on the triple bottom line concept. This paper examined the problem of identifying best supplier based on sustainability principles for supplier selection operations in supply chains. Due to it's multi-criteria nature, the sustainable supplier selection process requires an appropriate multi-criteria analysis and solution approach. Fuzzy TOPSIS method is applied for the performance evaluation and selection of an appropriate sustainable supplier of an energy company. According to the results, Supplier$_1$ is recommended with low risk as the best sustainable supplier alternative.*

**Keywords**: Sustainable supply chain, triple bottom line, fuzzy TOPSIS method.

**JEL Classification**: C61, M40, Q56

## 1. Introduction

Because of global warming and depletion of natural resources, consumers and stakeholders expect firms to be responsible from their business operations, and act environmentally and socially responsible as well as their economic responsibility. Nowadays, there has been rising concern about sustainability and companies start to inform their stakeholders about their operations and applications by issuing reports, in the name of "sustainability reports", "corporate social responsibility reports" or "triple bottom line reports". Thus sustainable development has become a buzzword in society and business world. In Brundtland Report[1] sustainability development defined as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). While it is the most quoted definition, various definitions of sustainability exist and the concept of "Triple Bottom Line" (TBL) approach operationalizes sustainability as a central concept. Three components of sustainability - economic, environmental, and social- are collectively called "triple bottom line". According to the TBL approach, minimum performance is to be achieved in the environmental, economic, and social dimensions (Seuring and Müller, 2008, p. 1700). TBL is a tool to measure an organization's progress towards the goal of sustainable development (Pagell and Wu, 2009, p. 38).

[a] Lecturer, PhD., Uludag University Faculty of Economics and Administrative Sciences, Department of Business Administration, Numerical Methods, Bursa, Turkiye, bavci@uludag.edu.tr
[b] Lecturer, PhD., Uludag University Faculty of Economics and Administrative Sciences, Department of Business Administration, Accounting and Finance, Bursa, Turkiye, fundacar@uludag.edu.tr

Suppliers play an important role in an organizations' overall value creation and total environmental impact, thus sustainability issues (environmental, social, and economic) are started to be taken into consideration by both academics and practitioners in supply chain management (SCM) (Paulraj, 2011, p. 19). Upon this, attention is given to the convergence of sustainable supply chain management (SSCM). Organizations are aware of the importance of their suppliers' sustainability responsibility in their own development, and the environmental sustainability of any organization is impossible without incorporating SSCM practices (Govindan, Khodaverdi and Jafarian, 2013, p. 346). SSCM refers to the integration of environmental and social issues into SCM with the aim of improving company's environmental and social performance in addition to its economic performance (Gimenez, Sierra and Rodon, 2012, p. 150).

Traditionally, organizations take into account the criteria such as price, quality, flexibility, etc. in the evaluation of supplier performance and supplier selection. As the sustainability enters the agenda of businesses, many organizations have started to select suppliers according to sustainability criteria and measure their suppliers' sustainability performance resulting from the sustainability activities. In the selection of appropriate suppliers, importance degree of selection criteria, and suppliers' performance with respect to these criteria are important subjects need to be verified by decision makers (DMs). In some situations, decision making problems involve several criteria and alternatives. These kind of problems are called multi-criteria decision making (MCDM) problems. MCDM problems often requires decision makers to provide qualitative and quantitative assesments for determinig the performance of alternatives with respect to each criterion, and the relative importance of evaluation criteria with respect to the overall objective of the problems (Amiri-Aref, Javadian and Kazemi, 2012, p. 92). The supplier performance evaluation and selection process involves different supplier alternatives and various criteria. Because of this, supplier performance evaluation and selection process may be considered as a type of MCDM problem which is complex and involves qualitative and quantitative criteria simultaneously (Büyükozan, 2012, p. 2892-2893).

DMs generally answer questions and express their perceptions in linguistic terms instead of numerical forms. In order to deal with the vagueness existing in the supplier selection process, fuzzy decision making methods can be applied. This study examined the problem of sustainable supplier performance evaulation and selection based on the TBL approach for supplier selection operations in supply chains by presenting a fuzzy multi criteria approach. Triangular fuzzy numbers are used to express linguistic values of DMs' subjective preferences.

Although there are a lot of researches on supplier selection in the literature, the research on sustainable supplier selection is rather limited. In this study supplier selection decision problem modelled within the context of sustainable supply chain based on the triple bottom line concept. The rest of the paper is structured as follows. Firstly, triple bottom line, SSCM concept, and major factors triggering sustainable supply chain practices are introduced. In the later section, sustainable supplier performance evaluation and selection criteria are described. The subsequent section includes a brief description of the Fuzzy set theory, and fuzzy TOPSIS method. After that an application in an energy company is given.

## 2. Triple bottom line (TBL)

John Elkington (1994) developed the term “Triple Bottom Line” as a method for the measurement of sustainability performance (Jackson, Boswell and Davis, 2011, p. 56). TBL, is an approach for management and performance evaluation that emphasizes the importance of economic, environmental, and social performance. TBL consists of the initial letters of the three words -People, Planet, Profit- and implies measuring success of the organization on three parameters (social, environmental, and economic). TBL approach not only take into account the economic value that businesses create, but also the environmental, and social value they create and destroy (Goel, 2010, p. 31, 32). Organizations that engage in activities which are at the intersection of social, environmental, and economic performance, positively affect the natural environment and society. At the same time they gain long-term economic success and competitive advantage (Carter and Rogers, 2008, p. 364, 365).

As a sign of their loyalty to sustainability practices firms issue TBL reports. TBL reporting demonstrates increased transparency and accountability. Through TBL reports, businesses increase stakeholders’ knowledge about company’s impact on the world around it in addition to it’s financial performance (Jackson et al., 2011, p. 56).

## 3. Sustainable Supply Chain Management (SSCM)

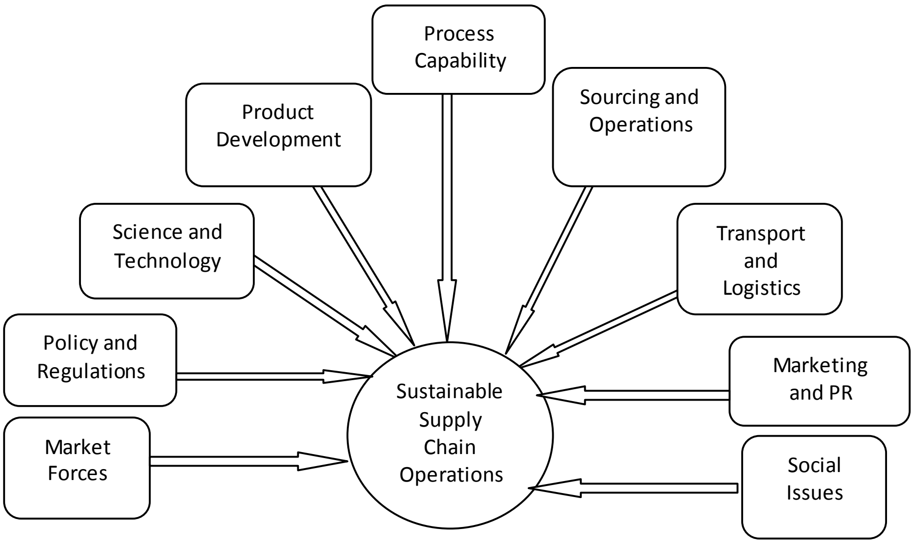
A supply chain includes the activities associated with the transformation and flow of goods and services and their related information flows from raw materials to the end user. Management represents the integration of these activities (Beske, 2012, p. 373, 374; Büyüközkan and Çiftçi, 2011, p. 164). Supply chain management (SCM) is relevant in addressing responsible behaviour at all stages of the supply chain. It represents a potentially important discipline for establishing integration of environmental, and social issues and practices into business operations and achieving sustainability goal (Ashby, Leat and Hudson-Smith, 2012, p. 497).

SSCM is 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 (Amindoust, Ahmed, Saghafinia and Bahreininejad, 2012, p. 1668; Büyüközkan and Çiftçi, 2011, p. 164; Seuring and Müller, 2008, p. 1700). In other words SSCM is the management of supply chain operations, resources, information, and funds to maximize the supply chain profitability, at the same time minimizing environmental impacts and maximizing the social well-being of the supply chain (Hassini, Surti and Searcy, 2012, p. 70). By this way the supply chain during the stages of production, consumption, customer service and post-disposal disposition of products considered entirely (Büyüközkan and Çiftçi, 2011, p. 164). In sustainable supply chains, members are wanted to meet the environmental and social criteria in addition to the economic criteria (Seuring and Müller, 2008, p. 1700). A sustainable supply chain is one that performs well on both traditional financial measures and environmental and social dimensions of sustainability, which means performing well on all elements of TBL (Pagell and Wu, 2009, p. 38). In order to achieve a sustainable supply chain, all the members of the supply chain must have compatibility with sustainability from suppliers to top managers (Amindoust, Ahmed, Saghafinia and Bahreininejad, 2012, p. 1668; Büyüközkan and Çiftçi, 2011, p. 165). Incorporating SSCM practices are essential for the sustainability of any organization (Ageron, Gunasekaran and Spalanzani, 2012, p. 169).

### 3.1. Major Factors Triggering Sustainable Supply Chain Practices

In order to react to pressures and incentives from environment, governments, non-governmental organizations (NGOs), and other stakeholders and for reputation and competitiveness, organizations start to engage in sustainability and SSCM practices. Major external and internal factors that trigger and enable supply chains to adopt sustainable operations are shown in Figure 1.

**Figure 1.** Factors Triggering Sustainable Supply Chain Practices




**Source:** Hassini, E., Surti, C., & Searcy, C. (2012). A literature review and a case study of sustainable supply chains with a focus on metrics. *International Journal of Production Economics*, 140 (1), 69–82, p. 75.

Market forces including consumers, retailers etc. may demand environmentally friendly products and their suppliers to act socially responsible. Nowadays customers are more conscious about their personal environmental impact and they are willing to pay more for environmentally friendly products. And this triggers companies to adopt more SSCM practices. Financial stakeholders require the company to follow sustainable practices and may be in the future access to capital markets restricted only firms that operate in accordance with the sustainability. Policy and regulations factor include governments legislation and regulation. In the adoption of SSCM practices regulatory pressures have major role. Through legislation or regulation, governments control pollution, reduce environmental damages, and curtail certain business practices (Hassini et al., 2012, p. 75; Ageron et al., 2012, p. 169, 170; Gopalakrishnon, Yusuf, Musa, Abubakar and Ambursa, 2012, p. 195). Science and technology factors try to find materials and processes that are not toxic and use less energy. The product development factor includes greening the existing product and developing new sustainable products by using more recycled content, using biodegradable materials, and design for disassembly etc. The process capability factor requires greening of existing process by using energy efficient machines and fuel efficient transportation etc. The supply chain should ensure the processes' capability of absorbing returns into manufacturing or production of new goods when the products returned after the useful life of the product. The sourcing and operations factors call for firms to deal with green sourcing practices and suppliers' adoption to environmentally friendly processes. The transport and logistics factors lead firms to take into account the economics of reverse logistics and closed loop supply chains and reuse, recycle, and return programs. The marketing and public relations factors involve value proposition for the customer in order to justify the high priced environmentally friendly products. The social issues factor focuses on the labor force applications, sourcing practices and environmental impact on their communities (Hassini et al., 2012, p. 75).

Because suppliers can affect the performance of the company and entire supply chain, companies have to integrate sustainable practices in the selection and performance evaluation of their suppliers. Reputation about sustainability can enhance the competitiveness of a company (Ageron et al., 2012, p. 169, 170).

### 3.2. Sustainable Supplier Performance Evaluation and Selection

In order to build a sustainable supply base, supplier selection constitutes one of the most important activities. Sustainable supplier selection requires the evaluation of suppliers' performance in terms of several metrics. While traditional supplier selection process only considers the economic aspects, competitive market situations and demands of stakeholders make necessary the addition of environmental and social criteria. Traditional performance criteria can be assessed at the point of delivery but the criteria related to the environmental and social aspects of sustainability can only be assessed at suppliers' locations by assessing under which conditions they were produced. In order to reduce the focal company's risk to encounter unsustainable behavior, suppliers' production processes, facilities and attitudes towards society and environment need to be evaluated cautiously (Goebel, Reuter, Pibernik and Sichtmann, 2012, p. 8).

The supplier performance evaluation and selection process involves different supplier alternatives and various criteria. Because of this, supplier performance evaluation and selection process may be considered as a type of MCDM problem. A MCDM problem often deals with subjective human preferences. Human judgments and preferences are often vague and complex, and DMs assess their preferences with linguistic terms instead of assessing with an exact scale. Because of this, fuzzy set theory is introduced into the MCDM framework, which is put forward to solve such uncertainty problems (Govindan et al., 2013, p. 346).

According to sustainable supplier performance evaluation and selection literature, economic, environmental and social criteria for selecting appropriate supplier to an energy company are identified and shown in Table 1.

There are several articles about supplier performance evaluation and selection and in recent times, articles about green supplier selection are widespread. In the literature review the articles about supplier selection that are based on TBL are taken into account. Bai and Sarkis (2010) used grey system and rough set theory as an effective and realistic modeling approach for sustainable supplier selection. Büyüközkan and Çifçi (2011) proposed a novel fuzzy multi criteria decision framework for sustainable supplier selection with incomplete information. Erol, Sencer and Sari (2011) proposed a multi-criteria framework based on fuzzy entropy and fuzzy multi-attribute utility (FMAUT) in order to evaluate and compare the sustainability performances of suppliers of a supply chain. Amindoust et al. (2012) determined sustainable supplier selection criteria and sub-criteria and based on those criteria and sub-criteria a methodology is proposed on to evaluation and ranking of a given set of suppliers. To handle the subjectivity of decision makers' assessments, fuzzy logic has been applied and a new ranking method on the basis of fuzzy inference system (FIS) is proposed for supplier selection problem. Verdecho, Alfara-Saiz and Rodriguez (2012), applied a BSC-AHP performance measurement framework for supply chain sustainability. Rabenasolo and Zeng (2012) proposed a risk-based multi-criteria decision support system for evaluating risks of different textile materials and suppliers using the criteria of sustainable development and fuzzy multi-criteria methods are applied in order to select the most appropriate textile material and textile company's supplier. Govindan, Khodaverdi and Jafarian (2013) explored sustainable supply chain initiatives and identified an effective model based on the TBL approach for supplier selection in supply chains by presenting fuzzy TOPSIS method. Wen, Xu and Wang (2013) proposed a new method for supplier selection based on intuitionistic fuzzy sets and an emprical study was researched to test validity and efficiency of the indicators for sustainable supplier evaluation.

**Table 1.** Sustainable Supplier Performance Evaluation and Selection Criteria

| **CRITERIA** | **DEFINITION** |
|---|---|
| **ECONOMIC CRITERIA** | |
| Costs | Product cost, ordering and logistic cost, inventory cost, custom and insurance cost. |
| Quality | Rejection rate, quality related certificates, capability of quality management, capability of handling abnormal activity. |
| Lead Time and On Time Delivery | Time between placement and arrival of an order, ability of following delivery schedule. |
| Technology Capability | Technology and R&D support, technology level and capability of design. |
| **ENVIRONMENTAL CRITERIA** | |
| Pollution Control | Air emmissions, waste water, solid wastes and use of harmful materials. |
| Resource Consumption | Consumption of raw materials, energy and water. |
| Green Product and Eco-design | Use of environmentally friendly technology and materials, design capability for reduced consumption of material/energy, reuse, recycle of material, design of products to avoid or reduce use of harmful materials, green packaging. |
| Environmental Management System | Environment related certificates like ISO 14001, environmental policies, checking and control of environmental processes. |
| **SOCIAL CRITERIA** | |
| Health and Safety Practices | Occupational health and safety programs, education, training, counseling, prevention, and risk-control programs in place to assist workforce members or community members regarding serious diseases. |
| Social Responsibility | Supporting community projects, supporting educational institutions, grants and donations. |
| Education Infrastructure | Programs for skills management and lifelong learning that support the continued employability of employees and assist them in managing career endings. |
| Employment Practices | Labor relations, human rights and interest of employee, flexible working arrangements, working conditions and abolution of child labor, equity of labor sources, diversity and discrimination |

### 4. Fuzzy Set Theory

In real-life conditions, exact data isn't adequate for modeling human judgements and preferences which are often subjective, uncertain and ambiguous. They souldn't be expressed by certain numbers (Shen, Olfat, Govindan, Khodaverdi and Diabat, 2013, p. 172). If the uncertainty of human decisions is not taken into account, the results of decisions may be misleading (Lee, Kang, Hsu and Hung, 2009, p. 7919). In order to represent human judgements expressed by linguistic terms in decision process, fuzzy set theory was introduced by Zadeh (1965). Fuzzy set theory enables DMs to deal with the linguistic expressions of human judgements. Bellman and Zadeh (1970) first applied fuzzy set theory in decision making process and they initiated the Fuzzy Multi-Criteria Decision Making (FMCDM) methodology (Bellman and Zadeh, 1970; Govindan et al., 2013, p. 349). As usage and calculation of a triangular fuzzy number is easy, in this paper, triangular fuzzy numbers are used to define the preferences of DMs.

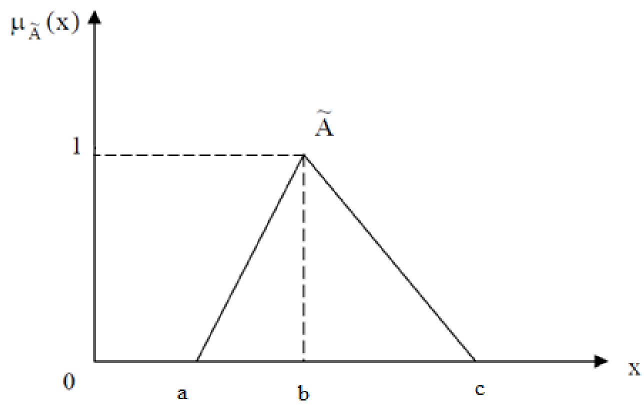
A fuzzy set is a class of objects with a continuum of membership grades, where the membership grade can be taken as an intermediate value between 0 and 1. A fuzzy subset A of a universal set X is defined by a membership function $f_A(x)$ which maps each element x in X to a real number [0, 1]. When the grade of membership for an element is 1, it means that the element is absolutely in that set. When the grade of membership is 0, it means that the element is absolutely not in that set. Ambiguous cases are assigned values between 0 and 1. A triangular fuzzy number can be shown as (a, b, c). The parameters a, b, and c respectively, denote the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event (Zadeh, 1965, p. 339; Govindan, 2013, p. 350; Erol, Sencer and Sari, 2011, p. 1089).

A fuzzy number $\tilde{A}$ in real line $\Re$ is a triangular fuzzy number if the fuzzy number's membership function $\mu_{\tilde{A}}:\Re \rightarrow [0,1]$ is ( $-\infty < a \leq b \leq c < \infty$ ) (Ding, 2011, p. 342; Shen et al., 2013, p. 173):

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-a)/(b-a) & a \leq x \leq b \\ (c-x)/(c-b) & b \leq x \leq c \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

The membership function of a triangular fuzzy number is shown in Figure 2 (Lee et al., 2009, p. 7919; Erol et al., 2011, p. 1090; Shen et al., 2013, p. 173)

**Figure 2.** A Triangular Fuzzy Number



Let $\tilde{A}=(a_1,b_1,c_1)$ and $\tilde{B}=(a_2,b_2,c_2)$ be two triangular fuzzy numbers. The basic arithmetic operations of triangular fuzzy numbers are defined as follows (Shen et al, 2013, p. 173; Ding, 2011, p. 342; Erol et al, 2011, p. 1090):

$$\tilde{A}(+)\tilde{B}=(a_1,b_1,c_1)(+)(a_2,b_2,c_2)=(a_1+a_2,b_1+b_2,c_1+c_2)$$

$$\tilde{A}(-)\tilde{B}=(a_1,b_1,c_1)(-)(a_2,b_2,c_2)=(a_1-c_2,b_1-b_2,c_1-a_2) \quad (3)$$

$$k\tilde{A}=(ka_1,kb_1,kc_1) \quad (4)$$

$$(\tilde{A})^{-1}=\left(\frac{1}{c_1},\frac{1}{b_1},\frac{1}{a_1}\right) \quad (5)$$

The distance between fuzzy numbers $\tilde{A}$ and $\tilde{B}$ using vertex method is calculated as follows (Govindan et al, 2013: 350):

$$d(\tilde{A},\tilde{B})=\sqrt{1/3\left[(a_1-a_2)^2+(b_1-b_2)^2+(c_1-c_2)^2\right]} \quad (6)$$

**5. Fuzzy TOPSIS Method**

TOPSIS (Technique for Order Preference by Similarity to Ideal solution), proposed by Hwang and Yoon (1981) is a MCDM problem solving method which is based on the principle that the chosen alternative should have the longest distance from the negative ideal solution (NIS) and the shortest distance from the positive ideal solution (PIS). NIS maximizes the cost criteria and minimizes the benefit criteria; PIS maximizes the benefit criteria and minimizes the cost criteria (Ashrafzadeh, Rafiei, Isfahani and Zare, 2012, p. 659). In traditional TOPSIS, measurement of importance weight of criteria and preferences of each alternative with respect to criteria are determined by crisp numbers. However, in many situations crisp data are inadequate for modeling real life situations and it may be difficult to get exact data because of the vaguness, subjectivity and uncertainty of human judgements which shouldn't be expressed by exact numeric values (Gao, Feng and Yang, 2008, p. 1; Ashrafzadeh et al, 2012, p. 659). In order to deal with uncertainty and vaguness of human judgements Chen and Hwang (1992) are first proposed to use fuzzy numbers in MCDM problems. Then Chen (2000) first used triangular fuzzy numbers in TOPSIS method. He extended the concept of TOPSIS to develop a methodology for solving multi-criteria and multi-person decision making problems in fuzzy environment (Chen, 2000, p. 2).

Fuzzy TOPSIS deals with linguistic variables which enable DMs to specify both the importance weights of criteria and the preferences of each alternative with respect to a set of criteria by using fuzzy numbers instead of crisp numbers in group MCDM problems (Gao et al., 2008, p. 1-2).

Fuzzy TOPSIS method is selected to apply for sustainable supplier selection process among the other MCDM techniques such as AHP, ELECTRE and etc. because of the following features (Govindan et al, 2013, s. 351):

**1.** Number of criteria and alternatives are unlimited and each of them is evaluated independently without making any comparisons.

**2.** MCDM methods like AHP require pairwise comparisons. Pairwise comparison matrices are likely to be inconsistent when there are large number of criteria and alternatives.

**3.** It has relatively simple computing process with a systematic procedure and it is appropriate for group decision making in multi-person MCDM problems.

**4.** According to the simulation comparison among the MCDM methods from Zanakis, Solomon, Wishart and Dublish (1998), TOPSIS has the fewest rank reversals when an alternative is added or removed.

**5.** Some MCDM methods such as ELECTRE only determines the rank of each alternative but preferential ranking of alternatives with a numerical value provides a better understanding of differences and similarities between alternatives.

Supplier performance evaluation and selection problem is a fuzzy group MCDM problem which may be described by the following sets (Chen, Lin and Huang, 2006, p. 294):

**1.** A set of k DMs called E = {$DM_1$, $DM_2$, ....., $DM_k$};

**2.** A set of m suppliers called S = {$S_1$, $S_2$, ....., $S_m$};

**3.** A set of n criteria called C = {$C_1$, $C_2$, ....., $C_n$};

**4.** A set of performance ratings of $S_i$ (i=1, 2, ..... ,m) with respect to criteria $C_j$ (j=1, 2, ..... ,n) called X = {$\tilde{x}_{ij}$, i=1, 2, ..... ,m; j=1, 2, ..... ,n}

Application steps and algorithm of the fuzzy TOPSIS method for dealing with the supplier selection are given as follows (Chen, 2000; Chen et al., 2006; Ghorbani, Velayati and Ghorbani, 2011; Ashrafzadeh et al., 2012)

**Step 1:** Form a committee of DMs and then identify the evaluation criteria.

**Step 2:** Choose the appropriate linguistic variables for the importance weight of the criteria and the linguistic ratings for suppliers.

**Table 2.** Linguistic Variable for Relative İmportance Weights of Criteria

| Linguistic variable | Fuzzy numbers |
|---|---|
| Very low (VL) | (0, 0, 0.1) |
| Low (L) | (0, 0.1, 0.3) |
| Medium low (ML) | (0.1, 0.3, 0.5) |
| Medium (M) | (0.3, 0.5, 0.7) |
| Medium high (MH) | (0.5, 0.7, 0.9) |
| High (H) | (0.7, 0.9, 1.0) |
| Very high (VH) | (0.9, 1.0, 1.0) |

**Table 3.** Linguistic Variable for Rating

| Linguistic variable | Fuzzy numbers |
|---|---|
| Very poor (VP) | (0, 0, 1) |
| Poor (P) | (0, 1, 3) |
| Medium poor (MP) | (1, 3, 5) |
| Medium (M) | (3, 5, 7) |
| Medium good (MG) | (5, 7, 9) |
| Good (G) | (7, 9, 10) |
| Very good (VG) | (9, 10, 10) |

In fuzzy TOPSIS method, the importance weights of various criteria and the ratings of alternatives with respect to each criterion are considered as linguistic variables. Linguistic variable for relative importance weights of criteria and linguistic variable for ratings can be expressed in positive triangular fuzzy numbers in Table 2 and 3 (Chen, 2000, p. 6).

**Step 3:** Aggregate the weight of criteria to get the aggregated fuzzy weight $\tilde{w}_{ij}$ of criterion $C_j$, and the DMs' ratings to get the aggregated fuzzy rating $\tilde{x}_{ij}$ of supplier $S_i$ under criterion $C_j$ .

Assume that a decision group has k people, the group decisions which show the importance of the criteria and the ratings of alternatives with respect to each criterion can be calculated as follows, where $\tilde{x}_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk})$ and $\tilde{w}_{jk} = (w_{jk1}, w_{jk2}, w_{jk3})$ are the rating and importance weight of the $k^{th}$ DM respectively. (Chen et al., 2006, p. 294; Ding, 2011, p. 346; Başkaya and Avcı Öztürk, 2012, p. 162, 163).

$$\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$$

$$a_{ij} = Min_k\{a_{ijk}\} \qquad b_{ij} = \left(\prod_{i=1}^{k} b_{ijk}\right)^{1/k} \qquad c_{ij} = Max_k\{c_{ijk}\} \tag{7}$$

$$\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3})$$

$$w_{j1} = Min_k\{w_{jk1}\} \qquad w_{j2} = \left(\prod_{i=1}^{k} w_{jk2}\right)^{1/k} \qquad w_{j3} = Max_k\{w_{jk3}\} \tag{8}$$

**Step 4:** Construct the fuzzy decision matrix and the normalized fuzzy decision matrix.

A fuzzy MCDM problem can be consisely expressed in matrix format as (Büyükozan, 2012: 2901);

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \qquad \tilde{W} = [\tilde{w}_1, \tilde{w}_2, \ldots\ldots, \tilde{w}_n] \tag{9}$$

$\tilde{D}$ represents the fuzzy decision matrix (Büyükozan, 2012, p. 2901) and $\tilde{x}_{ij}$ (i=1, 2, ..... ,m; j=1, 2, ..... ,n) is the performance rating of the $i^{th}$ alternative with respect to $j^{th}$ criterion, $\tilde{w}_j$ (j=1, 2, ..... ,n) represents the weight of the $i^{th}$ criterion (Amiri-Aref et al., 2012, p. 94).

Normalization method is used to eliminate anomalies which are caused by different measurement units and scales and make criteria comparable. Linear scale transformation is used to normalize the fuzzy decision matrix and normalization function provides that the ranges of normalized triangular fuzzy numbers will be in interval [0, 1]. Let $\tilde{R}$ denotes normalized fuzzy decision matrix, where B and C are the set of benefit criteria and cost criteria respectively (Gao et al., 2008, p. 2).

$$\tilde{R} = \left[ \tilde{r}_{ij} \right]_{mxn} \qquad i = 1,2,......,m \qquad j = 1,2,......,n$$

$$\tilde{r}_{ij} = \left( \frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right) \quad , \ j \in B \tag{11}$$

$$\tilde{r}_{ij} = \left( \frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}} \right) \quad , \ j \in C \tag{14}$$

$$c_j^* = Max_i \, c_{ij} \quad , \quad j \in B \tag{13}$$

$$a_j^- = Min_i \ a_{ij} \quad , \quad j \in C$$

Weigted normalized fuzzy decision matrix $\tilde{V}$ is calculated by multiplying fuzzy weights of the criteria with normalized fuzzy decision matrix where $\tilde{r}_{ij}$ denotes the weighted normalized fuzzy numbers and $\tilde{w}_j$ is the fuzzy weight of the $j^{th}$ criterion (Shen et al., 2013, p. 174).

$$\tilde{V} = \left[ \tilde{v}_{ij} \right]_{mxn} \qquad i = 1,2,......,m \qquad j = 1,2,......,n \tag{15}$$

$$\tilde{v}_{ij} = \tilde{r}_{ij} \, (\otimes) \, \tilde{w}_j \tag{16}$$

**Step 6:** Determine fuzzy positive ideal solution (FPIS, $\tilde{A}^*$) and fuzzy negative ideal solution (FNIS, $\tilde{A}^-$).

FPIS, $\tilde{A}^*$ and FNIS, $\tilde{A}^-$ can be defined as (Govindan et al, 2013: 351):

$$\tilde{A}^* = \left( \tilde{v}_1^*, \tilde{v}_2^*, ......., \tilde{v}_n^* \right) \tag{17}$$

$$\tilde{A}^- = \left( \tilde{v}_1^-, \tilde{v}_2^-, ......., \tilde{v}_n^- \right) \tag{18}$$

$$\tilde{v}_j^* = Max_i \left\{ v_{ij3} \right\} \tag{19}$$

$$\tilde{v}_j^- = Min_i \left\{ v_{ij1} \right\} \qquad i = 1,2,......,m \quad , \quad j = 1,2,......,n \tag{20}$$

**Step 7:** Calculate the distance of each supplier from $\tilde{A}^*$ and $\tilde{A}^-$ respectively.

The distance of each alternative from $\tilde{A}^*$ and $\tilde{A}^-$ is calculated as follows (Shen et al., 2013, p. 174):

$$d_i^* = \sum_{j=1}^{n} d\left( \tilde{v}_{ij}, \tilde{v}_j^* \right) \qquad i = 1,2,.......,m \tag{21}$$

$$d_i^- = \sum_{j=1}^{n} d\left( \tilde{v}_{ij}, \tilde{v}_j^- \right) \qquad i = 1,2,.......,m \tag{22}$$

$d\left(\tilde{v}_{ij},\tilde{v}_j^*\right)$ and $d\left(\tilde{v}_{ij},\tilde{v}_j^-\right)$ are the distances between two fuzzy numbers and they are calculated by Vertex method.

**Step 8:** Calculate the closeness coefficient ($CC_i$) of each supplier.

$CC_i$ is calculated for determining the ranking order of all possible suppliers. The $CC_i$ of each alternative supplier can be calculated as (Chen, 2000, p. 6; Govindan et al., 2013, p. 351):

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \quad , \qquad i = 1,2,......,m \tag{23}$$

**Step 9:** According to the $CC_i$, we can understand the assessment status of each supplier and determine the ranking order of all suppliers.

At the end of the fuzzy TOPSIS method, alternative suppliers are ranked with respect to $CC_i$ values. The best alternative has the highest $CC_i$ value. Alternative supplier $S_i$ is closer to the FPIS, $\tilde{A}^*$ and farther from FNIS, $\tilde{A}^-$ as $CC_i$ approaches to 1 (Shen et al., 2013, p. 174).

According to the $CC_i$ values there are five classes for approval status of suppliers (Chen et al., 2006, p. 296):

**Class 1:** If $CC_i \in [0, 0.2)$, then supplier $S_i$ belongs to Class 1 and the assessment status of supplier $S_i$ is "not recommend";

**Class 2:** If $CC_i \in [0.2, 0.4)$, then supplier $S_i$ belongs to Class 2 and the assessment status of supplier $S_i$ is "recommend with high risk";

**Class 3:** If $CC_i \in [0.4, 0.6)$, then supplier $S_i$ belongs to Class 3 and the assessment status of supplier $S_i$ is "recommend with low risk";

**Class 4:** If $CC_i \in [0.6, 0.8)$, then supplier $S_i$ belongs to Class 4 and the assessment status of supplier $S_i$ is "approved";

**Class 5:** If $CC_i \in [0.8, 1.0]$, then supplier $S_i$ belongs to Class 5 and the assessment status of supplier $S_i$ is "approved and preferred to recommend".

If any two or more suppliers belong to the same class, the supplier which has the higher value of $CC_i$ takes the higher place in the ranking.

## 6. A Fuzzy Multi-Criteria Method for Sustainable Supplier Selection

In order to gain the best results from sustainable supplier management, suppliers must improve their environmental and social performance in addition to their economic performance. In this paper the problem of supplier selection based on sustainability principles in supply chains is examined. A case study is illustrated to show how fuzzy TOPSIS method is used for sustainable supplier selection.

According to sustainable supplier performance evaluation and selection literature, economic, environmental and social criteria for selecting appropriate supplier to an energy company are identified. Selected criteria and their definitions are shown in Table 1 and the hierarchical structure of sustainable supplier selection MCDM problem is shown in Figure 3.

**Figure 3.** Hierarchical structure of sustainable supplier selection MCDM problem

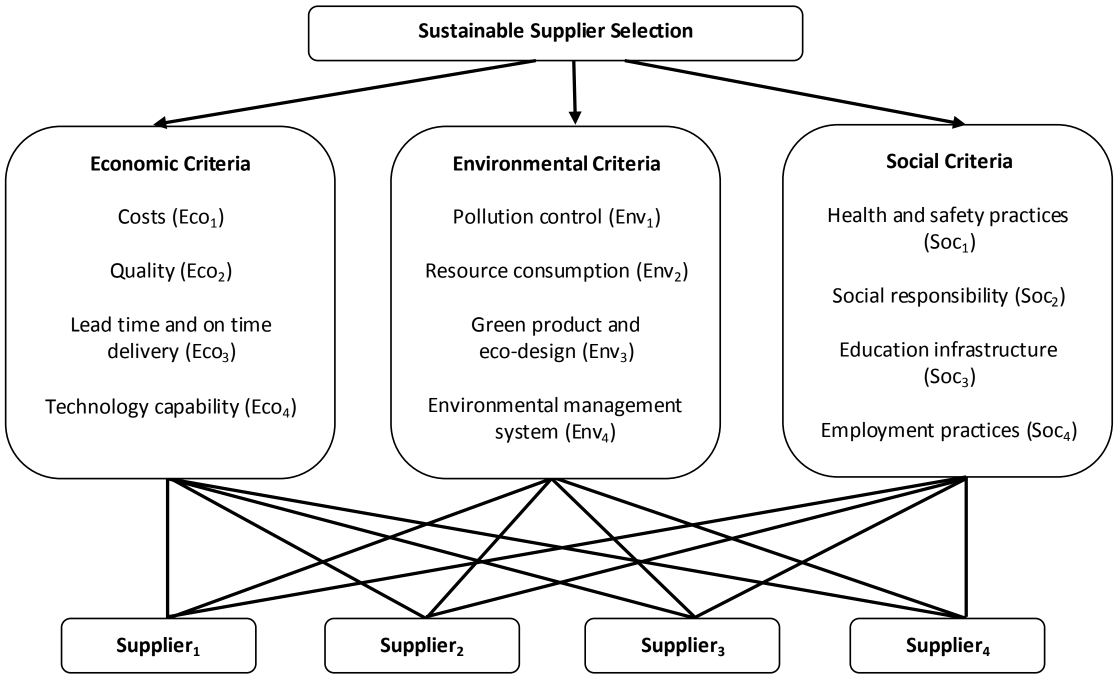



**Table 4.** Linguistic Assessments of Criteria from DMs

| Decision Makers (DMs) | CRITERIA | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $Eco_1$ | $Eco_2$ | $Eco_3$ | $Eco_4$ | $Env_1$ | $Env_2$ | $Env_3$ | $Env_4$ | $Soc_1$ | $Soc_2$ | $Soc_3$ | $Soc_4$ |
| $DM_1$ | H | H | H | MH | VH | H | H | M | M | VH | M | MH |
| $DM_2$ | VH | VH | H | M | MH | H | M | ML | M | H | ML | H |
| $DM_3$ | VH | VH | H | MH | VH | H | H | M | MH | VH | M | MH |

**Table 5.** Fuzzy Weights of Criteria and Group Decision

| Criteria | Decision Makers (DMs) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $DM_1$ | | | $DM_2$ | | | $DM_3$ | | | Group Decision | | |
| $Eco_1$ | 0.7 | 0.9 | 1 | 0.9 | 1 | 1 | 0.9 | 1 | 1 | 0.7 | 0.965 | 1 |
| $Eco_2$ | 0.7 | 0.9 | 1 | 0.9 | 1 | 1 | 0.9 | 1 | 1 | 0.7 | 0.965 | 1 |
| $Eco_3$ | 0.7 | 0.9 | 1 | 0.7 | 0.9 | 1 | 0.7 | 0.9 | 1 | 0.7 | 0.9 | 1 |
| $Eco_4$ | 0.5 | 0.7 | 0.9 | 0.3 | 0.5 | 0.7 | 0.5 | 0.7 | 0.9 | 0.3 | 0.626 | 0.9 |
| $Env_1$ | 0.9 | 1 | 1 | 0.5 | 0.7 | 0.9 | 0.9 | 1 | 1 | 0.5 | 0.888 | 1 |
| $Env_2$ | 0.7 | 0.9 | 1 | 0.7 | 0.9 | 1 | 0.7 | 0.9 | 1 | 0.7 | 0.9 | 1 |
| $Env_3$ | 0.7 | 0.9 | 1 | 0.3 | 0.5 | 0.7 | 0.7 | 0.9 | 1 | 0.3 | 0.74 | 1 |
| $Env_4$ | 0.3 | 0.5 | 0.7 | 0.1 | 0.3 | 0.5 | 0.3 | 0.5 | 0.7 | 0.1 | 0.422 | 0.7 |
| $Soc_1$ | 0.3 | 0.5 | 0.7 | 0.3 | 0.5 | 0.7 | 0.5 | 0.7 | 0.9 | 0.3 | 0.559 | 0.9 |
| $Soc_2$ | 0.9 | 1 | 1 | 0.7 | 0.9 | 1 | 0.9 | 1 | 1 | 0.7 | 0.965 | 1 |
| $Soc_3$ | 0.3 | 0.5 | 0.7 | 0.1 | 0.3 | 0.5 | 0.3 | 0.5 | 0.7 | 0.1 | 0.422 | 0.7 |
| $Soc_4$ | 0.5 | 0.7 | 0.9 | 0.7 | 0.9 | 1 | 0.5 | 0.7 | 0.9 | 0.5 | 0.761 | 1 |

An interview was conducted on three DMs (general director, coporate management director, purchasing and supply director) to acquire their opinions about relative importance of criteria and performance of suppliers with respect to each criterion. There are twelve criteria that involve four economic, four environmental and four social criteria for determining the best supplier alternative for the company. DMs expressed their opinions about twelve criteria independently. Table 4 shows linguistic assessments of DMs about each criterion and Table 5 shows fuzzy weights of criteria and fuzzy group decision for relative importance of twelve criteria.

**Table 6.** Ratings of Suppliers by DMs Under Various Criteria

| Decision Makers (DMs) | Criteria | Suppliers ($S_i$) | | | |
|---|---|---|---|---|---|
| | | $S_1$ | $S_2$ | $S_3$ | $S_4$ |
| $DM_1$ | $Eco_1$ | MG | G | VG | M |
| | $Eco_2$ | G | M | M | G |
| | $Eco_3$ | G | G | MG | G |
| | $Eco_4$ | VG | M | MP | G |
| | $Env_1$ | G | MP | M | G |
| | $Env_2$ | MG | M | M | MG |
| | $Env_3$ | M | MG | M | MG |
| | $Env_4$ | VG | G | MG | VG |
| | $Soc_1$ | MG | G | M | G |
| | $Soc_2$ | G | G | MG | MG |
| | $Soc_3$ | M | MP | MP | M |
| | $Soc_4$ | G | G | G | VG |
| $DM_2$ | $Eco_1$ | MG | VG | G | MP |
| | $Eco_2$ | VG | MP | MP | G |
| | $Eco_3$ | G | MG | MG | G |
| | $Eco_4$ | VG | MP | MP | G |
| | $Env_1$ | G | M | M | G |
| | $Env_2$ | MG | M | M | MG |
| | $Env_3$ | MG | MG | MP | G |
| | $Env_4$ | G | G | M | G |
| | $Soc_1$ | MG | G | M | MG |
| | $Soc_2$ | VG | MG | MG | MG |
| | $Soc_3$ | M | MP | MP | MG |
| | $Soc_4$ | G | G | MG | G |
| $DM_3$ | $Eco_1$ | MG | G | VG | M |
| | $Eco_2$ | G | M | M | G |
| | $Eco_3$ | G | MG | M | G |
| | $Eco_4$ | G | M | M | G |
| | $Env_1$ | G | MP | M | MG |
| | $Env_2$ | M | G | MG | M |
| | $Env_3$ | MG | M | M | G |
| | $Env_4$ | G | G | MG | G |
| | $Soc_1$ | G | G | MG | G |
| | $Soc_2$ | G | MG | G | MG |
| | $Soc_3$ | M | MP | M | M |
| | $Soc_4$ | G | G | G | VG |

DMs evaluated supplier alternatives with respect to each sustainable supplier evaluation and selection criterion. The ratings of each supplier under various criteria which are described by linguistic variables are defined in Table 6.

DMs' linguistic assesments are turned into triangular fuzzy numbers and group decisions for ratings are calculated for each criterion and supplier. The results are given in Table 7 which is called fuzzy decision matrix.

**Table 7.** Fuzzy Decision Matrix

| Criteria | $Supplier_1$ | | | $Supplier_2$ | | | $Supplier_3$ | | | $Supplier_4$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $Eco_1$ | 5.000 | 7.000 | 9.000 | 7.000 | 9.322 | 10.000 | 7.000 | 9.655 | 10.000 | 1.000 | 4.217 | 7.000 |
| $Eco_2$ | 7.000 | 9.322 | 10.000 | 1.000 | 4.217 | 7.000 | 1.000 | 4.217 | 7.000 | 7.000 | 9.000 | 10.000 |
| $Eco_3$ | 7.000 | 9.000 | 10.000 | 5.000 | 7.612 | 10.000 | 3.000 | 6.257 | 9.000 | 7.000 | 9.000 | 10.000 |
| $Eco_4$ | 7.000 | 9.655 | 10.000 | 1.000 | 4.217 | 7.000 | 1.000 | 3.557 | 7.000 | 7.000 | 9.000 | 10.000 |
| $Env_1$ | 7.000 | 9.000 | 10.000 | 1.000 | 3.557 | 7.000 | 3.000 | 5.000 | 7.000 | 5.000 | 8.277 | 10.000 |
| $Env_2$ | 3.000 | 6.257 | 9.000 | 3.000 | 6.082 | 10.000 | 3.000 | 5.593 | 9.000 | 3.000 | 6.257 | 9.000 |
| $Env_3$ | 3.000 | 6.257 | 9.000 | 3.000 | 6.257 | 9.000 | 1.000 | 4.217 | 7.000 | 5.000 | 8.277 | 10.000 |
| $Env_4$ | 7.000 | 9.322 | 10.000 | 7.000 | 9.000 | 10.000 | 3.000 | 6.257 | 9.000 | 7.000 | 9.322 | 10.000 |
| $Soc_1$ | 5.000 | 7.612 | 10.000 | 7.000 | 9.000 | 10.000 | 3.000 | 5.593 | 9.000 | 5.000 | 8.277 | 10.000 |
| $Soc_2$ | 7.000 | 9.322 | 10.000 | 5.000 | 7.612 | 10.000 | 5.000 | 7.612 | 10.000 | 5.000 | 7.000 | 9.000 |
| $Soc_3$ | 3.000 | 5.000 | 7.000 | 1.000 | 3.000 | 5.000 | 1.000 | 3.557 | 7.000 | 3.000 | 5.593 | 9.000 |
| $Soc_4$ | 7.000 | 9.000 | 10.000 | 7.000 | 9.000 | 10.000 | 5.000 | 8.277 | 10.000 | 7.000 | 9.655 | 10.000 |

Fuzzy decision matrix is normalized by linear transformation method, by dividing Table 7 to 10 ( $c_j^*$ ) which is the benefit criteria set's maximum $c_{ij}$ value of fuzzy decision matrix.

Normalized fuzzy decision matrix is illustrated in Table 8. After that weighted fuzzy decision matrix is calculated by multiplying fuzzy weights of the criteria with normalized fuzzy decision matrix and is shown in Table 9.

**Table 8.** Normalized Fuzzy Decision Matrix

| Criteria | $Supplier_1$ | | | $Supplier_2$ | | | $Supplier_3$ | | | $Supplier_4$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $Eco_1$ | 0.500 | 0.700 | 0.900 | 0.700 | 0.932 | 1.000 | 0.700 | 0.965 | 1.000 | 0.100 | 0.422 | 0.700 |
| $Eco_2$ | 0.700 | 0.932 | 1.000 | 0.100 | 0.422 | 0.700 | 0.100 | 0.422 | 0.700 | 0.700 | 0.900 | 1.000 |
| $Eco_3$ | 0.700 | 0.900 | 1.000 | 0.500 | 0.761 | 1.000 | 0.300 | 0.626 | 0.900 | 0.700 | 0.900 | 1.000 |
| $Eco_4$ | 0.700 | 0.965 | 1.000 | 0.100 | 0.422 | 0.700 | 0.100 | 0.356 | 0.700 | 0.700 | 0.900 | 1.000 |
| $Env_1$ | 0.700 | 0.900 | 1.000 | 0.100 | 0.356 | 0.700 | 0.300 | 0.500 | 0.700 | 0.500 | 0.828 | 1.000 |
| $Env_2$ | 0.300 | 0.626 | 0.900 | 0.300 | 0.608 | 1.000 | 0.300 | 0.559 | 0.900 | 0.300 | 0.626 | 0.900 |
| $Env_3$ | 0.300 | 0.626 | 0.900 | 0.300 | 0.626 | 0.900 | 0.100 | 0.422 | 0.700 | 0.500 | 0.828 | 1.000 |
| $Env_4$ | 0.700 | 0.932 | 1.000 | 0.700 | 0.900 | 1.000 | 0.300 | 0.626 | 0.900 | 0.700 | 0.932 | 1.000 |
| $Soc_1$ | 0.500 | 0.761 | 1.000 | 0.700 | 0.900 | 1.000 | 0.300 | 0.559 | 0.900 | 0.500 | 0.828 | 1.000 |
| $Soc_2$ | 0.700 | 0.932 | 1.000 | 0.500 | 0.761 | 1.000 | 0.500 | 0.761 | 1.000 | 0.500 | 0.700 | 0.900 |
| $Soc_3$ | 0.300 | 0.500 | 0.700 | 0.100 | 0.300 | 0.500 | 0.100 | 0.356 | 0.700 | 0.300 | 0.559 | 0.900 |
| $Soc_4$ | 0.700 | 0.900 | 1.000 | 0.700 | 0.900 | 1.000 | 0.500 | 0.828 | 1.000 | 0.700 | 0.965 | 1.000 |

**Table 9.** Weighted Normalized Fuzzy Decision Matrix

| Criteria | $Supplier_1$ | | | $Supplier_2$ | | | $Supplier_3$ | | | $Supplier_4$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $Eco_1$ | 0.350 | 0.676 | 0.900 | 0.490 | 0.900 | 1.000 | 0.490 | 0.932 | 1.000 | 0.070 | 0.407 | 0.700 |
| $Eco_2$ | 0.490 | 0.900 | 1.000 | 0.070 | 0.407 | 0.700 | 0.070 | 0.407 | 0.700 | 0.490 | 0.869 | 1.000 |
| $Eco_3$ | 0.490 | 0.810 | 1.000 | 0.350 | 0.685 | 1.000 | 0.210 | 0.563 | 0.900 | 0.490 | 0.810 | 1.000 |
| $Eco_4$ | 0.210 | 0.604 | 0.900 | 0.030 | 0.264 | 0.630 | 0.030 | 0.223 | 0.630 | 0.210 | 0.563 | 0.900 |
| $Env_1$ | 0.350 | 0.799 | 1.000 | 0.050 | 0.316 | 0.700 | 0.150 | 0.444 | 0.700 | 0.250 | 0.735 | 1.000 |
| $Env_2$ | 0.210 | 0.563 | 0.900 | 0.210 | 0.547 | 1.000 | 0.210 | 0.503 | 0.900 | 0.210 | 0.563 | 0.900 |
| $Env_3$ | 0.090 | 0.463 | 0.900 | 0.090 | 0.463 | 0.900 | 0.030 | 0.312 | 0.700 | 0.150 | 0.612 | 1.000 |
| $Env_4$ | 0.070 | 0.393 | 0.700 | 0.070 | 0.380 | 0.700 | 0.030 | 0.264 | 0.630 | 0.070 | 0.393 | 0.700 |
| $Soc_1$ | 0.150 | 0.426 | 0.900 | 0.210 | 0.503 | 0.900 | 0.090 | 0.313 | 0.810 | 0.150 | 0.463 | 0.900 |
| $Soc_2$ | 0.490 | 0.900 | 1.000 | 0.350 | 0.735 | 1.000 | 0.350 | 0.735 | 1.000 | 0.350 | 0.676 | 0.900 |
| $Soc_3$ | 0.030 | 0.211 | 0.490 | 0.010 | 0.127 | 0.350 | 0.010 | 0.150 | 0.490 | 0.030 | 0.236 | 0.630 |
| $Soc_4$ | 0.350 | 0.685 | 1.000 | 0.350 | 0.685 | 1.000 | 0.250 | 0.630 | 1.000 | 0.350 | 0.735 | 1.000 |

For each criteria positive ( $\tilde{A}^+$ ) and negative ( $\tilde{A}^-$ ) ideal solutions are determined.

$\tilde{A}^+$ = [(1, 1, 1), (1, 1, 1), (1, 1, 1), (0.9, 0.9, 0.9), (1, 1, 1), (1, 1, 1), (1, 1, 1), (0.7, 0.7, 0.7), (0.9, 0.9, 0.9), (1, 1, 1), (0.63, 0.63, 0.63), (1, 1, 1)]

$\tilde{A}^-$ = [(0.07, 0.07, 0.07), (0.07, 0.07, 0.07), (0.21, 0.21, 0.21), (0.03, 0.03, 0.03), (0.05, 0.05, 0.05), (0.21, 0.21, 0.21), (0.03, 0.03, 0.03), (0.03, 0.03, 0.03), (0.09, 0.09, 0.09), (0.35, 0.35, 0.35), (0.01, 0.01, 0.01), (0.25, 0.25, 0.25)]

The distance of each supplier alternatives from the fuzzy positive and negative ideal solution is calculated and shown in Table 10. Finally relative closeness coefficients of suppliers are found (Table 11).

**Table 10.** Distances Between Suppliers and $\tilde{A}^*$ , $\tilde{A}^-$ With Respect to Each Criterion

| | $Eco_1$ | $Eco_2$ | $Eco_3$ | $Eco_4$ | $Env_1$ | $Env_2$ | $Env_3$ | $Env_4$ | $Soc_1$ | $Soc_2$ | $Soc_3$ | $Soc_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $d(S_1, A^*)$ | 0.423 | 0.300 | 0.314 | 0.433 | 0.393 | 0.524 | 0.613 | 0.405 | 0.512 | 0.300 | 0.430 | 0.417 |
| $d(S_2, A^*)$ | 0.300 | 0.660 | 0.417 | 0.641 | 0.698 | 0.526 | 0.613 | 0.408 | 0.459 | 0.405 | 0.489 | 0.417 |
| $d(S_3, A^*)$ | 0.297 | 0.660 | 0.524 | 0.655 | 0.611 | 0.542 | 0.708 | 0.463 | 0.580 | 0.405 | 0.460 | 0.483 |
| $d(S_4, A^*)$ | 0.660 | 0.304 | 0.314 | 0.443 | 0.459 | 0.524 | 0.539 | 0.405 | 0.501 | 0.423 | 0.414 | 0.405 |
| $d(S_1, A^-)$ | 0.615 | 0.759 | 0.595 | 0.611 | 0.720 | 0.448 | 0.562 | 0.441 | 0.507 | 0.498 | 0.301 | 0.504 |
| $d(S_2, A^-)$ | 0.759 | 0.413 | 0.538 | 0.372 | 0.405 | 0.496 | 0.562 | 0.437 | 0.530 | 0.436 | 0.208 | 0.504 |
| $d(S_3, A^-)$ | 0.771 | 0.413 | 0.448 | 0.364 | 0.443 | 0.433 | 0.420 | 0.372 | 0.435 | 0.436 | 0.289 | 0.485 |
| $d(S_4, A^-)$ | 0.413 | 0.748 | 0.595 | 0.598 | 0.686 | 0.448 | 0.657 | 0.441 | 0.516 | 0.369 | 0.381 | 0.519 |

**Table 11.** Computations of $d_i^-$, $d_i^*$ and $CC_i$ for Suppliers

| | $d_i^-$ | $d_i^*$ | $d_i^-$ (+) $d_i^*$ | $CC_i$ |
|---|---|---|---|---|
| $Supplier_1$ | 6.560 | 5.065 | 11.625 | 0.564 |
| $Supplier_2$ | 5.660 | 6.033 | 11.693 | 0.484 |
| $Supplier_3$ | 5.308 | 6.389 | 11.697 | 0.454 |
| $Supplier_4$ | 6.370 | 5.393 | 11.763 | 0.542 |

On the basis of $CC_i$ values, the rankings of suppliers according to sustainability performance can be shown as follows:

$Supplier_1 > Supplier_4 > Supplier_2 > Supplier_3$

Based on these results it can be concluded that $Supplier_1$ has the best sustainability performance when taking into account DMs' opinions and group decisions.

Although $supplier_1$ is the best alternative, according to $CC_i$ value, it is recommended with low risk.

**End Notes**

1. *The Brundtland Commission's mission is to unite countries to pursue sustainable development together. The Report of the Brundtland Commission, Our Common Future, was published in 1987. The report deals with sustainable development and the change of politics needed for achieving it.*

**References**

Ageron, B., Gunasekaran, A., & Spalanzani, A. (2012). Sustainable supply management: An empirical study. International Journal of Production Economics, 140 (1), 168–182.

Amindoust, A., Ahmed, S., Saghafinia, A., & Bahreininejad, A. (2012). Sustainable supplier selection: A ranking model based on fuzzy inference system. Applied Soft Computing, 12 (6), 1668–1677.

Amiri-Aref, M., Javadian, N., & Kazemi, M. (2012). A new fuzzy pozitive and negative ideal solution for fuzzy TOPSIS. WSEAS Transactions on Circuits and Systems, 11 (3), 92–103.

Ashby, A., Leat, M., & Hudson-Smith, M. (2012). Making connections: A review of supply chain management and sustainability literature. Supply Chain Management: An International Journal, 17 (5), 497–516.

Asrafzadeh, M., Rafiei, F. M., Isfahani, N. M., & Zare, Z. (2012). Application of fuzzy TOPSIS method for the selection of warehouse location: A case study. Interdiciplinary Journal of Contemporary Research in Business, 3 (9), 655–671.

Bai, C., & Sarkis, J. (2010). Integrating sustainability into supplier selection with grey system and rough set methodologies. International Journal of Production Economics, 124 (1), 252–264

Başkaya, Z., & Avcı Öztürk, B. (2012). Tedarikçi değerlendirme probleminde bulanık TOPSIS algoritması ile grup karar verme ve karar vericilerin bireysel kararları arasındaki ilişkiler. Uludağ Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, XXXI (1), 153–178.

Bellman R. E., & Zadeh L. A. (1970). Decision-making in a fuzzy environment. Management Science, 17 (4), 141–164.

Beske, P. (2012). Dynamic capabilities and sustainable supply chain management. International Journal of Physical Distribution & Logistics Management, 42 (4), 372–387.

Büyüközkan, G., & Çifçi, G. (2011). A novel fuzzy multi-criteria decision framework for sustainable supplier selection with incomplete information. Computers in Industry, 62 (2), 164–174.

Büyüközkan, G. (2012). An integrated fuzzy multi-criteria group decision-making approach for green supplier evaluation. International Journal of Production Research, 50 (11), 2892–2909.

Carter, C. R., & Rogers, D. S. (2008). A framework of sustainable supply chain management: Moving toward new theory. International Journal of Physical Distribution & Logistics Management, 38 (5), 360–387.

Chen, C. (2000). Extensions of the TOPSIS for group decision making under fuzzy environment. Fuzzy Sets And Systems, 114 (1), 1–9.

Chen, C., Lin, C., & Huang, S. (2006). A fuzzy approach for supplier evaluation and selection in supply chain management. International Journal Of Production Economics, 102 (2), 289 –301.

Chen, S. J., & Hwang, C. L. (1992). Fuzzy multi attribute decision making. Lecture Notes in Economics and Mathematical System Series, Vol: 375, NewYork: Springer-Verlag.

Ding, J. (2011). An integrated fuzzy TOPSIS method for ranking alternatives and its application. Journal Of Marine Science And Technology, 19 (4), 341–352.

Erol, İ., Sencer, S., & Sari, R. (2011). A new fuzzy multi-criteria framework for measuring sustainability performance of a supply chain. Ecological Economics, 70 (6), 1088–1100.

Ghorbani, M., Velayati, R., & Ghorbani, M. M. (2011). Using fuzzy TOPSIS to determine strategy priorities by SWOT analysis – Singapore, International Conference on Financial Management and Economics. IPEDR, vol. 11, IACSIT Press, 135–139.

Gimenez, C., Sierra, V., & Rodon, J. (2012). Sustainable operations: Their impact on the triple bottom line. International Journal of Production Economics, 140 (1), 149–159.

Goebel, P., Reuter, C., Pibernik, R., & Sichtmann, C. (2012). The influence of ethical culture on supplier selection in the context of sustainable sourcing. International Journal of Production Economics, 140 (1), 7–17.

Goel, P. (2010). Triple bottom line reporting: An analytical approach for corporate sustainability. Journal of Finance, Accounting and Management, 1 (1), 27–42.

Gopalakrishnan, K., Yusuf, Y. Y., Musa, A., Abubakar, T., & Ambursa, H. M. (2012). Sustainable supply chain management: A case study of British Aerospace (BAe) systems. International Journal of Production Economics, 140 (1), 193–203.

Govindan K., Khodaverdi R., & Jafarian A. (2013). A fuzzy multi criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach. Journal of Cleaner Production, 47, 345–354.

Guo, P., Feng, J., & Yang, L. (2008). Fuzzy TOPSIS algorithm for multiple criteria decision making with an application in information systems project selection – USA WiCOM 08. 4th International Conference on Wireless Communications, Networking and Mobile Computing. IEEE, 1–4.

Hassini, E., Surti, C., & Searcy, C. (2012). A literature review and a case study of sustainable supply chains with a focus on metrics. International Journal of Production Economics, 140 (1), 69–82.

Hwang, C. L., & Yoon, K. (1981). Multiple attribute decision making: methods and applications : a state-of-the-art survey. New York: Springer-Verlag.

Jackson, A., Boswell, K., & Davis, D. (2011). Sustainability and triple bottom line reporting – What is it all about?. International Journal of Business, Humanities and Technology, 1 (3), 55–59.

Lee, A. H. I., Kang, H., Hsu, C., & Hung, H. (2009). A green supplier selection model for high-tech industry. Expert Systems with Applications, 36 (4), 7917–7927.

Pagell, M., & Wu, Z. (2009). Building a more complete theory of sustainable supply chain management using case studies of 10 exemplars. Journal of Supply Chain Management, 45 (2), 37–56.

Paulraj, A. (2011). Understanding the relationships between internal resources and capabilities, sustainable supply management and organizational sustainability. Journal of Supply Chain Management, 47 (1), 19–37.

Rabenasolo, B., & Zeng, X. (2012). A risk-based multi-criteria decision support system for sustainable development in the textile supply chain. (Ed.) J. Lu, L. C. Jain & G. Zang, Handbook on Decision Making (pp. 151–170). Berlin: Springer-Verlag.

Seuring, S., & Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. Journal of Cleaner Production, 16 (15), 1699–1710.

Shen, L., Olfat, L., Govindan, K., Khodaverdi, R., & Diabat, A. (2013). A fuzzy multi criteria approach for evaluating green supplier's performance in green supply chain with linguistic preferences. Resources, Conservation and Recycling, 74, 170–179.

Verdecho, M. J., Alfaro-Saiz, J. J., & Rodriguez, R. R. (2012). A performance measurement framework for monitoring supply chain sustainability – Vigo. 6th International Conference on Industrial Engineering and Industrial Management.

WCED report: Our common future (1987). http://conspect.nl/pdf/Our_Common_Future-Brundtland_Report_1987.pdf (Erişim Tarihi, 05 Haziran 2012).

Wen, L., Xu, L., & Wang, R. (2013). Sustainable supplier evaluation based on intuitionistic fuzzy sets group decision methods. Journal of Information & Computational Science, 10 (10), 3209–3220.

Zadeh, L. A. (1965). Fuzzy Sets. Information And Control, 8 (3), 338–353.

Zanakis, S. H., Solomon, A., Wishart, N., & Dublish, S. (1998). Multi-attribute decision making: a simulation comparison of selection methods. European Journal of Operational Research, 107 (3), 577–529.

**This Page Intentionally Left Blank**