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# THE EVALUATION OF THE CRITERIA FOR SUSTAINABLE SUPPLIER SELECTION BY USING THE FUCOM METHOD

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***Abstract.*** *The selection of a sustainable supplier has a strategic significance and represents the critical phase for the whole sustainable supply chain. The process of the functioning of the supply chain depends on this activity. This paper is aimed at defining the most important criteria for the assessment and selection of a sustainable supplier in the company for lime production. For the purpose of decision-making in this process, a team of experts was formed for the comparison and assessment of the criteria grouped at two levels. At the first level, there are the economic, social and environmental criteria which consist of the seven sub-criteria for each of the main groups. In order to determine the significance of the criteria, the Full Consistency method (FUCOM) was applied. The obtained results show the significance of the criteria at both decision-making levels with respect to the selection of a sustainable supplier. An adequate supplier selection is carried out by using the sustainable criteria that will ensure a possibility of having both timely and quality production. This generates competition growth in the market for companies.*

***Key words****: sustainable supplier selection, FUCOM, evaluation of criteria, decision-making*

## 1. Introduction

Sustainable supply chains have a large influence on the modern market, so the problem of the selection of a sustainable supplier is very important and frequent in all fields. The selection of sustainable suppliers is a constant process that requires the consideration of a certain number of the criteria needed to make a decision on the selection of the most suitable suppliers (Büyüközkan and Çifçi, 2011; Luhtra et al. 2017; Ayadnia et al. 2015). Modern business conditions require a business to quickly adapt to changes in the environment. In line with developments in the market, business entities need adequate sustainable supply chains (Stojanović et al., 2017; Stević et al. 2019). A well-designed supply chain management system is important for improving competitive advantage in the era of international economics and the rapid development of information technology (Liu and Wang, 2007). Manufacturing companies are highly dependent on their suppliers. Due to the constant changes that the market is exposed to

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and the ever-growing demands, it is certainly challenging to maintain a competitive position (Stević, 2017). According to Kagnicioglu (2006), the selection of suppliers is a critical procurement activity in the supply chain management due to the key role of the supplier characteristics on the price, quality, delivery, and service in achieving the supply chain objectives.

The aim of the supplier selection is to identify suppliers with the greatest potential to meet the company's needs and at an acceptable price (De Boer et al. 2001). One of the important issues in the process of selecting a sustainable supplier is choosing the appropriate method and criteria for the selection of a supplier. Essentially, group decision-making according to multiple criteria is the problem in choosing a sustainable supplier in the supply chain system. In solving this problem, the degree of uncertainty, the number of decision-makers, and the nature of the criteria must be taken into account (Chen et al., 2006).

The rest of the paper is structured as follows: the second section describes the steps of the used method, i.e. the FUCOM method. In the third section, the problem postulate with the hierarchical structure of the model and a detailed explanation of the used criteria. In the fourth section, the FUCOM method is applied in the group decision-making process for the two levels of hierarchy. After that, the fifth section shows a discussion of the obtained results, while in the sixth section the conclusions of the study are presented.

## 2. FUCOM (Full Consistency Method)

The FUCOM method was developed by Pamučar et al. (2018) for the purpose of determining criteria weights. So, for now, the method has been applied in a few studies (Prentkovskis et al. 2018; Zavadskas et al. 2018; Fazllolahtabar 2019; Matić et al 2019).

The steps of the FUCOM method are as follows:

*Step 1* In this step, the criteria from the predefined set of the evaluation criteria $C=\{C_1,C_2,...,C_n\}$. The ranking is performed according to the significance of the criteria, i.e. starting from the criterion which is expected to have the highest weight coefficient to the criterion of the least significance:

$$C_{j(1)} > C_{j(2)} > ... > C_{j(k)} \tag{1}$$

*Step 2* In this step, a comparison of the ranked criteria is carried out and the comparative priority ($\varphi_{k/(k+1)}$, $k=1,2,...,n$, with k representing the rank of the criteria) of the evaluation criteria is determined:

$$\Phi=\left(\varphi_{1/2},\varphi_{2/3},...,\varphi_{k/(k+1)}\right) \tag{2}$$

*Step 3* In this step, the final values of the weight coefficients of the evaluation criteria $\left(w_1,w_2,...,w_n\right)^T$ are calculated. The final values of the weight coefficients should satisfy the following two conditions: (1) The ratio of the weight coefficients is equal to the comparative priority among the observed criteria ($\varphi_{k/(k+1)}$) defined in Step 2, i.e. the following condition is met:

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \tag{3}$$

(2) In addition to the condition (2), the final values of the weight coefficients should satisfy the condition of mathematical transitivity, i.e. t $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$. Then

$\varphi_{k/(k+1)} = \frac{w_k}{w_{k+1}}$ and $\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$ $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$ are obtained.

Thus, the second condition that the final values of the weight coefficients of the evaluation criteria should meet is obtained, namely:

$$\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \tag{4}$$

Based on the defined settings, the final model for determining the final values of the weight coefficients of the evaluation criteria can be defined as:

$$\begin{aligned}
&\min \chi \\
&s.t. \\
&\left| \frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)} \right| = \chi, \ \forall j \\
&\left| \frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \right| = \chi, \ \forall j \\
&\sum_{j=1}^{n} w_j = 1, \ \forall j \\
&w_j \geq 0, \ \forall j
\end{aligned} \tag{5}$$

## 3. Problem Postulate

This research study was performed with the aim of determining the most important criteria for the selection of a sustainable supplier, which depends on the precise determination and selection of adequate criteria. The evaluation of the criteria was performed by a group of the experts employed in the company which is the subject matter of the research study (a lime production company). Figure 1 shows the hierarchical structure of the criteria evaluation at both levels of decision-making:

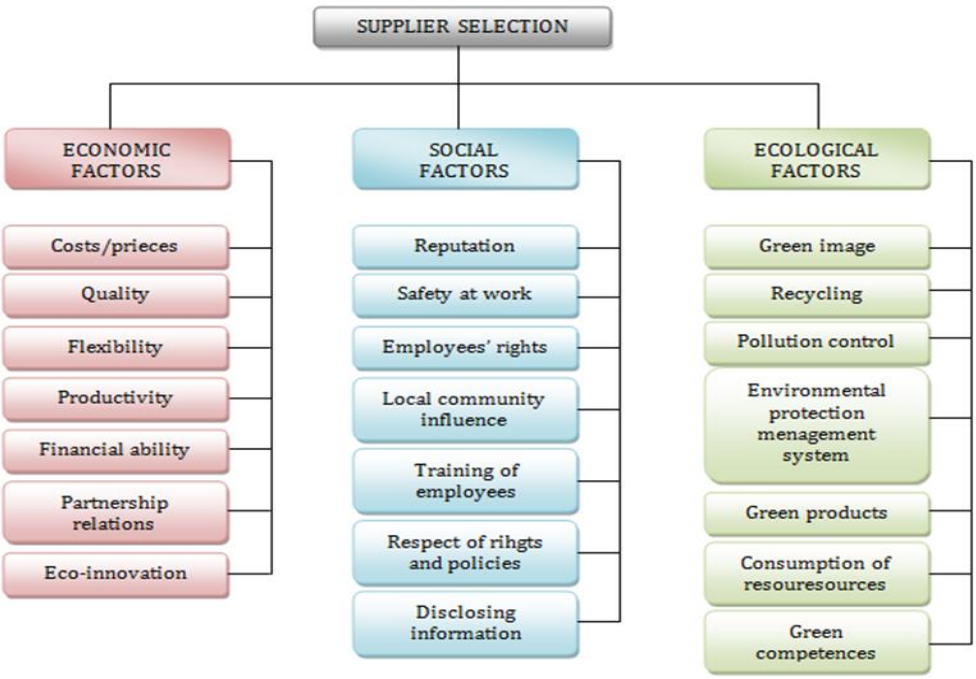


Figure 1. The hierarchical structure of the proposed model

Table 1 shows the criteria for the selection of a sustainable supplier and their respective definitions. All of the criteria displayed below were used in this study.

Table 1. The criteria for the selection of a sustainable supplier and their respective definitions

| Seq. no | Name | Definition |
|---|---|---|
| **C1** | **Economic** | |
| C11 | Costs/prices | The final cost of purchasing a unit of raw or semi-finished product |
| C12 | Quality | Quality is the degree to which a set of product characteristics meet customer requirements |
| C13 | Flexibility | The demand that can be profitably sustained, and the time or the cost required for adding new products to the existing production operations |
| C14 | Productivity | Satisfying customer needs and delivery on time |
| C15 | Financial ability | The capital needed to maintain the normal business activities of an enterprise during a certain period of time |
| C16 | Partnership relations | Determining the willingness to establish long-term and close business relations with suppliers to jointly develop the market |
| C17 | Technology capability | The sum of all the knowledge of an enterprise in support of technological innovation. |
| **C2** | **Social** | |
| C21 | Reputation | Reputation marks the general opinion of the supplier which relates to the supplier's reputation |
| C22 | Safety and health at work | This criterion concerns the safety, health, and welfare of people at work |
| C23 | Employees' rights | A group of legal rights and claimed human rights related to the labor relations between workers and their employers |

| | | |
|---|---|---|
| C24 | Local community influence | Neighboring relations between the company and the local government, the community and all the residents, representing the public image of the organization |
| C25 | Training of employees | The process of enhancing the employees' skills and capabilities for and knowledge of a particular job |
| C26 | Respect of rights and policies | Enterprises comply with all the laws and regulations of the country, assume legal obligations, and promote good social public morals |
| C27 | Disclosing information | Providing information to stakeholders about the materials used, carbon emissions, toxins released during production, and so on |
| **C3** | **Environmental** | |
| C31 | Green image | The identity that consumers prioritize environmental conservation and sustainable business practices |
| C32 | Recycling | The reuse of the used materials and energy |
| C33 | Pollution control | The control of the pollutants released into the air, water, or soil |
| C34 | Environmental protection management system | A system that comprehensively evaluates the internal and external environmental performances of an organization. |
| C35 | ECO design | An approach to designing products, with a special consideration for the environmental impacts of a product during its whole lifecycle. |
| C36 | Consumption of resources | The use of nonrenewable or, less frequently, renewable resources |
| C37 | Green competences | The capacity to balance the containment relationships between economic and environmental performance |

## 4. The Evaluation of the Criteria for the Selection of a Sustainable Supplier

### 4.1. The Determination of the Criteria Weights at the First Level of Decision-Making

First, the decision-makers (DMs) ranked and made a comparison of the criteria at the first level of decision-making. After that, the steps of the FUCOM method for the calculation of their normalized values were applied as follows:

*Step 1:* In this step, the team of experts performed the ranking of the criteria. DM1: C1>C2>C3; DM2: C1>C2>C3; DM3: C1>C2>C3;

*Step 2:* In this step, the decision-makers performed a comparison of the previously ranked criteria. In that way, the significance of the criteria ( $\varpi_{C_{j(k)}}$ ) (Table 2) was obtained.

Table 2. The significance of the criteria at the first level

| **DM1** | | | |
|---|---|---|---|
| Criteria | C1 | C3 | C2 |
| Significance ( $\varpi_{C_{j(k)}}$ ) | 1 | 1.9 | 2.5 |
| **DM2** | | | |
| Criteria | C1 | C2 | C3 |
| Significance ( $\varpi_{C_{j(k)}}$ ) | 1 | 2.1 | 2.5 |
| **DM3** | | | |
| Criteria | C1 | C3 | C2 |
| Significance ( $\varpi_{C_{j(k)}}$ ) | 1 | 1.8 | 2.4 |

Based on the obtained significance of the criteria, it is necessary to calculate the comparative priority of the criteria for each one of the decision-makers:

DM1: $\varphi_{C_1/C_2} = 1.9/1 = 1.9$, $\varphi_{C_2/C_3} = 2.5/1.9 = 1.32$; DM2: $\varphi_{C_1/C_2} = 2.1/1 = 2.1$, $\varphi_{C_2/C_3} = 2.5/2.1 = 1.19$; DM3: $\varphi_{C_1/C_2} = 1.8/1 = 1.8$, $\varphi_{C_2/C_3} = 2.4/1.8 = 1.33$

*Step 3:* In this step, the final values of the weight coefficients were calculated and they should meet the two conditions (3) and (4):
Condition (3):

DM1: $w_1 / w_2 = 1.9$, $w_2 / w_3 = 1.32$; DM2: $w_1 / w_2 = 2.1$, $w_2 / w_3 = 1.19$; DM3: $w_1 / w_2 = 1.8$, $w_2 / w_3 = 1.33$

and the condition (4):

$$w_1 / w_3 = 2.51,\ w_1 / w_3 = 2.50,\ w_1 / w_3 = 2.39$$

By applying Expression (5), the final model for the determination of the weight coefficients can be defined as follows:

$DM1$

$$\min \chi$$

$$s.t. \begin{cases} \left| \frac{w_1}{w_2} - 1.9 \right| = \chi,\ \left| \frac{w_2}{w_3} - 1.32 \right| = \chi, \\ \left| \frac{w_1}{w_3} - 2.51 \right|, \\ \sum_{j=1}^{3} w_j = 1,\ w_j \geq 0, \forall j \end{cases}$$

$DM2$

$$\min \chi$$

$$s.t. \begin{cases} \left| \frac{w_1}{w_2} - 2.1 \right| = \chi,\ \left| \frac{w_2}{w_3} - 1.19 \right| = \chi, \\ \left| \frac{w_1}{w_3} - 2.50 \right|, \\ \sum_{j=1}^{3} w_j = 1,\ w_j \geq 0, \forall j \end{cases}$$

$DM3$

$$\min \chi$$

$$s.t. \begin{cases} \left| \frac{w_1}{w_2} - 1.8 \right| = \chi,\ \left| \frac{w_2}{w_3} - 1.33 \right| = \chi, \\ \left| \frac{w_1}{w_3} - 2.39 \right|, \\ \sum_{j=1}^{3} w_j = 1,\ w_j \geq 0, \forall j \end{cases}$$

By solving the presented model by using the Lingo 17 software, the final values of the weight coefficients were obtained for the first level of decision-making (Table 3).

Table 3. The final values of the weight coefficients obtained for the first level of decision-making

| | **DM1** | **DM2** | **DM3** |
|---|---|---|---|
| C1 | 0.519 | 0.533 | 0.507 |
| C2 | 0.273 | 0.254 | 0.282 |
| C3 | 0.208 | 0.213 | 0.211 |
| DFC | 0.000 | 0.000 | 0.000 |

### 4.2. The Determination of the Criteria Weights at the Second Level of Decision-Making

The DMs performed the ranking of the criteria at the second level, and the significances of the criteria were obtained for each group. The calculation of the criteria weights for the second level of decision-making was done in the same way as for the first level. The obtained final values for the sub-criteria are shown in Tables 4 and 5 for the group of the economic criteria, in Tables 6 and 7 for the group of the social criteria, and in Tables 8 and 9 for the group of the environmental criteria.

*4.2.1. Determining the sub-criteria weights of the group of the economic criteria*

*Step 1:* DM1: C2>C1>C4>C6>C5>C7>C3; DM2: C2>C4>C3>C5>C1>C6>C7; DM3: C2>C1>C4>C6>C3>C5>C

*Step 2:*

Table 4. The significance of the criteria at the second level for the group of the economic criteria

| **DM1** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Economic factors | C12 | C11 | C14 | C16 | C15 | C17 | C13 |
| $\varpi_{C_{j(k)}}$ | 1 | 1.2 | 1.7 | 2.0 | 2.4 | 2.8 | 3.1 |
| **DM2** | | | | | | | |
| Economic factors | C12 | C14 | C13 | C15 | C11 | C16 | C17 |
| $\varpi_{C_{j(k)}}$ | 1 | 1.4 | 1.7 | 2.2 | 2.4 | 2.6 | 3.0 |
| **DM3** | | | | | | | |
| Economic factors | C12 | C11 | C14 | C16 | C13 | C15 | C17 |
| $\varpi_{C_{j(k)}}$ | 1 | 1.6 | 1.8 | 2.2 | 2.6 | 2.9 | 3.1 |

DM1: $\varphi_{C_2/C_1}=1.2/1=1.2$, $\varphi_{C_1/C_4}=1.7/1.2=1.42$, $\varphi_{C_4/C_6}=2.0/1.7=1.18$
$\varphi_{C_6/C_5}=2.4/2.0=1.2$ $\varphi_{C_5/C_7}=2.8/2.4=1.17$, $\varphi_{C_7/C_3}=3.1/2.8=1.11$;

DM2: $\varphi_{C_2/C_4}=1.4/1=1.4$, $\varphi_{C_4/C_3}=1.7/1.4=1.21$, $\varphi_{C_3/C_5}=2.2/1.7=1.29$
$\varphi_{C_5/C_1}=2.4/2.2=1.09$, $\varphi_{C_1/C_6}=2.6/2.4=1.08$, $\varphi_{C_6/C_7}=3.0/2.6=1.15$;

DM3: $\varphi_{C_2/C_1}=1.6/1=1.6$, $\varphi_{C_1/C_4}=1.8/1.6=1.13$, $\varphi_{C_4/C_6}=2.2/1.8=1.22$
$\varphi_{C_6/C_3}=2.6/2.2=1.18$, $\varphi_{C_3/C_5}=2.9/2.6=1.12$, $\varphi_{C_5/C_7}=3.1/2.9=1.07$;

*Step 3:*

1) DM1: $w_2/w_1=1.2$, $w_1/w_4=1.42$, $w_4/w_6=1.18$, $w_6/w_5=1.2$, $w_5/w_7=1.17$, $w_7/w_3=1.11$; DM2: $w_2/w_4=1.4$, $w_4/w_3=1.21$, $w_3/w_5=1.29$, $w_5/w_1=1.09$, $w_1/w_6=1.08$, $w_6/w_7=1.15$; DM3: $w_2/w_1=1.6$, $w_1/w_4=1.13$, $w_4/w_6=1.22$, $w_6/w_3=1.18$, $w_3/w_5=1.12$, $w_5/w_7=1.07$;

2) DM1: $w_2/w_4=1.7$, $w_1/w_6=1.68$, $w_4/w_5=1.42$, $w_6/w_7=1.4$, $w_5/w_3=1.3$;
DM2: $w_2/w_3=1.69$, $w_4/w_5=1.56$, $w_3/w_1=1.41$, $w_5/w_6=1.18$, $w_1/w_7=1.24$;
DM3: $w_2/w_4=1.81$, $w_1/w_6=1.38$, $w_4/w_3=1.44$, $w_6/w_5=1.32$, $w_3/w_7=1.20$;

$DM1$

$$\min \chi$$

$$s.t.\begin{cases}\left|\frac{w_2}{w_1}-1.2\right|=\chi,\ \left|\frac{w_1}{w_4}-1.42\right|=\chi,\left|\frac{w_4}{w_6}-1.18\right|=\chi,\ \left|\frac{w_6}{w_5}-1.2\right|=\chi,\left|\frac{w_5}{w_7}-1.17\right|=\chi,\\ \left|\frac{w_7}{w_3}-1.11\right|=\chi,\left|\frac{w_2}{w_4}-1.7\right|=\chi,\left|\frac{w_1}{w_6}-1.68\right|=\chi,\left|\frac{w_4}{w_5}-1.42\right|=\chi,\left|\frac{w_6}{w_7}-1.4\right|=\chi,\\ \left|\frac{w_5}{w_3}-1.3\right|=\chi,\\ \sum_{j=1}^{3}w_j=1,\ w_j\geq 0,\forall j\end{cases}$$

$DM2$

$$\min \chi$$

$$s.t.\begin{cases}\left|\frac{w_2}{w_4}-1.4\right|=\chi,\ \left|\frac{w_4}{w_3}-1.21\right|=\chi,\left|\frac{w_3}{w_5}-1.29\right|=\chi,\ \left|\frac{w_5}{w_1}-1.09\right|=\chi,\left|\frac{w_1}{w_6}-1.08\right|=\chi,\\ \left|\frac{w_6}{w_7}-1.15\right|=\chi,\left|\frac{w_2}{w_3}-1.69\right|=\chi,\left|\frac{w_4}{w_5}-1.56\right|=\chi,\left|\frac{w_3}{w_1}-1.41\right|=\chi,\left|\frac{w_5}{w_6}-1.18\right|=\chi,\\ \left|\frac{w_1}{w_7}-1.24\right|=\chi,\\ \sum_{j=1}^{3}w_j=1,\ w_j\geq 0,\forall j\end{cases}$$

$$DM3$$

$$\min \chi$$

$$s.t.\begin{cases} \left|\frac{w_2}{w_1}-1.6\right|=\chi,\ \left|\frac{w_1}{w_4}-1.13\right|=\chi,\left|\frac{w_4}{w_6}-1.22\right|=\chi,\ \left|\frac{w_6}{w_3}-1.18\right|=\chi,\left|\frac{w_3}{w_5}-1.12\right|=\chi, \\ \left|\frac{w_5}{w_7}-1.07\right|=\chi,\left|\frac{w_2}{w_4}-1.81\right|=\chi,\left|\frac{w_1}{w_6}-1.38\right|=\chi,\left|\frac{w_4}{w_3}-1.44\right|=\chi,\left|\frac{w_6}{w_5}-1.32\right|=\chi, \\ \left|\frac{w_3}{w_7}-1.2\right|=\chi, \\ \sum_{j=1}^{3} w_j=1,\ w_j\geq 0,\forall j \end{cases}$$

Table 5. The values of the criteria for the second level of decision-making for each of the DMs for the group of the economic criteria

| | **DM1** | **DM2** | **DM3** |
|---|---|---|---|
| C1 | 0.207 | 0.107 | 0.170 |
| C2 | 0.249 | 0.257 | 0.271 |
| C3 | 0.080 | 0.151 | 0.104 |
| C4 | 0.146 | 0.184 | 0.151 |
| C5 | 0.104 | 0.117 | 0.094 |
| C6 | 0.124 | 0.099 | 0.123 |
| C7 | 0.089 | 0.086 | 0.087 |
| DFC | 0.000 | 0.000 | 0.000 |

*4.2.2. Determining the sub-criteria weights for the group of the social criteria*

*Step 1:* DM1: C2>C6>C1>C3>C5>C7>C4; DM2: C2>C7>C5>C6>C3>C1>C4; DM3: C1>C2>C6>C7>C3>C5>C4

*Step 2:*

Table 6. The significance of the criteria at the second level for the group of the social criteria

| **DM1** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Social factors | C22 | C26 | C21 | C23 | C25 | C27 | C24 |
| $\varpi_{C_{j(k)}}$ | 1 | 1.5 | 1.6 | 1.9 | 2.1 | 2.3 | 2.5 |
| **DM2** | | | | | | | |
| Social factors | C22 | C27 | C25 | C26 | C23 | C21 | C24 |
| $\varpi_{C_{j(k)}}$ | 1 | 1.3 | 1.6 | 1.9 | 2.3 | 2.5 | 2.8 |
| **DM3** | | | | | | | |
| Social factors | C21 | C22 | C26 | C27 | C23 | C25 | C24 |
| $\varpi_{C_{j(k)}}$ | 1 | 1.3 | 1.6 | 2.0 | 2.2 | 2.5 | 3.0 |

DM1: $\varphi_{C_2/C_6}=1.5/1=1.5$, $\varphi_{C_6/C_1}=1.6/1.5=1.07$, $\varphi_{C_1/C_3}=1.9/1.6=1.19$, $\varphi_{C_3/C_5}=2.1/1.9=1.11$, $\varphi_{C_5/C_7}=2.3/2.1=1.10$, $\varphi_{C_7/C_4}=2.5/2.3=1.09$;

DM2: $\varphi_{C_2/C_7}=1.3/1=1.3$, $\varphi_{C_7/C_5}=1.6/1.3=1.23$, $\varphi_{C_5/C_6}=1.9/1.6=1.19$, $\varphi_{C_6/C_3}=2.3/1.9=1.21$, $\varphi_{C_3/C_1}=2.5/2.3=1.09$, $\varphi_{C_1/C_4}=2.8/2.5=1.12$;

DM3: $\varphi_{C_1/C_2}=1.3/1=1.3$, $\varphi_{C_2/C_6}=1.6/1.3=1.23$, $\varphi_{C_6/C_7}=2.0/1.6=1.25$, $\varphi_{C_7/C_3}=2.2/2.0=1.1$, $\varphi_{C_3/C_5}=2.5/2.2=1.14$, $\varphi_{C_5/C_4}=3.0/2.5=1.2$;

*Step 3:*

1) DM1: $w_2/w_6=1.5$, $w_6/w_1=1.07$, $w_1/w_3=1.19$, $w_3/w_5=1.11$, $w_5/w_7=1.1$, $w_7/w_4=1.09$; DM2: $w_2/w_7=1.3$, $w_7/w_5=1.23$, $w_5/w_6=1.19$, $w_6/w_3=1.21$, $w_3/w_1=1.09$, $w_1/w_4=1.12$; DM3: $w_1/w_2=1.3$, $w_2/w_6=1.23$, $w_6/w_7=1.25$, $w_7/w_3=1.1$, $w_3/w_5=1.14$, $w_5/w_4=1.2$;

2) DM1: $w_2/w_1=1.61$, $w_6/w_3=1.27$, $w_1/w_5=1.32$ $w_3/w_7=1.22$ $w_5/w_4=1.2$; DM2: $w_2/w_5=1.6$, $w_7/w_6=1.46$, $w_5/w_3=1.44$, $w_6/w_1=1.32$, $w_3/w_4=1.22$; DM3: $w_1/w_6=1.6$, $w_2/w_7=1.54$, $w_6/w_3=1.38$, $w_7/w_5=1.25$, $w_3/w_4=1.37$;

$DM1$

$$\min \chi$$

$$s.t.\begin{cases}\left|\frac{w_2}{w_6}-1.5\right|=\chi,\ \left|\frac{w_6}{w_1}-1.07\right|=\chi,\left|\frac{w_1}{w_3}-1.19\right|=\chi,\ \left|\frac{w_3}{w_5}-1.11\right|=\chi,\left|\frac{w_5}{w_7}-1.1\right|=\chi,\\ \left|\frac{w_7}{w_4}-1.09\right|=\chi,\left|\frac{w_2}{w_1}-1.61\right|=\chi,\left|\frac{w_6}{w_3}-1.27\right|=\chi,\left|\frac{w_1}{w_5}-1.32\right|=\chi,\left|\frac{w_3}{w_7}-1.22\right|=\chi,\\ \left|\frac{w_5}{w_4}-1.2\right|=\chi,\\ \sum_{j=1}^{3}w_j=1,\ w_j\geq 0,\forall j\end{cases}$$

$DM2$

$$\min \chi$$

$$s.t.\begin{cases} \left|\frac{w_2}{w_7}-1.3\right|=\chi,\ \left|\frac{w_7}{w_5}-1.23\right|=\chi,\left|\frac{w_5}{w_6}-1.19\right|=\chi,\ \left|\frac{w_6}{w_3}-1.21\right|=\chi,\left|\frac{w_3}{w_1}-1.09\right|=\chi, \\ \left|\frac{w_1}{w_4}-1.12\right|=\chi,\left|\frac{w_2}{w_5}-1.60\right|=\chi,\left|\frac{w_7}{w_6}-1.46\right|=\chi,\left|\frac{w_5}{w_3}-1.44\right|=\chi,\left|\frac{w_6}{w_1}-1.32\right|=\chi, \\ \left|\frac{w_3}{w_4}-1.22\right|=\chi, \\ \sum_{j=1}^{3} w_j=1,\ w_j\geq 0,\forall j \end{cases}$$

$DM3$

$$\min \chi$$

$$s.t.\begin{cases} \left|\frac{w_1}{w_2}-1.3\right|=\chi,\ \left|\frac{w_2}{w_6}-1.23\right|=\chi,\left|\frac{w_6}{w_7}-1.25\right|=\chi,\ \left|\frac{w_7}{w_3}-1.1\right|=\chi,\left|\frac{w_3}{w_5}-1.14\right|=\chi, \\ \left|\frac{w_5}{w_4}-1.2\right|=\chi,\left|\frac{w_1}{w_6}-1.6\right|=\chi,\left|\frac{w_2}{w_7}-1.54\right|=\chi,\left|\frac{w_6}{w_3}-1.38\right|=\chi,\left|\frac{w_7}{w_5}-1.25\right|=\chi, \\ \left|\frac{w_3}{w_4}-1.37\right|=\chi, \\ \sum_{j=1}^{3} w_j=1,\ w_j\geq 0,\forall j \end{cases}$$

Table 7. The values of the criteria for the second level of decision-making for each of the DMs for the group of the social criteria

| | **DM1** | **DM2** | **DM3** |
|---|---|---|---|
| C1 | 0.151 | 0.097 | 0.245 |
| C2 | 0.242 | 0.243 | 0.188 |
| C3 | 0.127 | 0.106 | 0.111 |
| C4 | 0.097 | 0.087 | 0.082 |
| C5 | 0.115 | 0.152 | 0.098 |
| C6 | 0.161 | 0.128 | 0.153 |
| C7 | 0.105 | 0.187 | 0.122 |
| DFC | 0.000 | 0.000 | 0.000 |

*4.2.3. Determining the sub-criteria weights for the group of the environmental criteria*

*Step 1:* DM1: C3>C1>C5>C2>C4>C7>C6; DM2: C3>C2>C4>C5>C7>C6>C1; DM3: C3>C2>C1>C5>C7>C4>C6;

*Step 2:*

Table 8. The significance of the sub-criteria for the group of the environmental criteria

| **DM1** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Environmental factors | C33 | C31 | C35 | C32 | C34 | C37 | C36 |
| $\varpi_{C_{j(k)}}$ | 1 | 1.2 | 1.3 | 1.4 | 1.7 | 2.0 | 2.3 |
| **DM2** | | | | | | | |
| Environmental factors | C33 | C32 | C34 | C35 | C37 | C36 | C31 |
| $\varpi_{C_{j(k)}}$ | 1 | 1.1 | 1.3 | 1.6 | 1.9 | 2.3 | 2.5 |
| **DM3** | | | | | | | |
| Environmental factors | C33 | C32 | C31 | C35 | C37 | C34 | C36 |
| $\varpi_{C_{j(k)}}$ | 1 | 1.3 | 1.6 | 1.9 | 2.1 | 2.4 | 2.9 |

DM1: $\varphi_{C_3/C_1}=1.2/1=1.2$, $\varphi_{C_1/C_5}=1.3/1.2=1.08$, $\varphi_{C_5/C_2}=1.4/1.3=1.08$, $\varphi_{C_2/C_4}=1.7/1.4=1.21$, $\varphi_{C_7/C_4}=2.0/1.7=1.18$, $\varphi_{C_7/C_6}=2.3/2.0=1.15$;

DM2: $\varphi_{C_3/C_2}=1.1/1=1.1$, $\varphi_{C_2/C_4}=1.3/1.1=1.18$, $\varphi_{C_4/C_5}=1.6/1.3=1.23$, $\varphi_{C_5/C_7}=1.9/1.6=1.19$, $\varphi_{C_7/C_6}=2.3/1.9=1.21$, $\varphi_{C_6/C_1}=2.5/2.3=1.09$;

DM3: $\varphi_{C_3/C_2}=1.3/1=1.3,$ $\varphi_{C_2/C_1}=1.6/1.3=1.23,$ $\varphi_{C_1/C_5}=1.9/1.6=1.19,$ $\varphi_{C_5/C_7}=2.1/1.9=1.11$, $\varphi_{C_7/C_4}=2.4/2.1=1.14$, $\varphi_{C_4/C_6}=2.9/2.4=1.21$;

*Step 3:*

1) DM1: $w_3/w_1=1.2$, $w_1/w_5=1.08$, $w_5/w_2=1.08$, $w_2/w_4=1.21$, $w_4/w_7=1.18$, $w_7/w_6=1.15$; DM2: $w_3/w_2=1.1$, $w_2/w_4=1.18$, $w_4/w_5=1.23$, $w_5/w_7=1.19$, $w_7/w_6=1.21$, $w_6/w_1=1.09$; DM3: $w_3/w_2=1.3$, $w_2/w_1=1.23$, $w_1/w_5=1.19$, $w_5/w_7=1.11$, $w_7/w_4=1.14$, $w_4/w_6=1.21$;

2) DM1: $w_3/w_5=1.3$, $w_1/w_2=1.17$, $w_5/w_4=1.31$, $w_2/w_7=1.43$, $w_4/w_6=1.36$; DM2: $w_3/w_4=1.3$, $w_2/w_5=1.45$, $w_4/w_7=1.46$, $w_5/w_6=1.44$, $w_7/w_1=1.32$; DM3: $w_3/w_1=1.6$, $w_2/w_5=1.46$, $w_1/w_7=1.32$, $w_5/w_4=1.27$, $w_7/w_6=1.38$;

$DM1$

$$\min \chi$$

$$s.t.\begin{cases} \left|\frac{w_3}{w_1}-1.2\right|=\chi,\ \left|\frac{w_1}{w_5}-1.08\right|=\chi,\left|\frac{w_5}{w_2}-1.08\right|=\chi,\ \left|\frac{w_2}{w_4}-1.21\right|=\chi,\left|\frac{w_4}{w_7}-1.18\right|=\chi, \\ \left|\frac{w_7}{w_6}-1.15\right|=\chi,\left|\frac{w_3}{w_5}-1.3\right|=\chi,\left|\frac{w_1}{w_2}-1.17\right|=\chi,\left|\frac{w_5}{w_4}-1.31\right|=\chi,\left|\frac{w_2}{w_7}-1.43\right|=\chi, \\ \left|\frac{w_4}{w_6}-1.36\right|=\chi, \\ \sum_{j=1}^{3} w_j=1,\ w_j\geq 0,\forall j \end{cases}$$

$DM2$

$$\min \chi$$

$$s.t.\begin{cases} \left|\frac{w_3}{w_2}-1.1\right|=\chi,\ \left|\frac{w_2}{w_4}-1.18\right|=\chi,\left|\frac{w_4}{w_5}-1.23\right|=\chi,\ \left|\frac{w_5}{w_7}-1.19\right|=\chi,\left|\frac{w_7}{w_6}-1.21\right|=\chi, \\ \left|\frac{w_6}{w_1}-1.09\right|=\chi,\left|\frac{w_3}{w_4}-1.3\right|=\chi,\left|\frac{w_2}{w_5}-1.45\right|=\chi,\left|\frac{w_4}{w_7}-1.46\right|=\chi,\left|\frac{w_5}{w_6}-1.44\right|=\chi, \\ \left|\frac{w_7}{w_1}-1.32\right|=\chi, \\ \sum_{j=1}^{3} w_j=1,\ w_j\geq 0,\forall j \end{cases}$$

$DM3$

$$\min \chi$$

$$s.t.\begin{cases} \left|\frac{w_3}{w_2}-1.3\right|=\chi,\ \left|\frac{w_2}{w_1}-1.23\right|=\chi,\left|\frac{w_1}{w_5}-1.19\right|=\chi,\ \left|\frac{w_5}{w_7}-1.11\right|=\chi,\left|\frac{w_7}{w_4}-1.14\right|=\chi, \\ \left|\frac{w_4}{w_6}-1.21\right|=\chi,\left|\frac{w_3}{w_1}-1.6\right|=\chi,\left|\frac{w_2}{w_5}-1.46\right|=\chi,\left|\frac{w_1}{w_7}-1.32\right|=\chi,\left|\frac{w_5}{w_4}-1.27\right|=\chi, \\ \left|\frac{w_7}{w_6}-1.38\right|=\chi, \\ \sum_{j=1}^{3} w_j=1,\ w_j\geq 0,\forall j \end{cases}$$

Table 9. The values of the criteria for the 2nd level of decision-making for each of the DMs for the group of the environmental criteria

| | DM1 | DM2 | DM3 |
|---|---|---|---|
| C1 | 0.172 | 0.086 | 0.150 |
| C2 | 0.148 | 0.195 | 0.185 |
| C3 | 0.207 | 0.214 | 0.240 |
| C4 | 0.122 | 0.165 | 0.100 |
| C5 | 0.159 | 0.134 | 0.127 |
| C6 | 0.090 | 0.093 | 0.083 |
| C7 | 0.103 | 0.113 | 0.115 |
| DFC | 0.000 | 0.000 | 0.000 |

Table 10 accounts for the final values of the criteria and the sub-criteria weights (the global and the local ranks). The final values for the global rank were obtained by the multiplication of the values of the main criteria by the obtained values within the group which they belong to.

Table 10. The final results of the proposed model

| | Criteria | wj | | Sub-criteria | Local weights | Global weights | Local rank | Global rank |
|---|---|---|---|---|---|---|---|---|
| 1. | Economic | 0.520 | 1.1 | Cost/prices | 0.161 | 0.084 | 2 | 2 |
| | | | 1.2 | Quality | 0.259 | 0.135 | 1 | 1 |
| | | | 1.3 | Flexibility | 0.112 | 0.058 | 5 | 6 |
| | | | 1.4 | Productivity | 0.160 | 0.083 | 3 | 3 |
| | | | 1.5 | Financial ability | 0.105 | 0.055 | 6 | 7 |
| | | | 1.6 | Partnership relations | 0.115 | 0.060 | 4 | 4 |
| | | | 1.7 | Tech.-innovation | 0.087 | 0.045 | 7 | 9 |
| 2. | Social | 0.270 | 2.1 | Reputation | 0.164 | 0.044 | 2 | 10 |
| | | | 2.2 | Safety at work | 0.224 | 0.060 | 1 | 5 |
| | | | 2.3 | Employees' rights | 0.115 | 0.031 | 6 | 15 |
| | | | 2.4 | Local community influence | 0.089 | 0.024 | 7 | 19 |
| | | | 2.5 | Training of employees | 0.122 | 0.033 | 5 | 14 |
| | | | 2.6 | Respect of rights and policies | 0.147 | 0.040 | 3 | 11 |
| | | | 2.7 | Disclosing information | 0.138 | 0.037 | 4 | 13 |
| 3. | Environmental | 0.211 | 3.1 | Green image | 0.136 | 0.029 | 4 | 17 |
| | | | 3.2 | Recycling | 0.176 | 0.037 | 2 | 12 |
| | | | 3.3 | Pollution control | 0.220 | 0.046 | 1 | 8 |
| | | | 3.4 | Environmental protection management system | 0.129 | 0.027 | 5 | 18 |
| | | | 3.5 | Green products | 0.140 | 0.030 | 3 | 16 |
| | | | 3.6 | Consumption of resources | 0.089 | 0.019 | 7 | 21 |
| | | | 3.7 | Green competences | 0.110 | 0.023 | 6 | 20 |

## 5. Discussion

According to the respective decisions of all the three experts, when selecting a sustainable supplier, the economic factors have the greatest influence at the first level of decision-making. Those factors are followed by the social and, finally, the ecological factors, as the second- and the third-ranked (having the least influence), respectively. The obtained results showing the criteria values were expected at the beginning of the research study because the standards of environmental protection and human life and health are still insufficiently developed in the territory of Bosnia and Herzegovina, where the company is located and operates. At the second level of decision-making, quality is the most important criterion in the group of the economic factors, and is also the most important criterion in general our of all the other criteria, which is understandable given the fact that the selection of a sustainable supplier of input resources for production is carried out. In order to achieve a good quality of the output product, it is necessary that the quality of the input resource should be satisfactory. The price, productivity and partner relationships are also the criteria ranked the same in the local and the global ranks of the criteria. Once, the price was the most important criterion; with the development of the market and an increase in the number of competitors, however, quality began gaining in importance, whereas the price became less important; in this case, it ranks the second. In order to meet the conditions and the needs of the customers of the final product, it is important to provide the required quantity of products at the required time, which is achieved by timely and continuous production, for which reason it is important that the selected supplier should be reliable and make his/her deliveries at the right time. For this reason, reliability is the decision-makers' third highest priority in this research study. The selection of a supplier is a strategic decision, and therefore it is very important that the supplier should be ready to develop long-term partnerships and joint market development, due to which fact partnership relations rank the fourth. The fifth-ranked is safety at work in the global ranking, simultaneously being the first-ranked in the group of the social factors. In the course of its business, the company pays great attention to its employees' safety at work, for the reason of which fact this criterion is of great importance in the selection of suppliers. The sixth and the seventh ranks in the global ranking are assigned to the criteria of the group of the economic factors, namely to flexibility and the financial ability. As a consequence of the lesser importance of the group of the social factors, the reputation ranked the second in the local ranking, whereas it ranked the tenth in the global ranking. Out of the group of the environmental factors, pollution control is highlighted, which ranks much more importantly than the other criteria belonging to this group, out of which it ranks the eighth in the global ranking, and it is understandable for that reason that it is of the highest importance and ranks the first at the local level. Given the fact that green competence and resource consumption rank the last in the global ranking, they are the criteria least considered in the evaluation and selection of suppliers.

## 6. Conclusion

Nowadays, increasing attention is paid to the selection of a supplier given the fact that the establishment of long-term cooperation with a reliable supplier can affect a reduction in the total production costs and reaching a competitive position on the market. Considering the fact that manufacturing processes are both numerous and complex, the

manufacturer's requirements for suppliers are very complex as well. Such requirements, i.e. criteria, have increasingly been growing in number, making it difficult for decision-makers to choose suppliers. In order to facilitate the selection of a sustainable supplier, the multi-criteria FUCOM method for criteria evaluation was applied in this paper. In order to assess the significance of the criteria formed at two levels, an expert team of three decision-makers was selected. The results obtained by the applied methodology demonstrate that the most important criteria for the selection of suppliers are the quality, the price, productivity, partnership relations, safety at work, flexibility and the financial ability. Based on the most important criteria mentioned in this paper, future research should study the application of certain MCDM methods for the assessment and selection of suppliers in the company for the production of lime.

## References

Azadnia, A. H., Saman, M. Z. M., & Wong, K. Y. (2015). Sustainable supplier selection and order lot-sizing: an integrated multi-objective decision-making process. *International Journal of Production Research*, *53*(2), 383-408.

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.

Chen, C. T., Lin, C. T., & Huang, S. F. (2006). A fuzzy approach for supplier evaluation and selection in supply chain management. International journal of production economics, 102(2), 289-301

De Boer, L., Labro, E., & Morlacchi, P. (2001). A review of methods supporting supplier selection. European journal of purchasing & supply management, 7(2), 75-89

Fazlollahtabar, H., Smailbašić, A., & Stević, Ž. (2019). FUCOM method in group decision-making: Selection of forklift in a warehouse. *Decision Making: Applications in Management and Engineering*, *2*(1), 49-65.

Kagnicioglu, C. H., 2006. A fuzzy multiobjective programming approach for supplier selection in a supply chain. The Business Review, 6(1), 107-115

Liu, H. W., & Wang, G. J. (2007). Multi-criteria decision-making methods based on intuitionistic fuzzy sets. European Journal of Operational Research, 179, 220–233

Luthra, S., Govindan, K., Kannan, D., Mangla, S. K., & Garg, C. P. (2017). An integrated framework for sustainable supplier selection and evaluation in supply chains. Journal of Cleaner Production, 140, 1686-1698.

Matić, B., Jovanović, S., Das, D. K., Zavadskas, E. K., Stević, Ž., Sremac, S., & Marinković, M. (2019). A New Hybrid MCDM Model: Sustainable Supplier Selection in a Construction Company. *Symmetry*, *11*(3), 353.

Pamučar, D., Stević, Ž., & Sremac, S. (2018). A New Model for Determining Weight Coefficients of Criteria in MCDM Models: Full Consistency Method (FUCOM). Symmetry, 10(9), 393

Prentkovskis, O., Erceg, Ž., Stević, Ž., Tanackov, I., Vasiljević, M., & Gavranović, M. (2018). A New Methodology for Improving Service Quality Measurement: Delphi-FUCOM-SERVQUAL Model. *Symmetry*, *10*(12), 757.

Stević, Ž. (2017). Evaluation of supplier selection criteria in agricultural company using Fuzzy AHP Method. 22th International Scientific Conference: Strategic Management and Decision Support Systems in Strategic Management, 607-612

Stević, Ž., Vasiljević, M., Puška, A., Tanackov, I., Junevičius, R., & Vesković, S. (2019). Evaluation of suppliers under uncertainty: a multiphase approach based on fuzzy AHP and fuzzy EDAS. *Transport*, *34*(1), 52-66.

Stojanović, M., Popović, P., & Milovanović, Ž. (2017). Višekriterijumski izbor dobavljača primjenom AHP metodologije i spoftverskog paketa Expert choise. Internacional Scientific Conference on Information Technology and Data Related Research, 400-408

Zavadskas, E. K., Nunić, Z., Stjepanović, Ž., & Prentkovskis, O. (2018). A novel rough range of value method (R-ROV) for selecting automatically guided vehicles (AGVs). *Studies in Informatics and Control*, *27*(4), 385-394.