



Green Outsourcing Service Procurement with Hybrid Fuzzy AHP-TOPSIS Method in the Public Sector

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Abstract

Comprehensively examining costs and benefits in supplier selection makes the right choice challenging. Globalization increases alternatives, yet selecting the most appropriate remains difficult. Therefore, the use of scientific methods is critical when choosing among alternatives. Such methods not only facilitate the decision-making process but also enable more accurate and reliable outcomes. In the public sector, outsourcing supplier selection is typically conducted through a tender-based process, where cost is primary; however, relying solely on it can lead to suboptimal decisions. Public procurement processes proceed by identifying needs, making announcements, and inviting companies to participate in the tender. Multi-Criteria Decision-Making (MCDM) methods are commonly used tools for addressing complex problems with multiple factors, such as supplier selection. MCDM methods allow decision makers to evaluate each criterion for all alternatives and determine the option that best meets the desired requirements. Furthermore, techniques such as fuzzy logic within MCDM methods go beyond numerical data and enable decision makers to evaluate the criteria and alternatives with more understandable linguistic expressions. Although supplier selection problems are frequently examined using Fuzzy AHP and Fuzzy TOPSIS methods, studies specifically focusing on the public sector remain limited. This study addresses the problem of selecting a cleaning company. It integrates Fuzzy AHP and Fuzzy TOPSIS, aiming first to determine criteria weights using Fuzzy AHP and then to identify the most suitable supplier via Fuzzy TOPSIS. The study was implemented as an alternative method to tender-based outsourcing company selection in the public sector and is deemed beneficial.

Keywords: Fuzzy AHP, Fuzzy TOPSIS, Green Supplier Selection, Multi Criteria Decision Making, Outsourcing, Public Sector.

Kamu Sektöründe Hibrit Bulanık AHP-TOPSIS yöntemiyle Yeşil Dış Kaynak Hizmet Alımı

Öz

Firmaların tedarikçi seçiminde maliyet ve fayda kapsamlı incelendiğinde doğru seçim yapmak zorlaşmaktadır. Globalleşen dünya şartlarında alternatifler artmakta fakat en uygun olanı seçmek zorlaşmaktadır. Bu nedenle, bilimsel yöntemlerin kullanımı, alternatifler arasında seçim yaparken kritik bir öneme sahiptir. Bu metodlar, hem daha kolay bir karar verme sürecini destekler hem de daha kesin ve güvenilir kararlar alınmasına olanak tanımaktadır. Kamu sektöründe, dış kaynak kullanımı için dış tedarikçilerin seçimi ihale esaslı bir süreçle gerçekleştirilir ve genellikle maliyet kriteri en önemli faktör olarak değerlendirilmektedir ancak bu kararlar ile daha az uygun seçimlere gidilebilmektedir. Kamu alım süreçleri, ihtiyaçların belirlenmesi, duyuruların yapılması ve şirketlerin ihaleye katılımının sağlanması ile ilerler. Çok Kriterli Karar Verme (ÇKKV) yöntemleri, tedarikçi seçimi gibi birden fazla faktör içeren karmaşık sorunları ele almak için yaygın olarak kullanılan araçlardır. ÇKKV yöntemleri, karar vericilere her bir kriteri tüm alternatifler üzerinde dikkatle değerlendirme olanağı sunar ve istenilen kriterlere en uygun sonucu sağlayan alternatifin belirlenmesine yardımcı olur. Ayrıca, ÇKKV yöntemlerinde bulanık mantık gibi teknikler, sayısal verilerin ötesine geçerek, karar vericinin kriterleri ve alternatifleri daha anlaşılır dilsel ifadelerle değerlendirmesini kolaylaştırır. Literatüre bakıldığında Bulanık AHP ve Bulanık TOPSIS metodlarıyla tedarikçi seçimi problemi çok fazla karşılaşılmışına rağmen özellikle kamu sektöründe bu alanda yapılan çalışmalar sınırlıdır. Bu çalışma, temizlikçi firması seçimi problemini ele almaktadır. Çalışmada Bulanık AHP ve Bulanık TOPSIS yöntemleri entegre kullanılmış, Bulanık AHP kullanılarak öncelikle kriterlerin ağırlıkları belirlenmiş, ardından Bulanık TOPSIS aracılığıyla en uygun tedarikçiyi belirlemeyi amaçlanmaktadır. Çalışma Kamu sektöründe ihale yöntemiyle dış kaynak firma seçimine alternatif bir yöntem olarak uygulanmış ve fayda sağlayacağı düşünülmüştür.

Anahtar kelimeler: Bulanık AHP, Bulanık TOPSIS, Çok Kriterli Karar Verme, Dış Kaynak Kullanımı, Kamu Sektörü, Yeşil Tedarikçi Seçimi.

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1. Introduction

Human beings enter into a decision-making process for the problems they face in almost every field we can think of, such as work and school life, our daily life. They want to predict whether the end of this decision will be right, wrong, unsuccessful or successful. The individual decision-making process is also valid for companies in the global world. Firms are in the process of making certain decisions in order to survive in the global market with the least damage from today's competitive environment. The need to get out of the increasing and increasingly difficult competitive environment with the least damage reveals the "choosing the cheapest supplier" approach in the stakeholder selection of companies. This approach causes companies to search for different ways to reduce the cost incurred while determining their suppliers, and cost reduction efforts may have the opposite effect, leading to a decrease in product quality and actually increasing costs. For these reasons, supplier selection decisions are of strategic importance to companies.

The decision-making process, which is of strategic importance, includes alternatives to be selected and many criteria related to these alternatives. From the past to the present, the focus on the supply chain in the international business environment has been seen as a strategic way to provide competitive advantage. The supplier selection process and evaluation issues in the supply chain are of strategic importance for the performance of the company with the importance of negative impact on the environmental dimension.

In the public sector, companies purchase services from another company other than themselves for a certain period of time, which we encounter as outsourcing. Thus, it prevents companies from allocating personnel and training for the operations to be carried out and avoids extra costs. Since the decisions taken in the public sector such as outsourcing are based on tenders, especially the cost criterion is taken into consideration. In Turkey, tenders are made in accordance with the Public Procurement Law No. 4734, which entered into force in 2002. The purpose of this law is not only to consider the cost, but also to try to prevent collusion by acting equally among the suppliers participating in the tender in return for the service to be received. No matter how much the non-price factor is taken into account in the evaluations, it is generally left to the supplier company that offers the lowest price economically. Unfortunately, this will lead to the weight of the price criterion being taken into account more and the level of importance given to environmental conditions by the supplier to be selected is not evaluated.

In the public sector, decision-making is generally not based on scientific knowledge and can therefore sometimes suffer from a lack of transparency and objectivity. In many cases, decisions are based on a limited set of criteria, personal judgment or procedural shortcuts. Occasionally, the lowest tender is chosen as

the best tender without any criteria being considered. In contrast, Multiple Criteria Decision Making (MCDM) methods provide a structured and transparent approach that includes multiple and sometimes conflicting criteria, leading to more balanced, fair and beneficial decisions in the long run.

The importance of MCDM methods in public procurement has been demonstrated in some studies. Şahin (2024) emphasizes the necessity of structured decision frameworks, pointing out that even with the flexibility granted by Public Procurement Law No. 4734, excessive administrative discretion and inadequate oversight frequently result in suboptimal method selection. Doğan and Akbal (2019) showed in a university hospital case that supplier selection was dominated by price, even though technical competence and service quality were critical. Akdemir and Büyükkelik (2022) successfully balanced cost, performance, and safety when choosing patrol cars for the Turkish Gendarmerie using the CRITIC, ENTROPI, TOPSIS, and WASPAS methodologies. It is considered that incorporating analytical decision-making methods like MCDM into public procurement procedures could guarantee the best possible supplier selection, guard against procurement decision abuse, and improve accountability, transparency, and the economical use of public funds.

Multi-Criteria Decision Making (MCDM) approaches are used in the literature for such supplier selection and outsourcing decisions. In the MCDM method, firstly, we need to define our criteria to determine the result while creating our alternatives for the companies to be selected. In order to reach the best result, the criteria and alternatives are evaluated by experts. It is important to evaluate the criteria taking into account all the weaknesses and strengths of the alternative suppliers to be selected.

The first study on supplier selection criteria is Dickson's study. In his study, Dickson (1966) prepared a list of criteria that were decided on 23 criteria and this study guided the researchers for the subsequent supplier selection studies.

In the study, Fuzzy AHP-TOPSIS hybrid approach, one of the MCDM methods, was used for the green outsourcing service procurement problem in the public sector, taking into account the environmental factors that are becoming increasingly important today. In the first part of the study, Fuzzy Analytic Hierarchy Process (AHP) was used to determine the importance levels of the main and sub-criteria. In the second part of the application, the criteria weights from Fuzzy AHP are integrated into the Fuzzy TOPSIS method and the best supplier is determined among four alternative companies. Although Fuzzy AHP and Fuzzy TOPSIS methods are widely used in supplier selection problems, there are few studies in this field, especially in the public sector.

As a result of the tender published for the selection of a service procurement company in the public sector,

4 companies applying to the tender were evaluated using 20 sub-criteria based on the Environmental, Social and Economic main criteria and the supplier with the highest coefficient was selected. The study represents an alternative method to tender-based supplier selection in the public sector.

2. Literature Review

Firms' service or raw material procurement processes are faced with the issue of Supplier Selection as a problem. Most firms need and receive support from supplier companies in order to realize their processes and move forward in line with their goals. In the global world, it becomes difficult to make the right decision due to the accelerating increase in the competitive environment and the increase in the number of alternative companies. For this reason, making the right decision and choosing the supplier is one of the most important steps towards achieving the supply chain objectives of the companies. Supplier selection is shaped as contract manufacturing, outsourcing, etc. according to the raw material, semi-finished product and/or service procurement needs of the companies and is the subject of research.

Tayyar and Arslan (2013) conducted a study by using AHP and VIKOR, which are two of the MCDM methods, for outsourcing company selection in the garment industry in Turkey. Karaođlan (2016) tried to choose among alternative firms by using DEMATEL and VIKOR methods for a hotel serving in Ankara in outsourcing. Eren and Gr (2017) used AHP and TOPSIS methods in the selection of a third-party logistics company to meet outsourcing needs.

alık (2018) in the green supplier selection problem, nal et al (2019) in the supplier selection of a hotel company in Antalya, elik et al. (2016) in the supplier selection problem in the automotive sector, Karabıak et al. (2020) applied the Fuzzy AHP method in the supplier selection of a mould company in the automotive sub-industry. Akay and Pehlivan (2018) applied the fuzzy AHP method in mobile phone selection, Aydın and Eren (2018) applied the fuzzy AHP method by integrating the fuzzy AHP method, which is one of the MCDM techniques, in determining the criteria weights in the supplier selection problem in the air defence industry.

lker (2019) in leader selection, Aydın (2018) in project selection, Karaatlı et al. (2016) in performance evaluation, Koca and Taşer (2018) in selecting the right financing customer for a bank in Eskişehir, Tekez and Bark (2016) in furniture sector supplier selection, Deđermenci and Ayvaz (2016) in personnel selection in the banking sector, Kargı (2016) in supplier selection for a textile company, Yıldız and Demir (2019) in the selection of the location for Turkey's first domestic automobile production, Ko (2020) in the selection of producers in the ready-mixed concrete sector for the first time, Singh et al. (2020) in reliability estimation, and

Syleyici (2020) in his Master's Thesis used the Fuzzy TOPSIS method. zen and Borat (2020) attempted to select among alternative firms using AHP, Fuzzy AHP and Fuzzy TOPSIS approaches for supplier selection in the automotive supply industry.

Looking at the theses with the topic 'Green Supplier Selection', it can be seen that the first thesis was carried out in 2015. When examining the studies, it can be seen that the use of AHP and TOPSIS methods is more common. Ardalı (2020) used the Fuzzy AHP approach to determine the evaluation criteria for green supplier selection. Mercan and etin (2020) used ANP, MOORA-Oran method, MOORA reference point approach, GRA and COPRAS approaches for green supplier selection in the paint sub-industry of the chemical industry. Karako et. al. (2023) in their study covers sustainable supplier selection (SSS) in sustainable supply chains, analysing 101 papers from 2018 to 2022. They assess social, economic and environmental factors and categorise the papers according to their approach and use of methods. Commonly used methods include TOPSIS, AHP, VIKOR, BWM, DEA, DEMATEL and MULTIMOORA.

Faydalı and Erkan (2020) addressed the problem of packaging machine selection for a textile company. Four alternatives and seven criteria were evaluated using the fuzzy VIKOR method, and the most appropriate option was determined with five expert opinions. alık (2021), focusing on the Industry 4.0 era, and Tirkolaei (2021), considering the agri-food supply chain, used decision making approaches for green supplier selection. Alshammari (2022) addressed the challenge of green supplier selection in a green supply chain management system, while Utama (2021) integrated AHP and TOPSIS methods for green supplier selection in Indonesia. These studies highlight the potential of the hybrid fuzzy AHP-TOPSIS method in improving the environmental sustainability of service procurement in the public sector.

Ulutaş et al. (2022) proposed a novel integrated MCDM model combining Grey WISP and Grey BWM methods for general sustainable supplier selection. As in the study by alık (2021), this research employs an integrated fuzzy MCDM approach to address the complexities of sustainable supplier selection under uncertainty, further validating the methodology through a comprehensive case study in the manufacturing sector.

Denizhan et al. (2017) also used classical AHP and fuzzy AHP methods to determine suppliers in their green supplier selection study and used Chang's (1996) scale in this study.

Tablo 1. References

Authors	Year	Application Area	Methods Used	Main Focus/Finding
Tayyar & Arslan	2013	Garment industry outsourcing	AHP, VIKOR	Selection of outsourcing company in garment industry
Karaođlan	2016	Hotel industry outsourcing (Ankara)	DEMATEL, VIKOR	Selection among alternative outsourcing firms
Eren & Gr	2017	Third-party logistics outsourcing	AHP, TOPSIS	Selection of 3PL company
alık	2018	Green supplier selection	Fuzzy AHP	Green supplier selection
Karabıak et al.	2020	Automotive sub-industry (mould company)	Fuzzy AHP	Supplier selection for a mould company
Akay & Pehlivan	2018	Mobile phone selection	Fuzzy AHP	Selection of mobile phones
Aydın & Eren	2018	Air defense industry supplier selection	Integrated Fuzzy AHP	Determining criteria weights for supplier selection
lker	2019	Leader selection	Fuzzy AHP	Leader selection using MCDM methods
Aydın	2018	Project selection	Fuzzy AHP	Project selection
Karaatlı et al.	2016	Performance evaluation	DEMATEL and Fuzzy TOPSIS	Performance evaluation using MCDM methods
Koca & Taşer	2018	Financing customer selection (banking)	Fuzzy TOPSIS	Selection of right financing customer
Tekez & Bark	2016	Furniture sector supplier selection	Fuzzy TOPSIS	Supplier selection in the furniture sector
Deđermenci & Ayvaz	2016	Banking sector personnel selection	Fuzzy TOPSIS	Personnel selection in the banking sector
Kargı	2016	Textile company supplier selection	Fuzzy TOPSIS	Supplier selection
Yıldız & Demir	2019	Automotive production site selection	Fuzzy TOPSIS	Selection of domestic car production location
Ko	2020	Ready-mixed concrete producer selection	Fuzzy TOPSIS	Selection of producers in the concrete sector
Singh et al.	2020	Reliability estimation	Fuzzy TOPSIS	Reliability estimation study
Syleyici	2020	Retail sector	Fuzzy TOPSIS	Supplier selection in Master's thesis work
zen & Borat	2020	Automotive supply industry	AHP, Fuzzy AHP, Fuzzy TOPSIS	Supplier selection using multiple MCDM approaches
Ardalı	2020	Green supplier selection	Fuzzy AHP	Determination of evaluation criteria for green supplier selection
Mercan & etin	2020	Paint sub-industry (Chemical industry)	ANP, MOORA, GRA, COPRAS	Green supplier selection with multiple methods
Karako et al.	2023	Sustainable supply chains	TOPSIS, AHP, VIKOR, BWM, DEA, DEMATEL and MULTIMOORA.	Review of 101 papers on sustainable supplier selection from 2018–2022
Faydalı & Erkan	2020	Textile sector	Fuzzy VIKOR	Packaging machine selection using expert opinions
alık	2021	Industry 4.0	Fuzzy AHP and Fuzzy TOPSIS	Green supplier selection in Industry 4.0 context
Tirkolae	2021	Agri-food supply chain	AHP and Fuzzy TOPSIS	Green supplier selection
Alshammari	2022	Green supply chain management	Fuzzy TOPSIS	Green supplier selection challenge addressed
Utama	2021	Green supplier selection (Indonesia)	AHP, TOPSIS	Integration of AHP and TOPSIS for green supplier selection
Denizhan et al.	2017	Green supplier selection	AHP, Fuzzy AHP	Supplier determination using Chang's (1996) scale
lutaş et al.	2022	General sustainable supplier selection	Grey WISP, Grey BWM	Proposed a novel integrated MCDM model combining Grey WISP and Grey BWM methods for sustainable supplier selection.
alık	2021	Manufacturing sector	Fuzzy AHP, Fuzzy TOPSIS, Fuzzy VIKOR and Fuzzy MULTIMOORA	Sustainable supplier selection under uncertainty
Haseli et al.	2023	Urban Waste Management	BCM-MARCOS, Fuzzy Z ^E -umbers	Addressed sustainable resilient recycling partner selection for urban waste management using a combined MCDM framework under a fuzzy environment.
Khulud et al.	2023	Sustainable Supplier Selection	Bibliometric Analysis	Conducted a bibliometric analysis of 121 publications from 2013 to 2022 on sustainable supplier selection using MCDM approaches.
Evciođlu & Kabak	2023	Defense Industry	AHP, TOPSIS	Proposed a decision model for supplier evaluation and selection in the defense sector
elik et al.	2021	Textile Industry	BWM-TODIM under Interval Type-2 Fuzzy Sets	Combined BWM and TODIM methods to evaluate green suppliers under uncertainty.

2.1. Fuzzy AHP

Analytic Hierarchy Process (AHP) is an approach first introduced by Satty. AHP is a method that facilitates us to choose among alternatives and helps us to compare alternatives, and when we look at the AHP problem, it is actually a hierarchical MCDM technique. When this technique is applied at the point of analysing the MCDM problems, the [1-9] criterion scale described by Saaty is used (Saaty, 1990).

In many decision-making problems where the fuzzy AHP method is used, the Extended Analysis method developed by Chang (1996) is used. According to Chang's extended analysis method, order analysis is applied by considering each criterion and each alternative. Thus, m order analysis values are obtained individually for all criteria. These values are shown as follows.

$$M_{gi}^1, M_{gi}^2, \dots, M_{gi}^m \quad i = 1, 2, \dots, n$$

Here all M_{gi}^j ($j = 1, 2, \dots, m$) represent triangular fuzzy numbers.

A hierarchical structure of the problem is created and pairwise comparisons of the elements in the hierarchy are made using fuzzy numbers. After the matrices are obtained by pairwise comparisons, Chang's order analysis is explained with the following steps.

Step 1: The value of the fuzzy synthetic order according to each criterion is defined as in Eq. 1.

$$S_i = \sum_{j=1}^m M_{gi}^j \otimes \left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1} \quad (1)$$

The expressions in this formulation are calculated using Eq. 2 and Eq. 3.

$$\sum_{j=1}^m M_{gi}^j = \left(\sum_{j=1}^m l_i, \sum_{j=1}^m m_i, \sum_{j=1}^m u_i \right) \quad (2)$$

For a matrix defined in Eq. 2, fuzzy addition is performed for m expansion analysis values.

In Eq. 3, we add all l, m and u values in the comparison matrix we obtained here and then inverse in triangular fuzzy numbers.

$$\left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1} = \left(\frac{1}{\sum_{j=1}^m u_i}, \frac{1}{\sum_{j=1}^m m_i}, \frac{1}{\sum_{j=1}^m l_i} \right) \quad (3)$$

Step 2: In this step, the degree of possibility is calculated. The degree of possibility

$M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined as follows:

$$V(M_2 \geq M_1) = \begin{cases} 1, & m_2 \geq m_1 \\ 0, & l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & \text{otherwise} \end{cases} \quad (4)$$

Step 3: At this stage, all V values for each criterion are calculated and compared and the minimum value obtained for each criterion is taken. The weight vector is obtained by combining the minimum values found for all criteria.

$$W' = (d'(A_1), d'(A_2), \dots, d'(A_n))^T \quad (5)$$

Step 4: The weight vector is normalised with W being a non-fuzzy number.

$$W = \left[\frac{d'(A_1)}{\sum_{i=1}^n d'(A_i)}, \frac{d'(A_2)}{\sum_{i=1}^n d'(A_i)}, \dots, \frac{d'(A_n)}{\sum_{i=1}^n d'(A_i)} \right]^T \quad (6)$$

2.2. Fuzzy TOPSIS

The Fuzzy TOPSIS method is a technique for ranking alternatives and allows the use of quantitative and qualitative criteria in a flexible structure. This method evaluates the performance of alternatives by calculating criteria weights with linguistic expressions as in the Fuzzy AHP method. The best solution is determined based on the distance to the positive and negative ideal solution. This method assumes that all criteria have an increasing or decreasing change. In this way, the comparison and ranking of alternatives in the problem is carried out more effectively. (Özdemir, 2015)

Many different fuzzy TOPSIS techniques have been developed in the literature and these differences are due to the methods used and the types of fuzzy numbers. While some studies prefer triangular fuzzy numbers, others prefer trapezoidal fuzzy numbers. According to the analysis of 170 articles on Fuzzy TOPSIS between 2007 and 2017, the most commonly used and preferred method is triangular fuzzy numbers (Salih, ve ark., 2019). With reference to these studies, the Fuzzy TOPSIS method developed by (Chen, 2000) was used in our study.

The application steps of the Fuzzy TOPSIS method can be summarized as follows:

Step 1: A group of decision-makers is formed and the criteria to be used in the problem are defined. Decision-makers are shown with 'k'.

Step 2: Appropriate linguistic variables are defined for the importance weights of the criteria. It is obtained through linguistic variables by considering alternatives according to the criteria.

Step 3: The importance weights of the criteria and the triangular fuzzy equivalents of the linguistic variables obtained for the alternatives are written.

Step 4: The importance weights of each criterion defined in the previous step are calculated by Eq. 7.

$$W_j = \frac{1}{k} [w_j^1 + w_j^2 + \dots + w_j^k] \quad (7)$$

Step 5: After the evaluations of all decision makers are reduced to a single value, the decision problem is represented in matrix format as follows. D is the fuzzy matrix, W is the fuzzy decision matrix showing the importance weights for each criterion.

$$\tilde{D} = \begin{bmatrix} \tilde{X}_{11} & \dots & \tilde{X}_{1j} & \dots & \tilde{X}_{1n} \\ \vdots & & \vdots & & \vdots \\ \tilde{X}_{i1} & \dots & \tilde{X}_{ij} & \dots & \tilde{X}_{in} \\ \vdots & & \vdots & & \vdots \\ \tilde{X}_{m1} & \dots & \tilde{X}_{mj} & \dots & \tilde{X}_{mn} \end{bmatrix}$$

$$\tilde{W} = [\tilde{w}_{11}, \tilde{w}_{12}, \dots, \tilde{w}_{1n}] \quad (8)$$

Step 6: The fuzzy decision matrix is converted into a normalised fuzzy decision matrix by Eq. 9. In this formulation, B defines the benefit and C defines the criteria reflecting the cost.

$$r_{ij} = \left(\frac{a_{ij} b_{ij} c_{ij}}{c_j^*, c_j^*, c_j^*} \right), \quad j \in B, c_j^* = \max c_{ij}$$

$$r_{ij} = \left(\frac{a_j^-, a_j^-, a_j^-}{c_{ij}^-, b_{ij}^-, a_{ij}^-} \right), \quad j \in C, a_j^- = \min a_{ij} \quad (9)$$

Step 7: A weighted normalized decision matrix is obtained by Eq. 10.

$$V_{ij}^k = r_{ij}^k * w_{ij}^k \quad (10)$$

Step 8: Calculate the fuzzy positive ideal solution (FPIS, \tilde{A}^+) and fuzzy negative ideal solution (FNIS, \tilde{A}^-) for each alternative by Eq. 11.

$$\tilde{A}^+ = (\tilde{v}_1^+, \tilde{v}_2^+, \dots, \tilde{v}_n^+)$$

$$\tilde{A}^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-)$$

$$\tilde{v}_j^+ = \max_i \{ \tilde{v}_{ij3} \}, \quad \tilde{v}_j^- = \min_i \{ \tilde{v}_{ij1} \},$$

$$i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n \quad (11)$$

Chen (2000) used A⁺ values (1,1,1) and A⁻ values (0,0,0) as standard for each alternative. In this study, the problem was solved by taking the best and worst values of each criterion for A⁺ and A⁻ values as used by Chen et al. (2006).

Step 9: Calculate the distances of each alternative to the fuzzy positive ideal solution and fuzzy negative ideal solution by Eq. 12, Eq. 13 and Eq. 14.

$$d_{ij}^+ = \sum_{j=1}^n d(v_{ij}, v_j^+) \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \quad (12)$$

$$d_{ij}^- = \sum_{j=1}^n d(v_{ij}, v_j^-) \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \quad (13)$$

d refers to distances and is calculated by the Vertex Method.

$$d_v(\tilde{m}, \tilde{n}) = \sqrt{\frac{1}{3} [(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2]} \quad (14)$$

Step 10: Closeness coefficients are obtained for each alternative by Eq. 15 (Chen, ve ark., 2006).

$$CC_{ij} = \frac{d_{ij}^-}{d_{ij}^- + d_{ij}^+}, \quad i = 1, 2, \dots, m \quad (15)$$

Step 11: According to the closeness coefficients, the ranking of the alternatives can be determined and the alternative with the highest coefficient is determined as the best solution.

The linguistic variables used in the evaluation of alternatives according to the determined criteria are shown as triangular fuzzy numbers in Table 1.

Table 2. Triangular fuzzy numbers

Linguistic Variable	Triangular Fuzzy Numbers			Inverse of Triangular Fuzzy Numbers		
Equally important (E.I.)	1,00	1,00	2,00	0,50	1,00	1,00
Equal to moderate (E.M.)	1,00	2,00	3,00	0,33	0,50	1,00
Moderate importance (M.I.)	2,00	3,00	4,00	0,25	0,33	0,50
Moderate to strong(M.S.)	3,00	4,00	5,00	0,20	0,25	0,33
Strong importance (.SI.)	4,00	5,00	6,00	0,17	0,20	0,25
Strong to very strong (S.V.S.)	5,00	6,00	7,00	0,14	0,17	0,20
Very strong importance (V.S.I.)	6,00	7,00	8,00	0,13	0,14	0,17
Very strong to extreme importance (V.S.E.)	7,00	8,00	9,00	0,11	0,13	0,14
Extreme importance (E.X.I.)	8,00	9,00	9,00	0,11	0,11	0,13

3. Application

In the study, 4 companies that applied to the tender published for the cleaning company needs of a company operating in the public sector were evaluated. According to the Tender Law No. 4734, companies applied to the tender in return for the need for supplier selection for cleaning work and the companies were evaluated by the commission officials. When public tenders are examined, the most economically advantageous bidder is generally taken into consideration. As a result of the evaluations made, the tender was left by the commission to the tenderer with the lowest bid. Although this tender

tried to consider non-price factors, the weight of the price criterion affected the selection criterion.

In the application, 3 main criteria and 20 sub-criteria and 4 companies working in the cleaning business sector were evaluated with the hybrid Fuzzy AHP-TOPSIS method. Afterwards, Sensitivity Analysis is applied for 3 different scenarios and the effects of the change in the weights of the criteria changed for each scenario on the company rankings are analysed. The main criteria for green outsourcing service procurement selection are economic, environmental and social criteria. The sub-criteria related to these criteria form the hierarchy shown below and Figure I shows the hierarchy model of the problem.

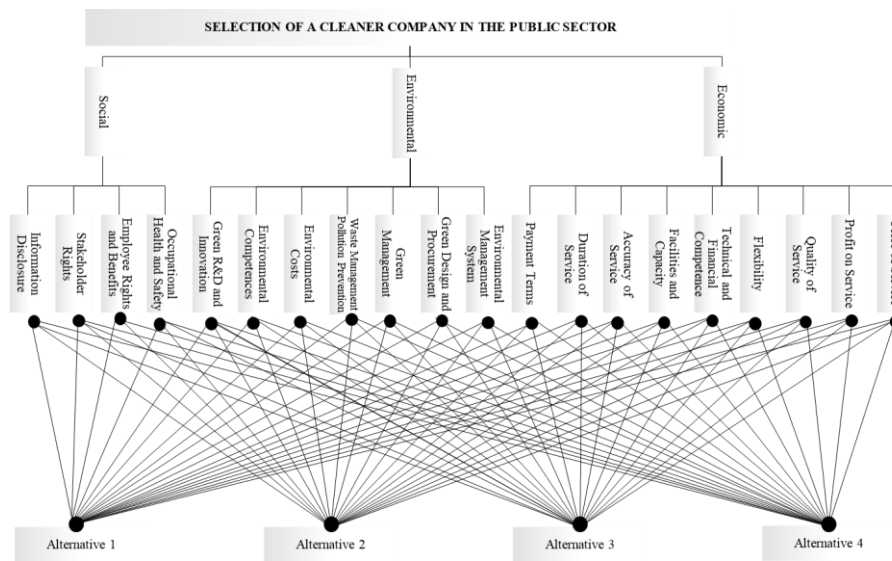


Figure 1. Hierarchy model for cleaning company

3.1. Fuzzy AHP application

In the solution of the problem, a survey form was prepared to evaluate the main-sub-criteria and alternatives. Fuzzy pairwise decision matrices were created using Geometric Mean in order to obtain a common value from the comparisons of decision makers in the survey. Excel was used to solve the criteria prioritisation part of the problem with the Fuzzy AHP method. The surveys answered by three decision makers (DM) for the main criteria are shown in Table 2. The pairwise comparison matrix in which the main criteria are evaluated according to the purpose is given in Table 3.

For example, the geometric mean of the Economic criterion with respect to the Environmental criterion is calculated as follows.

Survey answer for D.M. 1: Moderate to strong (M.S.) (3, 4, 5)

Survey answer for D.M. 2: Strong importance (S.I.) (4, 5, 6)

Survey answer for D.M. 3: Strong importance (S.I.) (4, 5, 6)

Accordingly, the geometric mean of (l, m, u) values for triangular fuzzy numbers;

$$l = \sqrt[3]{3 * 4 * 4} = 1,47$$

$$m = \sqrt[3]{4 * 5 * 5} = 1,84$$

$$u = \sqrt[3]{5 * 6 * 6} = 2,29$$

Table 3. Decision Makers' survey comparison for main criteria

Decision Makers	Main Criteria	E.X.I.	V.S.E.	V.S.I.	S.V.S.	S.I.	M.S.	M.I.	E.M.	E.I.	E.M.	M.I.	M.S.	S.I.	S.V.S.	V.S.I.	V.S.E.	E.X.I.	Main Criteria
D.M. 1	Economic													X					Environmental
	Economic											X							Social
	Environmental							X											Social
D.M. 2	Economic					X													Environmental
	Economic								X										Social
	Environmental							X											Social
D.M. 3	Economic					X													Environmental
	Economic								X										Social
	Environmental							X											Social

Table 4. Pairwise comparison of main criteria with fuzzy triangular numbers

Main Criteria	Economic			Environmental			Social		
Economic	1,00	1,00	1,00	1,47	1,84	2,29	0,63	1,10	1,65
Environmental	0,44	0,54	0,68	1,00	1,00	1,00	2,00	3,00	4,00
Social	0,61	0,91	1,59	0,25	0,33	0,50	1,00	1,00	1,00

According to Chang (1996)'s Extended Analysis Method, we need to calculate the value of the fuzzy synthetic order for all main criteria using Eq. 1. From the synthetic value formula;

$$S_{Economic} = (3.10, 3.94, 4.94) \otimes ((1/13.71), (1/10.73), (1/8.40)) = (0.226, 0.368, 0.588)$$

$$S_{Environmental} = (3.44, 4.54, 5.68) \otimes ((1/13.71), (1/10.73), (1/8.40)) = (0.251, 0.423, 0.676)$$

$$S_{Social} = (1.86, 2.24, 3.09) \otimes ((1/13.71), (1/10.73), (1/8.40)) = (0.135, 0.209, 0.368)$$

It was calculated as . Comparison operations are performed using these obtained vectors. Each criterion is compared with other criteria with the help of Eq. 2. For example;

$$V(S_{Economic} \geq S_{Social}) = 1$$

$$(m_{economic} = 0.368 \geq m_{social} = 0.209)$$

$$V(S_{Environmental} \geq S_{Social}) = 1$$

$$(m_{environmental} = 0.423 \geq m_{social} = 0.209)$$

Table 5. Synthetic values of main criteria comparison results and weight vector

	S _{Economic}	S _{Environmental}	S _{Social}
S _{Economic}	X	1,000	0,471
S _{Environmental}	0,858	X	0,353
S _{Social}	1,000	1,000	X
Min Value	0,858	1,000	0,353
Weights	0,388	0,452	0,160

The weight vectors for W are given in Table 4. The values of W are obtained by normalizing Eq. 6. Accordingly, if the importance levels of the main criteria are expressed in percentages, for the cleaning company, the economic criterion holds 38.8%, the environmental criterion 45.2%, and the social criterion 16% importance. In the same way, the Extended Analysis method of Chang (1996) was applied for each sub-criteria. The fuzzy matrices and weight vectors comparing the sub-criteria of the economic,

environmental and social main criteria were calculated similarly and their general weights are given in Table 5, Table 6 and Table 7.

Due to the large size of the matrices, the numbers in the pairwise comparison matrices calculated for the economic and environmental main criteria are rounded and written as single digits after the decimal point.

Table 6. Fuzzy pairwise comparison matrix and weights for sub-criteria of economic main criterion

	H.F.	H.K.	...	Ö.K.	W
H.F.	1,0;1,0;1,0	1,4; 2,5; 3,6	...	0,2; 0,3; 0,3	0,11
H.K.	0,3; 0,4; 0,7	1,0;1,0;1,0	...	0,7; 1,0; 1,8	0,00
H.K.A.	1,1; 1,9; 2,0	3,4; 4,5; 5,5	...	1,8; 2,3; 3,4	0,15
E.S.	0,6; 0,7; 0,8	4,2; 5,2; 6,2	...	0,6; 0,6; 1,1	0,21
T.F.Y.	0,4; 0,5; 0,7	0,5; 0,7; 1,0	...	0,3; 0,4; 0,8	0,00
T.K.	0,6; 0,7; 0,9	0,7; 0,9; 1,3	...	0,4; 0,4; 0,7	0,00
H.D.	0,6; 0,9; 1,6	2,9; 3,9; 4,9	...	0,9; 1,1; 1,7	0,20
H.S.	0,5; 0,6; 0,8	3,6; 4,6; 5,6	...	1,3; 1,8; 2,9	0,18
Ö.K.	3,0; 4,0; 5,0	0,6; 1,0; 1,4	...	1,0;1,0;1,0	0,14

Table 7. Fuzzy pairwise comparison matrix and weights for sub-criteria of environmental main criterion

	Ç.Y.S.	Y.T.S.	...	YARGE	W
Ç.Y.S.	1,0; 1,0; 1,0	1,0; 1,6; 2,6	...	0,2; 0,3; 0,4	0,06
Y.T.S.	0,4; 0,6; 1,0	1,0; 1,0; 1,0	...	0,9; 1,1; 2,0	0,10
Y.Y.	0,8; 1,3; 1,8	0,3; 0,4; 0,8	...	0,7; 0,8; 1,6	0,08
AYKÖ	1,3; 2,3; 3,3	2,3; 3,3; 4,3	...	1,0; 1,4; 2,0	0,24
Ç.M.	1,4; 2,5; 3,6	2,0; 3,1; 4,2	...	0,8; 1,0; 1,6	0,19
Ç.Y.	1,4; 2,3; 2,7	0,8; 1,3; 1,8	...	0,5; 0,6; 1,3	0,16
YARGE	2,5; 3,7; 4,8	0,5; 0,9; 1,1	...	1,0; 1,0; 1,0	0,17

Table 8. Fuzzy pairwise comparison matrix and weights for sub-criteria of social main criterion

	İSG	Ç.H.	P.H.	B.A.	W
İSG	1,00; 1,00; 1,00	1,52; 1,86; 2,24	3,17; 4,48; 5,45	2,00; 3,11; 4,16	0,51
Ç.H.	0,45; 0,54; 0,66	1,00; 1,00; 1,00	2,00; 3,11; 4,16	2,52; 3,56; 4,58	0,40
P.H.	0,18; 0,22; 0,31	0,24; 0,32; 0,5	1,00; 1,00; 1,00	0,28; 0,38; 0,63	0,00
B.A.	0,24; 0,32; 0,50	0,22; 0,28; 0,40	1,59; 2,62; 3,63	1,00; 1,00; 1,00	0,09

As shown in Table 5, the results obtained from the sub-criteria related to the main criterion "Economic", when expressed as percentages, are ranked as follows: flexibility 21%, accuracy of service 20%, duration of service 18%, quality of service 15%, payment terms 14%, and price of service 11%.

According to Table 6, the results of the sub-criteria related to the main criterion "Environment", expressed in percentages, are as follows: waste management and pollution prevention 24%, environmental costs 19%, green R&D and innovation 17%, environmental competencies 16%, green design and procurement 10%, green management 8% and environmental management system 6%.

According to Table 7, if the weights of the sub-criteria under the main criterion "Social" are expressed as percentages, it appears that Occupational Health and Safety (İSG) has the highest importance with 51%, followed by Employee Rights and Benefits with 40% and then Information Disclosure with 9%.

Hybrid Fuzzy AHP-TOPSIS method is used to select among the alternatives. In the first stage of the problem, the weights of the main and sub-criteria are calculated using the Fuzzy AHP method. As a result of the obtained solutions, the Fuzzy TOPSIS method is applied to select the best supplier among the four alternative companies

3.2. Fuzzy TOPSIS application

Fuzzy TOPSIS method was applied to the four alternative companies determined for the selection of the supplier company by using the weights of the main-sub-criteria determined by the Fuzzy AHP method as a hybrid. In the Fuzzy TOPSIS application, "Price of Service", "Duration of Service" and "Environmental Costs" were selected as the criteria to be minimised in the selection criteria. In Table 9, the criteria weights from Fuzzy AHP are summarised by writing min-max according to positivity-negativity.

The general weight values of 3 main criteria and 20 sub-criteria obtained by fuzzy AHP method are calculated in Table 9. In the table, it is seen that the criterion with the highest impact among the main criteria is Environmental factors with 0,452. Accordingly, the highest priority weight for the sub-criteria was found to be AYKÖ with 0.24. The weight of AYKÖ among the total criteria, calculated from the weights of interrelated main and sub-criteria, is determined to be 0,11.

Table 9. Weights from Fuzzy AHP for selection criteria

Main Criteria	Sub-criteria	Effect on Selection	Importance Weight		
			Main Criteria	Sub Criteria	Criteria General Weight
ECONOMIC	Price of Service (H.F.)	MIN		0,11	0,043
	Profit on Service (H.K.)	MAX		0,00	0,000
	Quality of Service (H.K.A.)	MAX		0,15	0,059
	Flexibility (E.S.)	MAX		0,21	0,081
	Technical and Financial Competence (T.F.Y)	MAX	0,388	0,00	0,000
	Facilities and Capacity (T.K.)	MAX		0,00	0,000
	Accuracy of Service (H.D.)	MAX		0,20	0,079
	Duration of Service (H.S.)	MIN		0,18	0,071
	Payment Terms (Ö.K.)	MAX		0,14	0,055
ENVIRONMENTAL	Environmental Management System (Ç.Y.S)	MAX		0,06	0,026
	Green Design and Procurement (Y.T.S.)	MAX		0,10	0,046
	Green Management (Y.Y.)	MAX		0,08	0,035
	Waste Management and Pollution Prevention (AYKÖ)	MAX	0,452	0,24	0,110
	Environmental Costs (Ç.M.)	MIN		0,19	0,087
	Environmental Competences (Ç.Y.)	MAX		0,16	0,072
	Green R&D and Innovation (YARGE)	MAX		0,17	0,076
SOCIAL	Occupational Health and Safety (İSG)	MAX		0,51	0,082
	Employees' Rights and Benefits (Ç.H.)	MAX		0,40	0,064
	Stakeholders' Rights (P.H.)	MAX	0,160	0,00	0,000
	Information Disclosure (B.A.)	MAX		0,09	0,014

Fuzzy TOPSIS decision matrices were created by calculating the average of the scores of three expert decision makers in the survey. Due to the size of the table, criteria are placed in rows and alternatives in columns in the Fuzzy TOPSIS decision matrix. For the hybrid solution, the Fuzzy TOPSIS method was used to try to select the appropriate alternative from among the alternatives, incorporating the criterion weights from Fuzzy AHP into the solution. In the Excel calculations, each criterion was reduced to the range [0,1], taking into account the benefit and cost characteristics.

For example, since the impact of the Price of Service criterion is minimal, it was calculated as follows for Alternative 1.

$$r_{ij} = \left(\frac{3}{5}, \frac{3}{4}, \frac{3}{3} \right), \quad \min a_j = (3,00; 4,00; 5,00)$$

Using this formulation, the triangular fuzzy numbers were calculated as (0.6; 0.75; 1.00) after normalization for Alternative 1.

Table 10. Fuzzy TOPSIS decision matrix

\tilde{D}	Alternative 1			Alternative 2			Alternative 3			Alternative 4		
H.F.	3,00	4,00	5,00	5,33	6,33	7,33	5,67	6,67	7,67	4,00	5,00	6,00
H.K.	5,67	6,67	7,67	6,67	7,67	8,33	6,67	7,67	8,33	6,00	7,00	8,00
.
.
P.H.	2,00	3,00	4,00	5,00	6,00	7,00	7,33	8,33	9,00	5,67	6,67	7,67
B.A.	2,67	3,67	4,67	8,00	9,00	9,00	6,00	7,00	8,00	6,00	7,00	8,00

Table 11. Fuzzy normalized decision matrix

	Alternative 1			Alternative 2			Alternative 3			Alternative 4		
H.F.	0,60	0,75	1,00	0,41	0,47	0,56	0,39	0,45	0,53	0,50	0,60	0,75
H.K.	0,68	0,80	0,92	0,80	0,92	1,00	0,80	0,92	1,00	0,72	0,84	0,96
.
.
P.H.	0,22	0,33	0,44	0,56	0,67	0,78	0,81	0,93	1,00	0,63	0,74	0,85
B.A.	0,30	0,41	0,52	0,89	1,00	1,00	0,67	0,78	0,89	0,67	0,78	0,89

The criteria weights calculated by the Fuzzy AHP are shown in Table 11. These weights were integrated into the Fuzzy TOPSIS method and multiplied by normalized values to obtain weighted normalization values. The Weighted Normalized Fuzzy Decision

Matrix is shown in Table 12. In step 7 of Fuzzy TOPSIS, a weighted normalized decision matrix was created using Eq. 10.

Table 12. Weighted normalized decision matrix (\tilde{V})

	Alternative 1			Alternative 2			Alternative 3			Alternative 4		
H.F.	0,026	0,032	0,043	0,017	0,020	0,024	0,017	0,019	0,023	0,021	0,026	0,032
H.K.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
H.K.A.	0,020	0,027	0,034	0,048	0,054	0,059	0,043	0,050	0,057	0,034	0,041	0,048
E.S.	0,059	0,070	0,081	0,044	0,055	0,066	0,022	0,033	0,044	0,052	0,063	0,074
.
.
YARGE	0,009	0,009	0,018	0,053	0,061	0,070	0,056	0,064	0,073	0,061	0,070	0,076
İSG	0,009	0,015	0,024	0,036	0,045	0,054	0,073	0,082	0,082	0,057	0,066	0,076
Ç.H.	0,010	0,015	0,022	0,042	0,049	0,056	0,049	0,056	0,064	0,051	0,059	0,064
P.H.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.A.	0,004	0,006	0,008	0,013	0,014	0,014	0,010	0,011	0,013	0,010	0,011	0,013

After the weighted normalized fuzzy decision matrix was created, the best-worst values specified in the Fuzzy TOPSIS application steps were calculated.

$$A^* = [(0,026; 0,032; 0,043), \dots, (0,013; 0,014; 0,014)]$$

$$A^- = [(0,017; 0,019; 0,023), \dots, (0,004; 0,006; 0,008)]$$

These values were then used to calculate the distances of each alternative to the FPIS and the FNIS for all criteria. The distances of all criteria were calculated for each alternative and the results are shown in Table 13.

Table 13. Distances to fuzzy ideal solution

	FPIS Distances				FNIS Distances			
	A1	A2	A3	A4	A1	A2	A3	A4
H.F.	0,000	0,014	0,015	0,008	0,015	0,001	0,000	0,007
H.K.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
H.K.A.	0,026	0,000	0,004	0,013	0,000	0,026	0,023	0,014
E.S.	0,000	0,015	0,037	0,007	0,037	0,022	0,000	0,029

·	·	·	·	·	·	·	·	·
·	·	·	·	·	·	·	·	·
·	·	·	·	·	·	·	·	·
YARGE	0,058	0,008	0,005	0,000	0,000	0,050	0,053	0,058
İSG	0,063	0,034	0,000	0,013	0,000	0,029	0,063	0,050
Ç.H.	0,042	0,009	0,002	0,000	0,000	0,033	0,041	0,042
P.H.	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
B.A.	0,008	0,000	0,003	0,003	0,000	0,008	0,005	0,005

Using the distances calculated in the tables, the distances of the alternatives to the total ideal solution are calculated in Table 14 by using Eq. 12 and Eq. 13 in the Fuzzy TOPSIS application steps. In the last step of the Fuzzy TOPSIS method, the closeness coefficients (CCi) of the alternatives should be calculated using Eq. 15 for the selection of a suitable supplier, Table 15 shows the closeness coefficient values of the alternatives.

For example, the closeness coefficient for Alternative 1 is calculated as follows.

$$CC_{A1} = 0,084 / (0,084 + 0,472) = 0,151$$

According to the Fuzzy TOPSIS results calculated in Table 15, it is seen that Alternative 4 is the best choice for green outsourcing service procurement with the highest weight (0.797). This result is followed by Alternative 3, Alternative 2 and Alternative 1 respectively.

3.3. Sensitivity analysis of the problem

The criteria evaluated for suppliers can be affected by rapidly changing conditions over time. Examples of these changes are the involvement of different decision makers in the solution and changes in criteria priorities over time. Sensitivity analyses were performed for the problem based on 3 different scenarios. The change in the solution according to the scenarios is shown in Figure 7.2.

Scenario 1: Sensitivity analysis was performed by assigning different weights to the sub-criteria related to the economic main criterion, considering that the weight values, which are equal and zero, will change for

Table 14. Distances to total ideal solution

	d _i *	d _i -
Alternative 1	0,472	0,084
Alternative 2	0,180	0,378
Alternative 3	0,161	0,396
Alternative 4	0,113	0,445

Table 15. Alternative values

Supplier	Cci	Ranking
Alternative 1	0,151	4
Alternative 2	0,678	3
Alternative 3	0,711	2
Alternative 4	0,797	1

different decision makers or over time. The highest criterion was given to Quality of Service (HKA), followed by Price of Service (HF). The 'New Criteria General Weights' to be used according to the criteria values are shown in Table 16. The solution steps for these values were applied in Excel. The alternative ranking for the new weights given is as shown in Table 17.

According to Table 17, when the Fuzzy TOPSIS values calculated in the Current and Scenario 1 are compared, it is seen that Alternative 4 is the best supplier as in the current situation, followed by Alternative 3, Alternative 2 and Alternative 1 respectively.

Table 16. New criteria general weights calculated according to the economic main criteria sub-criteria

	H.F.	H.K.	H.K.A.	E.S.	T.F.Y.	T.K.	H.D.	H.S.	Ö.K.
Old Values	0,11	0,00	0,15	0,21	0,00	0,00	0,20	0,18	0,14
New Weight Vectors	0,20	0,10	0,25	0,10	0,01	0,04	0,15	0,10	0,05
New Criteria General Weights	0,08	0,04	0,10	0,04	0,00	0,02	0,06	0,04	0,02

Tablo 17. First scenario alternative closeness coefficients

Supplier	Cci	Ranking
Alternative 1	0,108	4
Alternative 2	0,714	3
Alternative 3	0,753	2
Alternative 4	0,776	1

Scenario 2: Considering the increasing importance of green outsourcing, the subcriteria weights are calculated and changed according to the new scenario, depending on the environmental main criterion.

In this context, the subcriteria weights for supplier selection have been changed and the criteria weights have been calculated. The Environmental Cost (ÇM) criterion has the highest weight and the other criterion weights are shaped accordingly. The 'New General

Criteria Weights' for the criteria values according to the new calculated weights are shown in Table 18. The ranked alternatives for the new calculated weights are shown in Table 19.

When the Scenario values in Table 19 are compared with the current results, it is seen that Alternative 4 maintains its first place. In addition, it is observed that Alternative 2 ranks second in the ranking, ahead of Alternative 3. Alternative 1 is again in the last place.

Tablo 18. New criteria general weights calculated according to the environmental main criterion sub-criteria

	Ç.Y.S.	Y.T.S.	Y.Y.	AYKÖ	Ç.M.	Ç.Y.	YARGE
Old Values	0,06	0,10	0,08	0,24	0,19	0,16	0,17
New Weight Vectors	0,05	0,06	0,06	0,16	0,37	0,15	0,15
New Criteria General Weights	0,023	0,027	0,027	0,072	0,167	0,068	0,068

Tablo 19. Second scenario alternative closeness coefficients

Supplier	Cci	Ranking
Alternative 1	0,161	4
Alternative 2	0,688	2
Alternative 3	0,637	3
Alternative 4	0,764	1

Scenario 3: In this scenario, no changes were made in the weights of the sub-criteria. However, the weights of the main criteria were rearranged and the result of the

main criteria weights was obtained. The weights of the Social main criterion were not changed significantly, while the weights of the Economic and Environmental main criteria were given high and close to each other in such a way that their priority was in the opposite direction, and the result was calculated in Table 20.

Comparing the results of Scenario 3 in Table 21 with the current values, it is seen that Alternative 4 still maintains the first place as the best supplier. It is followed by Alternative 3, Alternative 2 and Alternative 1.

Based on the results of 3 different scenarios, Alternative 1 is always the last choice, while Alternative 4 is always the first choice.

Tablo 20. New weights from Fuzzy AHP to be used for the third scenario

Main Criteria	Sub-criteria	Effect on Selection	Importance Weight		Criteria General Weight
			Main Criteria	Sub Criteria	
ECONOMIC	H.F.	0,39	0,45	0,11	0,0493
	H.K.			0,00	0,0000
	H.K.A.			0,15	0,0684
	E.S.			0,21	0,0939
	T.F.Y.			0,00	0,0000
	T.K.			0,00	0,0000
	H.D.			0,20	0,0919
	H.S.			0,18	0,0823
	Ö.K.			0,14	0,0642

ENVIRONMENTAL	Ç.Y.S.			0,06	0,0228
	Y.T.S.			0,10	0,0406
	Y.Y.			0,08	0,0313
	AYKÖ	0,45	0,40	0,24	0,0977
	Ç.M.			0,19	0,0771
	Ç.Y.			0,16	0,0633
	YARGE			0,17	0,0672
SOCIAL	İSG			0,51	0,0767
	Ç.H.	0,16	0,15	0,40	0,0597
	P.H.			0,00	0,0000
	B.A.			0,09	0,0136

Table 21. Third scenario alternative closeness coefficients

Supplier	Cci	Ranking
Alternative 1	0,176	4
Alternative 2	0,663	3
Alternative 3	0,689	2
Alternative 4	0,791	1

4. Discussion

Today, supplier selection is of great importance to both the public and private sectors. By selecting suppliers that meet their objectives, organisations create long-term collaborations and mutually beneficial relationships.

In the procurement of goods and services by public institutions, although non-price factors are taken into account in the selections made under the Public Procurement Law No. 4734, the bidders offering the lowest price are generally preferred and the selection is made accordingly. However, this approach can sometimes lead to suppliers failing to fulfill their commitments, failing to provide services or products of the desired quality, and failing to meet the increasingly important green supplier criteria.

Supplier selection problems have been addressed in various studies in the literature. In such problems, there are multiple alternatives and multiple criteria used to evaluate these alternatives. Multi-criteria decision making (MCDM) methods are used to solve such problems. Frequently used MCDM methods include methods such as AHP, TOPSIS and Electre. In MCDM methods, it has been explained in studies that the decision maker may occasionally get into situations of indecision and inconsistency and may not be able to make such comparisons accurately with numbers, linguistic expressions are used instead of numerical comparisons. The need for Fuzzy MCDM techniques, which use linguistic expressions expressed in fuzzy triangular numbers and thus eliminate inconsistencies, has provided a solution to such difficulties. Thanks to these methods, studies have progressed more accurately and decision-making processes have become healthier.

In this context, the study examines the green outsourcing selection problem by considering a tender opened by a public organization for the procurement of water and canal services. Considering the situations where the Public Procurement Law No. 4734 is inadequate, Hybrid Fuzzy AHP-TOPSIS, one of the Fuzzy MCDM methods, was used to select a company for green outsourcing.

In the problem, three main criteria, namely Economic, Environmental and Social, and 20 sub-criteria based on these criteria were used to select the most suitable supplier. Fuzzy AHP-TOPSIS method was used in an integrated manner. In the first stage of the problem, the main criteria and sub-criteria weights were determined by Fuzzy AHP and the most suitable supplier which is the green outsourcing service selection, among the alternatives was ranked by Fuzzy TOPSIS method using the determined criteria weights. MS Excel application was used for these solution methods.

As shown in Figure 2 in Bayındır's (2021) Master's thesis, the highest weight (0.365) was calculated for Alternative 3 when the Fuzzy AHP method was used in the suitability ranking for green outsourcing service procurement. This was followed by Alternative 3 > Alternative 4 > Alternative 2 > Alternative 1. Figure 3 shows the results using the hybrid Fuzzy AHP-TOPSIS method. When the hybrid approach was used, the highest value (0.797) was found for Alternative 4 and the ranking continued as Alternative 4 > Alternative 3 > Alternative 2 > Alternative 1. As it is assumed that the criteria values of these rankings can be evaluated in different ways and may change over time, 3 different scenarios were applied to the problem for sensitivity analysis.

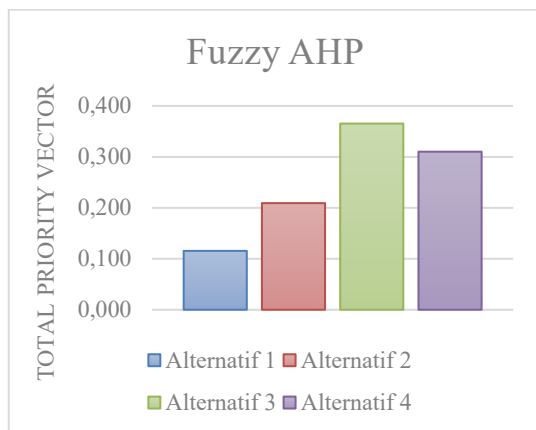


Figure 2. Fuzzy AHP and Fuzzy TOPSIS Results

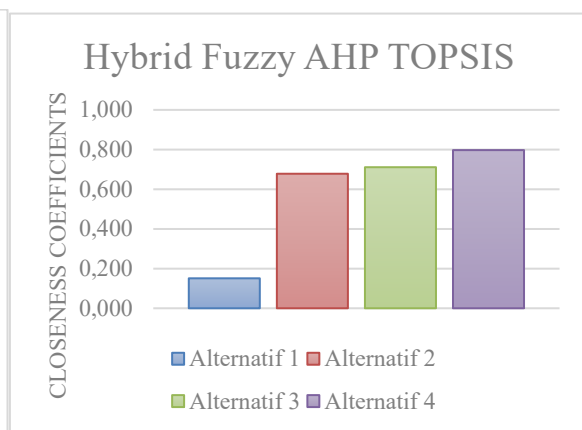


Figure 3. Fuzzy AHP and Fuzzy TOPSIS Results

As seen in Figure 4, green outsourcing service procurement rankings vary according to the sensitivity analysis results. According to the calculated results and the results in Scenario 3, the rankings should be equal and Alternative 4 should be selected as the best supplier, whereas in Scenario 1, Alternative 3 came too close to Alternative 4 and pushed the possibility of being the first supplier. In Scenario 2, due to the sub-criteria change related to the Environmental criterion, Alternative 2 moved ahead of Alternative 3 and rose to the second ranking and started to challenge the first place of Alternative 4.

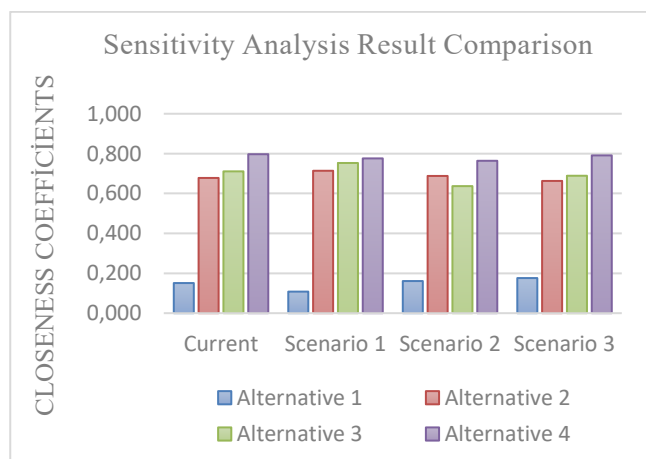


Figure 4. The results of the sensitivity analysis

The results show that Alternative 1 is always ranked last, while Alternative 4 is always ranked first. The other alternatives were close to each other with very small differences but failed to reach the first position. In Scenario 1, Alternative 3 came very close to Alternative 4, ranking second again with a difference of 8%.

The fact that Alternative 1 was selected as a result of the tender shows that when all criteria are evaluated and used in the Hybrid Fuzzy AHP-TOPSIS method, Alternative 1 is not the company that should be preferred. The fact that Alternative 1 is ranked last in all methods shows this situation.

As shown in Figure 5; Alternative 1, which was the cheapest, was selected at the end of the tender. The fact that Alternative 1 was selected as a result of the tender shows that when all criteria are evaluated and used in the Hybrid Fuzzy AHP-TOPSIS method, Alternative 1 is not the company that should be preferred. The fact that Alternative 1 is ranked last in all methods shows this situation.

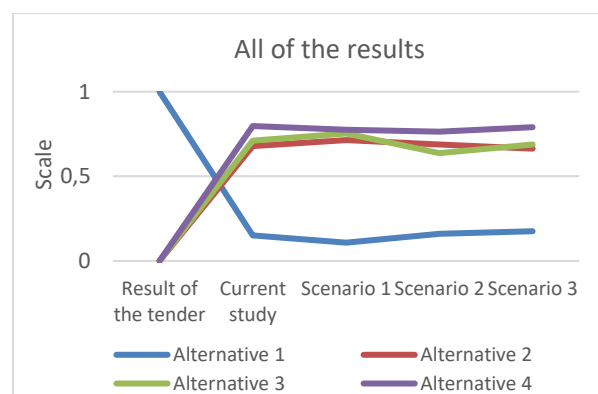


Figure 5. All of the results

The use of this study in the selection of green suppliers in public tenders is considered to be a very useful approach. Although there are statements that only the price factor is not taken into account in most tenders today, there is a tendency to award the tender to the supplier with the lowest bid. However, this may lead to lower service quality and price-related problems in the future. In addition, factors that may be important in the selection of other suppliers may not be sufficiently taken into account.

5. Conclusions

This study addressed the challenge of choosing outsourcing suppliers within the public sector using the Hybrid Fuzzy AHP-TOPSIS method. The problem involves three primary criteria: Economic, Environmental, and Social. To determine the most appropriate supplier, 20 sub-criteria obtained from these

main criteria were utilized. A combined evaluation of these criteria showed that Alternative 4 was the best tender both in the initial evaluation and across all sensitivity or scenario analyses. However, the lowest-cost bidder, Alternative 1, was chosen in the real tender procedure. The fact that Alternative 1's last-place ranking across all evaluation models indicates that price-oriented procurement decisions can overlook essential quality, sustainability, and capacity considerations, which may result in reduced service performance and long-term inefficiencies.

MCDM methods are effective tools for evaluating alternatives and making a more accurate supplier selection. These methods provide a more accurate evaluation of suppliers by considering all factors including non-price factors and green supplier criteria. Hybrid Fuzzy MCDM methods, which have been used more and more recently, make supplier selection more efficient and effective and facilitate better results.

This study supports a more comprehensive and informed approach to supplier selection by recommending the use of CRM methods in public procurement. It allows us to make better supplier choices by considering not only price, but also quality, sustainability and other important criteria. As a result, this study presents an alternative method of supplier selection to the current method of tender selection.

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