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Sustainable 3PL Service Provider Selection in the Pharmaceutical Industry Using Fuzzy-Based SWARA and MAIRCA Methods

Bulanık Tabanlı SWARA ve MAIRCA Yöntemlerini Kullanarak İlaç Endüstrisinde Sürdürülebilir 3PL Hizmet Sağlayıcı Seçimi

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Abstract: This study aims to develop a framework for the selection of sustainable third-party logistics service providers (3PLSPs) for the pharmaceutical industry by developing an integrated decision-making framework based on fuzzy SWARA and fuzzy MAIRCA methods. To achieve this goal, 21 selection criteria were determined within the scope of economic, infrastructure, environmental, and social basic dimensions through literature review and expert opinions. Then, the weights of these criteria were calculated using the fuzzy SWARA method. Finally, alternative sustainable 3PLSPs were ranked using the fuzzy MAIRCA method. The findings indicate that the most crucial criteria for selecting sustainable 3PLSPs are financial stability, industry-specific knowledge and experience, environmental protection, and worker health and safety, corresponding to economic, infrastructure, environmental, and social dimensions, respectively.

Keywords: 3PL service providers, Sustainability, Pharmaceutical industry, Fuzzy SWARA, Fuzzy MAIRCA

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Öz: Bu çalışmanın amacı, bulanık SWARA ve bulanık MAIRCA yöntemlerine dayalı bütünleşik bir karar alma çerçevesi geliştirerek ilaç endüstrisi için sürdürülebilir üçüncü taraf lojistik hizmet sağlayıcılarının seçimi için bir çerçeve oluşturmaktır. Bu hedefe ulaşmak için literatür taraması ve uzman görüşleri yoluyla ekonomik, altyapı, çevresel ve sosyal temel boyutlar kapsamında 21 seçim kriteri belirlenmiştir. Daha sonra bulanık SWARA yöntemi kullanılarak bu kriterlerin ağırlıkları hesaplanmıştır. Son olarak bulanık MAIRCA yöntemi kullanılarak alternatif sürdürülebilir üçüncü taraf lojistik hizmet sağlayıcıları sıralanmıştır. Bulgular, sürdürülebilir üçüncü taraf lojistik hizmet sağlayıcılarının seçilmesi için en önemli kriterlerin sırasıyla ekonomik, altyapı, çevresel ve sosyal boyutlara karşılık gelen finansal istikrar, sektöre özgü bilgi ve deneyim, çevre koruma ve işçi sağlığı ve güvenliği olduğunu göstermektedir.

Anahtar Kelimeler: 3PL hizmet sağlayıcıları, Sürdürülebilirlik, İlaç endüstrisi, Bulanık SWARA, Bulanık MAIRCA

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1. Introduction

Companies are increasingly turning to outsourcing at various stages of their supply chain processes to gain a competitive advantage by focusing on their core competencies. Outsourcing is when a company delegates specific tasks to external firms to improve supply chain performance, allowing the organization to focus on key strategic decisions related to its core strengths (Wu, 2005:2513). Logistics is a key activity that companies often choose to outsource (Aguezzoul, 2014:69). A logistics provider works with multiple companies at the same time, allowing them to benefit from economies of scale, which can lead to cost reductions for the firm (Govindan et al., 2019:610). On the other hand, cost reduction is not the only goal when making outsourcing decisions. Opportunities to improve services, increase performance satisfaction, enhance information security, and gain flexibility are also crucial (Yang, 2007:3769).

Logistics is a critical process for success in business ventures, as it helps firms improve their competitiveness and responsiveness in customer service (Mageto, 2022:3). Accurate logistics management can have a positive impact on the supply chain by reducing inventory, increasing productivity, improving agility, meeting short deadlines, monitoring events and flows, and enhancing customer service (Dadashpour and Bozorgi-Amiri, 2020:2234). Logistics outsourcing has become vital globally. One effective initiative that has enabled firms to concentrate on their core competencies is the outsourcing of logistics services to third-party logistics service providers (3PLSPs) (Liu and Lyons, 2011). Delegating logistics operations to external service providers has become a highly favorable choice. These 3PLSPs assume the essential risks associated with services and delivery, enabling companies to dedicate their efforts to their primary business functions (Gardas et al., 2019:959).

The logistics sector has made significant contributions to both society and the economy; however, it is essential to consider the impact on the environment (Froio and Bezerra, 2021). The logistics industry is the largest source of CO_2 emissions (Jayarathna et al., 2023:705). About 24% of the world's carbon emissions are caused by transportation and logistics activities. After the energy sector, this is the primary source of greenhouse gas emissions. Most of these emissions are produced by shipping, aviation, and road transport (Carboncare, 2023; Raut et al., 2018:77). The European Environment Agency anticipates that by 2050, without the implementation of effective measures, global logistics will be responsible for 40% of the world's carbon emissions (Carboncare, 2023). Hence, it is essential to integrate sustainable practices such as reducing carbon emissions, minimizing waste, and optimizing energy usage into every aspect of logistics operation, from sourcing to distribution.

Sustainability involves conserving natural resources and using them judiciously for long-term business continuity. With ongoing environmental degradation and resource scarcity, sustainability has become a critical concern for all organizations, including logistics service providers (Gupta and Singh, 2020:1629; Raut et al., 2018:77). This issue holds particular importance in the pharmaceutical industry, where sustainable practices directly impact public health and environmental safety due to the sensitive nature of pharmaceutical products and their supply chains. Selection of a suitable third-party logistics service provider (3PLSP) to adapt to sustainability is essential for improving business performance, reducing carbon tax, and contributing to society (Roy et al., 2020:670). 3PLSPs, as external stakeholders, play a pivotal role in aligning supply chain operations with sustainability goals by adopting green warehousing, efficient transportation, and waste minimization practices. Ultimately, the sustainability impacts of 3PLSPs depend on their practices. 3PLSPs can have a positive or negative effect on sustainability, and it is important for companies to select 3PLSPs that are adapted to sustainability.

In today's world, the demand for sustainable 3PLSPs is becoming an increasingly critical issue for industries aiming to achieve improved customer service, cost reduction, as well as sustainability goals. One such industry is the pharmaceutical sector. The medicines must be delivered under cost-effective and special transportation-protection conditions from the producer to the final consumer (Kahraman et al., 2022:362; Aytekin et al., 2023:5562). The effective management of the acquisition, storage, and dispersal of pharmaceutical supplies is of paramount importance for hospitals and pharmaceutical companies from both economic and organizational standpoints (Uthayakumar and Priyan, 2013:52). This is because it ensures the availability of vital medications and medical supplies, maintains cost-effectiveness, and supports the seamless functioning of healthcare facilities and the pharmaceutical industry.

It is important to identify and assess the criteria for selecting sustainable 3PLSPs for the pharmaceutical sector. Choosing a sustainable 3PLSP can improve the overall performance and competitiveness of the supply chain (Roy et al., 2020:669). Govindan et al. (2019:609) noted that while there are numerous studies on the selection of 3PLSPs, few of them take into account environmental and social sustainability factors alongside financial and technical aspects when evaluating third-party providers. Ali et al. (2021:4) emphasizes that the number of studies on sustainability in logistics and supply chain services is insufficient, especially in the 3PLSP scope. In addition, choosing a 3PLSP is a complex decision for decision-makers in the pharmaceutical industry due to industrial dynamics (Çelik Teker, 2017:114).

In their research, Gardas et al. (2019:960) highlight the lack of comprehensive studies focusing on selecting 3PLSPs in the pharmaceutical industry. They emphasize the need to expand the number of case studies conducted within this particular domain to provide a more thorough understanding of the criteria involved in the selection process. Accordingly, in this study, a novel integrated multi-criteria decision-making (MCDM) model based on fuzzy sets is presented for the selection of sustainable 3PLSPs in the context of the Turkish pharmaceutical manufacturing industry. The proposed model based on fuzzy sets can also help address uncertainties in evaluation processes (Mavi et al, 2017:2415; Prakash et al, 2016:69; Wang and Liao, 2023:15). Therefore, the study utilized the fuzzy Step-wise Weight Assessment Ratio Analysis (SWARA) method to determine the importance of weights of sustainable 3PLSP selection criteria. Subsequently, the fuzzy Multi Attributive Ideal-Real Comparative Analysis (MAIRCA) method was employed to select the appropriate sustainable logistics company. This study contributes to the growing body of research on sustainable 3PLSP selection and offers valuable insights for both decision-makers and logistics providers looking to align their strategies with the evolving demands of the marketplace.

The remainder of the paper is organized as follows: Section 2 comprises the literature review on sustainable 3PLSPs and selection criteria. methodology of the study is explained in Section 3. The methods used are explained in detail in this section. Section 4 includes the implementation of the study. The results are discussed in Section 5. Finally, the conclusion and recommendations are included in Section 6.

2. Literature Review

2.1. Sustainable 3PLSPs

Logistics is a management term that deals with the overall movement of resources and goods. This concept applies to both service and product-based industries. Logistics encompasses the entire supply chain, including procurement, storage, and transportation to the designated destination (Choudhury et al., 2018:427; (Roy et al., 2020:671). Logistics plays a crucial role in the success of a business venture by facilitating the efficient management of the flow of goods and services (Dadashpour and Bozorgi-Amiri, 2020:2233). This includes coordinating procurement, production, distribution, and delivery processes. By optimizing these processes, firms can enhance their competitiveness and responsiveness in customer service, ultimately leading to improved overall performance and success in the market.

The competitiveness of modern business is significantly influenced by the effectiveness of logistics operations. Therefore, many companies choose 3PLSPs to outsource their logistics activities as the best option (Çelik Teker, 2017:109). Outsourcing refers to a situation where one company hires another organization to handle a part of its internal operations, with the goal of enhancing its overall performance (McCarthy and Anagnostou, 2004:61). Logistics is a primary activity that companies often outsource. A logistics provider works with multiple companies simultaneously, gaining economies of scale, which can lead to cost reductions for the firm (Ali et al., 2021:3). In the current business landscape, companies increasingly outsource a wide range of logistics activities, including transportation, warehousing, and distribution, to specialized 3PLSPs. This strategic decision allows businesses to focus on their core competencies while leveraging the expertise and resources of external partners to streamline their supply chain operations and enhance overall efficiency (Nila and Roy, 2023:1; Barker et al., 2021:2).

3PLSPs play a crucial role by assuming the risks associated with services and delivery logistics. This strategic partnership allows organizations to direct their attention to their core business activities, such as product development, marketing, and customer relations, while entrusting their logistical needs to experienced and specialized 3PLSPs (Lieb and Lieb, 2010:525).

In today's global context, there is a growing recognition of the need to align economic operations with environmental preservation and social welfare standards (Nila and Roy, 2023:1). This involves ensuring that economic activities not only drive financial growth but also contribute to the protection of the environment and the well-being of society. Many governments worldwide are enacting laws requiring businesses to become carbon-neutral. As a result, companies will need their logistics service providers to support the circular economy agenda by offering sufficient and efficient sustainable logistics (Mageto, 2022:5). Improving sustainability in logistics entails implementing strategies and practices that aim to optimize economic and social advantages, while concurrently minimizing negative environmental effects (Wang et al., 2017:3).

Manufacturing companies should work with a logistics service provider that complies with sustainable development standards when outsourcing their logistics operations (Roy et al., 2020:670). Another dimension of sustainability is that corporations have social responsibility. Acting responsibly involves improving inter-firm relationships in the supply chain by sharing information and increasing visibility to eliminate human rights violations and corruption. Businesses will select logistics service providers with governance structures to enhance security and visibility (Mageto, 2022:5).

Logistics service providers, as part of the supply chain, need to prioritize sustainability practices to offer more environmentally friendly services (Ali et al., 2021:12). Implementing sustainability measures is prompting 3PLSPs to rethink their current operations. These providers must prioritize the transition to a low-carbon economy, with their value proposition incorporating green supply chain initiatives, CO_2 reduction, and cost savings (Gardas et al., 2019:961). A sustainable 3PLSP is a logistics company that integrates environmentally friendly, socially responsible, and economically viable practices into its operations. The goal is to reduce negative impacts on the environment while enhancing supply chain efficiency. Sustainable logistics service providers manage various components, including transportation, warehousing, packaging, distribution processing, information management, and waste management to connect production and consumption links in supply chains physically and virtually (Tochtrop et al., 2022:4; Su et al., 2022:2). A sustainable 3PLSP incorporates eco-friendly strategies into its core operations, balancing economic efficiency with environmental and social responsibility.

In today's rapidly changing business environment, where there is a growing emphasis on green and sustainable supply chain management, the fulfillment of cost, time, and quality criteria is no longer sufficient as a basis for decision-making (Raut et al., 2018:78). The current trend in sustainability and logistics outsourcing requires the selection of logistics service providers that can assist companies in meeting environmental sustainability objectives (Mageto, 2022:5).

2.2. Sustainable 3PLSP selection criteria

In today's competitive marketplace, selecting a 3PLSP has become a critical decision for many organizations. The right 3PLSP partner not only ensures efficiency but must also align with the company's long-term goals and specific needs. However, the decision-making process is becoming increasingly complex, especially as sustainability becomes a key criterion (Akhtar, 2023:108). The growing focus on sustainable business practices, driven by governments and organizations alike, underscores the importance of integrating environmental and social responsibility into business decisions (Dadashpour and Bozorgi-Amiri, 2020:2234).

Over the past decade, the logistics industry has faced growing pressure to incorporate sustainability into its operations. This shift reflects the broader move toward sustainable business development, which has received heightened attention from both profit and non-profit sectors. As a result, companies are increasingly expected to consider environmental, social, and economic dimensions when selecting logistics partners (Qian et al., 2021:358). The logistics sector plays a significant role in supply chains, and its environmental impact is undeniable (Lin and Ho, 2011). Given this, the selection of appropriate 3PLSPs can greatly influence the overall sustainability of a supply chain. Providers that fail to adopt sustainable practices risk damaging not only the environment but also the reputation and profitability of the companies they serve (Jovčić and Průša, 2021:15). Furthermore, customers now expect their logistics providers to deliver services that are both efficient and sustainable, making the incorporation of sustainability into 3PLSP selection frameworks essential (Qian et al., 2021:358).

Despite its importance, selecting a sustainable 3PLSP is far from straightforward. The process often involves a large pool of potential providers, each with different capabilities and varying levels of commitment to sustainability. This makes decision-making both time-consuming and complex. Additionally, many companies still base their logistics decisions primarily on economic factors, neglecting critical aspects like environmental impact (Mavi et al., 2017:2405). The integration of sustainability into logistics provider selection requires the use of MCDM approaches, which can account for the wide range of factors at play. These include not only traditional economic considerations but also sustainability components, such as environmental performance and social responsibility (Mavi et al., 2017:2403). However, decision-makers often face challenges, including conflicting priorities, lack of clear data, and the inherent uncertainty of human judgment (Mishra et al., 2022:295).

A comprehensive and sustainable selection process involves evaluating logistics providers based on environmental, social, and economic performance. Outsourcing logistics can help organizations achieve their sustainability objectives only if the 3PLSP aligns with these principles (Dadashpour and Bozorgi-Amiri, 2020:2234). By incorporating sustainability attributes alongside traditional service criteria, companies can better ensure long-term supply chain success (Chen et al., 2022:965). Moreover, the selection of a 3PLSP directly influences the environmental performance of the supply chain. For instance, logistics activities such as transportation and warehousing can have a significant environmental footprint. Therefore, choosing providers that prioritize green logistics practices is critical in minimizing this impact (Lin and Ho, 2011). This shift towards sustainability in logistics is further reinforced by customers' growing demand for responsible practices and the increasing recognition of sustainability as a key driver of competitive advantage (Gupta et al., 2022:1618).

The selection of a sustainable 3PLSP has emerged as a vital concern for global organizations aiming to improve their supply chain performance while reducing their environmental impact. This decision requires careful consideration of not only economic factors but also environmental and social attributes. By adopting sustainable practices, logistics providers can enhance their service quality, meet customer expectations, and secure long-term business partnerships. As previous research indicates, focusing solely on economic criteria is no longer sufficient; sustainability must be integrated into all stages of the decision-making process (Mavi et al., 2017:2405). Many articles have been written about choosing the best 3PLSP. However, more research is needed to prioritize expertise, different industries, and knowledge levels in logistics while also considering social, environmental, and economic factors (Mishra et al., 2022:296).

Pharmaceutical supply chain aims to transport and store drugs at the right time, place, and quantity, at an acceptable quality and optimum cost, at all stages from the manufacturers to the final consumer (Kahraman et al., 2022:362). The potential errors that may occur in the pharmaceutical industry are highly critical as they directly impact people's health (Kahraman et al., 2022:362). The pharmaceutical supply chain is crucial for human life due to the sensitive nature of drugs, their distinct tracking, storage, and transportation requirements, and the necessity of timely delivery to the point of need (Türk and Güner, 2021: 177). As a result, it's essential to set the pharmaceutical industry apart from other industries. The current study identified 21 criteria under 4 main dimensions for selecting a sustainable 3PLSP in the pharmaceutical industry through a comprehensive literature review and expert opinions. Table 1 displays the established criteria and descriptions for selecting a sustainable 3PLSP.

Table 1: Selection Criteria for Sustainable 3PLSPs in the Pharmaceutical Industry

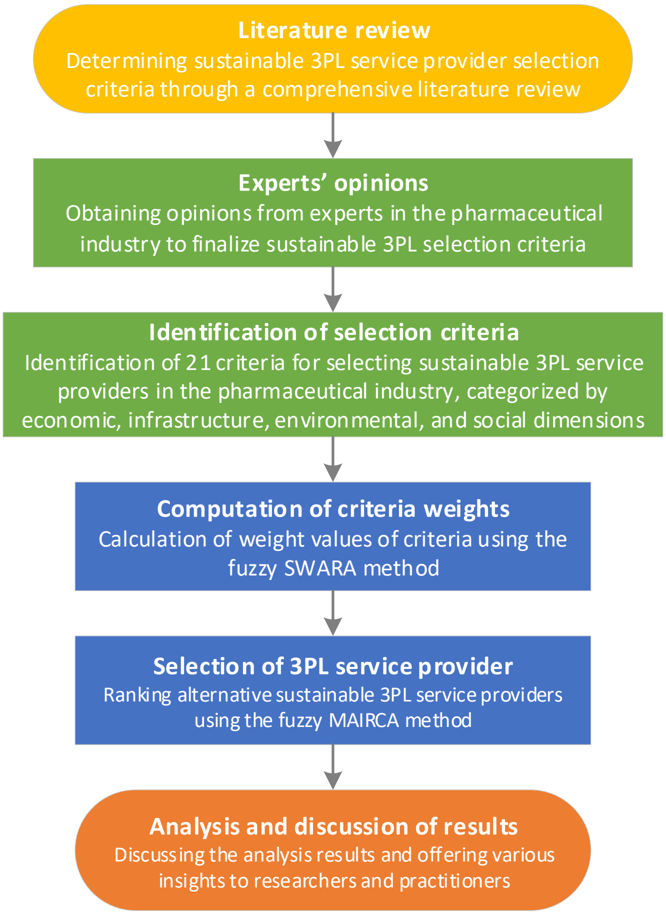
Dimension	Criteria	Goal	Description	References
Economic	Logistics costs (ECO1)	Min	It is important to keep the cost of the provided logistics services low (storage per pallet, transportation cost, handling cost per box, etc.)	Mavi et al. (2017), Wang et al. (2021), Ahtar (2023)
	Financial Situation and Stability (ECO2)	Max	The company's stable financial situation indicates that the logistics service provider continues to offer quality services. The company's financial situation can be measured using liquidity, profitability, and leverage ratios**.**	Gardas et al. (2019), Govindan et al. (2019), Wang et al. (2021), Ahtar (2023)
	Service quality (ECO3)	Max	It covers issues such as accuracy in order fulfillment, frequency of loss and damage, prompt handling of customer complaints, etc. Good service quality helps develop long-term relationships and reduces waste.	Gardas et al. (2019), Wang et al. (2021), Mishra and Pandey (2022)
	Delivery reliability (ECO4)	Max	Delivery reliability refers to timely delivery as per agreed conditions, including executing documentation and transportation processes reliably.	Govindan et al. (2019), Ahtar (2023), Ulutaş and Topal (2022)
	Flexibility and responsiveness (ECO5)	Max	The logistics service provider's flexibility in providing vehicles and transporting products to various regions enhances industry responsiveness and service quality, consequently improving the pharmaceutical industry's business performance.	Raut et al. (2018), Gardas et al. (2019), Mishra and Pandey (2022)
Infrastructure	Physical resources and infrastructure (INF1)	Max	Adequacy of infrastructure and physical resources, including transportation vehicles, material handling equipment, warehouses, and packaging operations, are evaluated under this criterion, taking into account the number of vehicles owned by the company, warehouse capacity, and the workforce employed.	Govindan et al. (2019), Ahtar (2023)
	Industry-specific knowledge and experience (INF2)	Max	Having knowledge and experience in the pharmaceutical industry	Govindan et al. (2019), Ahtar (2023)
	Geographic coverage/Distribution network capacity (INF3)	Max	It is related to the distribution coverage, market coverage, shipment destinations and the distance between the warehouse and the production unit of the logistics service provider.	Govindan et al. (2019), Ahtar (2023)
	Range of services offered (INF4)	Max	The variety and scope of services proposed by the logistics service provider (warehousing, transportation, order fulfillment)	Gardas et al. (2019), Ahtar (2023)
	Establishing partnerships and long-term relationships (INF5)	Max	The logistics service company's readiness for a long-term contract and business partnership.	Qian et al. (2021), Ahtar (2023)
	Reputation and trust (INF6)	Max	It is a criterion regarding the logistics service provider's reputation and reliability for its services.	Govindan et al. (2019), Ahtar (2023), Wang et al. (2021)
	Ability to adapt to technology and IT systems integration (INF7)	Max	It is the ability of the logistics service provider to adapt to technological developments and integrate IT systems. It includes information security, tracking, and monitoring capabilities.	Ulutaş and Topal (2022), Wang et al. (2021), Mishra and Pandey (2022)
Environmental	Environmental protection (ENV1)	Max	It involves the implementation of eco-friendly and low-pollution logistics and transportation operations. Transport vehicles and equipment must not harm the environment.	Ahtar (2023), Govindan et al. (2019), Qian et al. (2021)

	Green warehousing (ENV2)	Max	Energy-efficient warehouse design and operations	Ahtar (2023), Mishra and Pandey (2022)
	Recycling packaging materials (ENV3)	Max	Recycling packaging materials and minimizing waste	Ahtar (2023), Gardas et al. (2019), Wang et al. (2021)
	Environmental management certificate (ENV4)	Max	It is related to the logistics service provider having environmental management system certificates.	Gardas et al. (2019), Zarbakhshnia et al. (2018)
Social	Employee health and safety (SOC1)	Max	Having occupational health and safety policies for employees	Mishra and Pandey (2022), Wang et al. (2021)
	Employee satisfaction (SOC2)	Max	Ensuring employee satisfaction. Satisfied employees enhance the performance of the entire supply chain, as each employee is a vital part of the company.	Gardas et al. (2019)
	Workforce equality (SOC3)	Max	Having transparent policies for workforce equality	Govindan et al. (2019)
	Voice of customer (SOC4)	Max	Receiving customer feedback about the quality of products and services	Zarbakhshnia et al. (2018), Wang et al. (2021)
	Social responsibility (SOC5)	Max	To reduce transportation accidents and minimize their negative impact on human health.	Qian et al. (2021), Mishra and Pandey (2022)

3. Research Methodology

Multiple quantitative and qualitative criteria, as well as multiple decision-makers, are involved in evaluating and selecting 3PLSPs. Therefore, the selection of a logistics services provider is considered a multi-criteria group decision-making problem (Akhtar, 2023:111). The most popular methods for selecting 3PLSPs are MCDM methods. These methods can quickly and effectively address complex evaluation issues that are poorly structured and involve multiple incompatible objectives or criteria (Nila and Roy, 2023:2).

Figure 1. Flowchart of the Research Methodology



This paper presents a novel model for evaluating sustainable 3PLSP selection criteria by employing an integrated fuzzy MCDM approach in the context of the Türkiye pharmaceutical industry. In this presented model, the SWARA and MAIRCA methods, which are current MCDM methods, were used in an integrated manner. Fuzzy sets were also used to address the uncertainty and ambiguity in decision-making processes. Figure 1 displays the framework of the research methodology. The research methodology is discussed in three sub-sections. First, there is an overview of fuzzy set theory. Then, the steps of the fuzzy SWARA and fuzzy MAIRCA methods are explained in detail, respectively.

3.1. Fuzzy set theory

This study employs widely used triangular fuzzy numbers. Therefore, this section provides explanations and operations for an overview of the notations of fuzzy sets. The fuzzy set theory was initially introduced by Zadeh (1965) and has been widely used to deal with judgments derived from real-world issues that involve ambiguity and vagueness (García Mestanza and Bakhat, 2021:10). Fuzzy sets are particularly useful for transforming human judgments expressed in language and for representing the uncertainty and ambiguity present in real-world decision-making processes. As a result, fuzzy sets have been used in solving many problems (Gul and Ak, 2020:1235). There are different types of fuzzy numbers used in place of linguistic variables to calculate in fuzzy sets. Two common sets of numbers are triangular fuzzy numbers and trapezoidal fuzzy numbers. (Mohammadi et al., 2024:5124). Triangular fuzzy numbers consist of three numbers that define the upper, middle, and lower limits of the set (Gul and Ak, 2020:1235).

A triangular fuzzy number, symbolized by $\tilde{A} = (l, m, u)$ where l, m and u which is crisp and real numbers $(x \leq y \leq z)$. The membership function of a triangular fuzzy number is defined by Eq. 1 as follows:

$$\mu_{\tilde{A}} = \begin{cases} 0 & x < l \\ \frac{x-l}{m-l}, & l \\ \frac{u-x}{u-m}, & m \le x \le u \\ 0 & x \ge u \end{cases} \tag{1}$$

Basic arithmetic operations on two triangular fuzzy numbers $\tilde{A}_1 = (l_1, m_1, u_1)$, and $\tilde{A}_2 = (l_2, m_2, u_2)$, *where* $l_1 \le m_1 \le u_1$ and $l_2 \le m_2 \le u_2$ are elucidated as follows (Boral et al., 2020:5):

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{2}$$

$$\tilde{A}_1 \ominus \tilde{A}_2 = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \tag{3}$$

$$\tilde{A}_1 \otimes \tilde{A}_2 = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2) \tag{4}$$

$$\tilde{A}_1 \oslash \tilde{A}_2 = \left[\frac{l_1}{u_2}, \frac{m_1}{m_2}, \frac{u_1}{l_2}\right], if \;\; l_1 \ge 0 \; and \; l_2 > 0 \tag{5}$$

$$k \otimes \tilde{A}_1 = (k \times l_1, k \times m_1, k \times u_1), if \; k > 0 \tag{6}$$

$$k \otimes \tilde{A}_1 = (k \times u_1, k \times m_1, k \times l_1), if \; k < 0 \tag{7}$$

3.2. Fuzzy SWARA

The Step-Wise Weight Assessment Ratio Analysis (SWARA) is a MCDM method used to determine the subjective weights of the criteria, which was first proposed by Kersuliene et al., (2010). SWARA is an effective method that helps decision-makers and managers prioritize criteria by considering sustainability and environmental challenges in a specific supply chain (Zarbakhshnia et al., 2018:308). One of key benefits of the SWARA method is its ability to assess decision-makers' ideas and estimate the relative importance ratio of each criterion (Zolfani and Saparauskas, 2013).

The incorporation of fuzzy set theory into decision-making processes can enhance their comprehensiveness and reasonableness (Agarwal et al, 2020:2; Mavi et al, 2017:2405) through the introduction of a framework that allows for the representation of partial truths and uncertainties, providing a more nuanced and realistic model of complex real-world scenarios. Therefore, the SWARA method based on fuzzy sets is used instead of the classical SWARA method due to the effectiveness of fuzzy sets in dealing with vagueness and uncertainties in this study. Furthermore, Fuzzy SWARA is easier to understand and requires fewer pairwise comparisons compared to other MCDM methods, such as fuzzy AHP and ANP (Mardani et al., 2017:266). These user-friendly features facilitate obtaining more reliable information from decision-makers.

The following steps explain the process of using the fuzzy SWARA method to calculate weights for selection criteria (Agarwal et al, 2020:8; Mavi et al, 2017:2405):

Step 1. Sorting the criteria according to their level of importance. Criteria are ranked based on expert opinions, from most to least important.

Step 2. Determining the relative importance ratio for criteria. In this process, experts use linguistic terms specified in Table 2 to indicate the relative importance level with respect to the $(j-1)$ criterion, which holds a higher importance level than the j criterion itself. This process is then applied to each criterion. After collecting relative importance values from all experts, the aggregate judgment is obtained by calculating the geometric mean of the corresponding values. This ratio denotes the comparative importance of the average $\tilde{s}_j$ value.

Table 2. Scale for the Fuzzy SWARA Evaluations

Linguistic terms	Code	Triangular fuzzy scale
Equally important	EI	(1.000,1.000,1.000)
Moderately less important	MI	(0.667,1.000,1.500)
Less important	LI	(0.400,0.500,0.667)
Very less important	VLI	(0.286,0.333,0.400)
Much less important	MLI	(0.222,0.250,0.286)

Source: Chang, (1996)

Step 3. Calculating $\tilde{k}_j$, the fuzzy coefficient for each criterion. The $\tilde{k}_j$ value of the most important criterion is assigned 1. The coefficient is calculated using Eq. 8

$$\tilde{k}_j = \begin{cases} 1, & j = 1 \\ \tilde{s}_j + 1, & j > 1 \end{cases} \quad (8)$$

Step 4. Calculating the fuzzy weight $\tilde{q}_j$ of each criterion using Eq. 9

$$\tilde{q}_j = \begin{cases} 1, & j = 1 \\ \frac{\tilde{q}_{j-1}}{\tilde{k}_j} + 1, & j > 1 \end{cases} \quad (9)$$

Step 5. Computing the relative fuzzy weights $\tilde{w}_j$ of each criterion using Eq. 10

$$\tilde{w}_j = \frac{\tilde{q}_j}{\sum_{k=1}^{n} \tilde{q}_k} \quad (10)$$

where $\tilde{w}_j$, represents the relative fuzzy weight of criterion j, and n is the number of evaluation criteria.

Step 6. Converting the fuzzy relative importance weights $\tilde{w}_j$ to a crisp value w_j based on the Center of Area (COA) method using Eq. 11

$$\mathrm{w}_j(crisp) = \frac{1}{3}\tilde{w}_j = \frac{1}{3}(\tilde{w}_{jl} + \tilde{w}_{jm} + \tilde{w}_{ju}) \quad (11)$$

3.3. Fuzzy MAIRCA

The Multi-Attribute Ideal-Actual Comparative Analysis (MAIRCA) was first proposed by Pamucar et al. (2014). The method is based on the difference between the ideal weight and the experimental weight. It operates similarly to the TOPSIS approach and selects the most suitable alternative. In this method, the preferred alternative is one that is closest to the ideal weight, which forms the basis for its selection (Mohammadi et al., 2024:5125). This method is more stable than other popular MCDM methods, such as TOPSIS or ELECTRE. It utilizes a simple mathematical algorithm, and the potential to combine it with other methods makes it a feasible option for further exploration and advancement (Boral et al., 2020:4). Like the TOPSIS method, MAIRCA is based on the concept of ideal and anti-ideal solutions. However, its main advantage over previous methods is that each alternative is given equal preference. In other words, decision-makers are unbiased when choosing an alternative (Boral et al., 2020:4). As with other MCDM approaches, the MAIRCA method can be used by integrating fuzzy sets to resolve uncertainty and ambiguity in fuzzy environments (Mohammadi et al., 20245125). Furthermore, the aggregated performance of multiple decision-makers can be calculated using the fuzzy MAIRCA method without relying on crisp values (García Mestanza and Bakhat, 2021:13). Therefore, this study employs the MAIRCA method based on triangular fuzzy numbers to evaluate the alternatives

The implementation steps of the fuzzy MAIRCA method are as follows (Gul and Ak, 2020:1237):

Step 1. Building the fuzzy decision matrix. In the first step, the fuzzy decision matrix is constructed using the linguistic variables defined in Table 3, as in Eq. 12:

$$\tilde{D}^k = \begin{pmatrix} \tilde{A}_{11}^{(k)} & \cdots & \tilde{A}_{1n}^{(k)} \\ \vdots & \ddots & \vdots \\ \tilde{A}_{m1}^{(k)} & \cdots & \tilde{A}_{mn}^{(k)} \end{pmatrix} \tag{12}$$

Here, the *m-th* alternative is evaluated linguistically with respect to the *n-th* criterion by the *k-th* decision maker, denoted as $\tilde{A}_{11}^{(k)}$.

Table 3. Scale for the Fuzzy MAIRCA Evaluations

Linguistic terms	Code	Triangular fuzzy scale
Very poor	VP	(0, 0.5, 0.15)
Poor	P	(0.1, 0.2, 0.3)
Medium poor	MP	(0.2, 0.35, 0.5)
Fair	F	(0.3, 0.5, 0.7)
Medium good	MG	(0.5, 0.65, 0.8)
Good	G	(0.7, 0.8, 0.9)
Very good	VG	(0.85, 0.95, 1)

Source: Mohammadi et al., (2024)

Step 2. Constructing the fuzzy aggregated decision matrix. The fuzzy aggregated decision matrix is created using the arithmetic operator as represented in Eq. 13:

$$\tilde{D} = \begin{pmatrix} \tilde{A}_{11} & \cdots & \tilde{A}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{A}_{m1} & \cdots & \tilde{A}_{mn} \end{pmatrix} where\ \tilde{A}_{11} = \frac{\tilde{A}_{11}^{(1)} + \tilde{A}_{11}^{(2)} + \cdots + \tilde{A}_{11}^{(k)}}{k} \tag{13}$$

Step 3. Determining the preferences of alternatives. In this step, the preferences are determined according to the selection of alternatives P_{A_i}. The decision maker is not biased against the selection of an alternative. As there is an equal probability between alternatives, the preferences for each of the alternatives are computed by Eq. 14 as follows:

$$P_{A_i} = \frac{1}{m}; \sum_{i=1}^{m} P_{A_i} = 1 \tag{14}$$

In Eq. 4, m represents the total number of alternatives, where all possible choices P_{A_i} are equal.

Step 4. Calculating the matrix of fuzzy theoretical ponder. The fuzzy theoretical ponder matrix $\tilde{T}_{P_A}$ is calculated by multiplying the preferences according to alternatives, and fuzzy criteria weights. The $\tilde{T}_{P_A}$ is shown by Eq. 15 as follows:

$$\tilde{T}_{P_A} = \begin{pmatrix} \tilde{t}_{P_{11}} & \cdots & \tilde{t}_{P_{1n}} \\ \vdots & \ddots & \vdots \\ \tilde{t}_{P_{m1}} & \cdots & \tilde{t}_{P_{mn}} \end{pmatrix} \tag{15}$$

Step 5. Calculating normalized initial fuzzy aggregated decision matrix. In this step, the initial fuzzy aggregate decision matrix $\tilde{N}$ is obtained by normalizing the fuzzy aggregate decision matrix determined in Step 2. In this study, the normalization technique proposed by Borel et al. (2020:8) is utilized. This technique simplifies complex calculations and improves the accuracy of the results. Additionally, it relieves the decision-maker from concerns about the nature of the criteria, whether they are benefit or cost criteria. The normalization process is computed as follows by Eq.16

$$n_{ij}^{l} = \frac{a_{ij}^{l}}{\sqrt{\sum_{i=1}^{m}\left[\left(a_{ij}^{l}\right)^2+\left(a_{ij}^{m}\right)^2+\left(a_{ij}^{u}\right)^2\right]}} \quad n_{ij}^{m} = \frac{a_{ij}^{m}}{\sqrt{\sum_{i=1}^{m}\left[\left(a_{ij}^{l}\right)^2+\left(a_{ij}^{m}\right)^2+\left(a_{ij}^{u}\right)^2\right]}} \quad n_{ij}^{u} = \frac{a_{ij}^{u}}{\sqrt{\sum_{i=1}^{m}\left[\left(a_{ij}^{l}\right)^2+\left(a_{ij}^{m}\right)^2+\left(a_{ij}^{u}\right)^2\right]}} \tag{16}$$

Step 6. Calculating the matrix of fuzzy actual ponder. The fuzzy actual ponder matrix $\tilde{T}_{R_A}$ is determined by multiplying the normalized decision matrix $\tilde{N}$ and the fuzzy theoretical ponder matrix $\tilde{T}_{P_A}$. The $\tilde{T}_{R_A}$ is shown by Eq. 17 as follows:

$$\tilde{T}_{R_A} = \begin{pmatrix} \tilde{t}_{R_{11}} & \cdots & \tilde{t}_{R_{1n}} \\ \vdots & \ddots & \vdots \\ \tilde{t}_{R_{m1}} & \cdots & \tilde{t}_{R_{mn}} \end{pmatrix} \tag{17}$$

Step 7. Calculating the Euclidean distance between the fuzzy theoretical ponder matrix and the fuzzy actual ponder matrix. To compute the total gap matrix $\tilde{G}$, it is advised to employ the fuzzy Euclidean distance for each alternative under each criterion, based on the comparison between the theoretical and actual ponder matrices (García Mestanzaand Bakhat, 2021:15). The total gap matrix $\tilde{G}$ is calculated by using Eq. 18 as follows:

$$g_{ij} = \sqrt{\frac{1}{3}\left[\left({t_{P_{ij}}}^{l} - {t_{R_{ij}}}^{l}\right)^2 + \left({t_{P_{ij}}}^{m} - {t_{R_{ij}}}^{m}\right)^2 + \left({t_{P_{ij}}}^{u} - {t_{R_{ij}}}^{u}\right)^2\right]} \tag{18}$$

Step 8. Summing the gap values. In the last step, the sum of the gap values for each alternative with respect to each criterion determines the final value of the criteria functions by using Eq. 19. Then, the final values are ranked in ascending order. The alternative with the lowest gap value is the best alternative.

$$Q_i = \sum_{j=1}^{n} g_{ij}, i = 1,2, \dots, m \tag{19}$$

4. Case Study in the Pharmaceutical Manufacturing Industry

The pharmaceutical industry is recognized as a high-value sector that plays a crucial role in health care and economic development. Globally, the pharmaceutical sector is categorized as the "third sector" alongside agriculture and manufacturing. In Türkiye, this industry has deep historical roots, being one of the earliest established sectors that contribute significantly to the country's economy. Over the years, it has evolved to meet the needs of the population, adapting to advancements in technology and shifting health care demands (Ak, 2024:2).

In 2023, the global pharmaceutical market reached an impressive valuation of $1.6 trillion, reflecting the industry's rapid growth and continuous innovation. Within this global landscape, Türkiye ranked 19th, underscoring its rising importance as a critical player in the sector (IEIS, 2024). Türkiye's pharmaceutical market was valued at 109.8 billion TL in 2022, driven by strong demand and a diverse range of available medications. That year, total unit sales reached 2.55 billion (IEIS, 2024). By 2023, the sector witnessed significant expansion, with the market value surging to 211 billion TL (IEIS, 2024). This growth was fueled by advancements in research and development, increased healthcare investments, and an expanding presence in both domestic and international markets (Ak, 2024:2). As of the end of 2023, the Turkish pharmaceutical industry encompassed 870 organizations, including 109 pharmaceutical and radiopharmaceutical production facilities that meet international standards, four specialized medical diet food facilities, and 13 raw material production facilities. Additionally, the sector exports to 185 countries, offering approximately 15,000 health products, supported by a highly skilled workforce of over 47,500 professionals (IEIS, 2024)

In this research, an international pharmaceutical company located in Türkiye was chosen as a case study for selecting a sustainable 3PLSP. This pharmaceutical company was founded in 1954. Today, it operates five production facilities: three in Türkiye and two abroad, in Kazakhstan and Uzbekistan. With a workforce of approximately 4,000 professionals, the company exports high-quality pharmaceutical products to 50 countries, adhering to international standards. The company is committed to enhancing the quality of life by producing effective, high-quality products. It has established promotional and sales operations in 20 countries, including Germany, Albania, Azerbaijan, and Russia.

In its efforts to align with global sustainability trends, the company places great emphasis on integrating sustainable practices into its logistics operations. Recognizing the environmental impact of its extensive supply chain, it aims to work with 3PLSPs that prioritize sustainable solutions. For this reason, the company attaches significant importance to selecting the right logistics partners, ensuring they meet its stringent sustainability, reliability, and efficiency criteria. In this context, a working team was formed under the coordination of the logistics manager responsible for the logistics operations of the company. This team consists of experts who have undertaken various logistics activities in the company. The titles and experience information of the experts are shown in Table 4.

Table 4. Information about Experts

Experts	Title	Experience in the pharmaceutical industry	Total experience
Expert 1	Logistics Manager	11 years	24 years
Expert 2	Logistics Specialist	4 years	6 years
Expert 3	Logistics Executive	9 years	19 years
Expert 4	Logistics Executive	17 years	17 years

In the first stage of the research, a thorough literature review was conducted to identify the selection criteria for sustainable logistics service providers. The databases used for this review were SCOPUS and Dergipark. SCOPUS is a comprehensive global academic database (Baas et al., 2020). The literature search in SCOPUS was conducted using the keywords "third-party logistics" OR "3PL service provider*" AND "sustainability" AND "select*" AND "criteria." After completing the literature review, an expert team was formed under the coordination of the logistics manager responsible for the company's logistics operations. This team included four experts with extensive experience in the pharmaceutical sector and logistics operations, as detailed in Table 4 of the manuscript. The experts' diverse experience ensured that the criteria were rigorously evaluated and tailored specifically to the needs of the pharmaceutical sector. The team validated and refined the criteria through iterative discussions to align with sustainability, reliability, and efficiency goals. The final version of these criteria is presented in Table 1. A total of 21 criteria were established across economic, infrastructure, environmental, and social dimensions for the selection of sustainable 3PLSPs in the pharmaceutical production sector. Subsequently, the fuzzy SWARA method was applied through expert evaluations to determine the importance weights of the identified criteria.

4.1. Calculating the weights of the criteria using Fuzzy SWARA

In the fuzzy SWARA method, the weights of four dimensions and 21 criteria, along with the criteria rankings generated based on these weights, were obtained through a questionnaire form applied by four logistics experts. This section presents the results of the fuzzy SWARA calculation in detail.

In the first step of the Fuzzy SWARA application process, each expert was asked to rank the dimensions and the criteria under these dimensions according to their level of importance. Then, experts were asked to determine the relative importance of each criterion in relation to the previous criterion using the linguistic expressions in Table 2. These linguistic evaluations were transformed into triangular fuzzy numbers based on the scale shown in Table 2. Thus, the $\tilde{s}_j$ value for each expert was determined. Following this, the fuzzy coefficient $\tilde{k}_j$ values for each dimension and criterion were calculated using Eq. 8.

The fuzzy weight $\tilde{q}_j$ and the relative fuzzy weight $\tilde{w}_j$ for selecting sustainable 3PLSP criteria were then calculated using Eq. 9 and Eq. 10, respectively. To obtain the final fuzzy criterion weights, the weighted values of the criteria were multiplied by the weight values of their associated dimensions. Table 5 and Table 6 present the fuzzy SWARA results from Expert 1 as an example.

Table 5. Fuzzy SWARA Results from Expert 1 For the Dimensions of Sustainable 3PLSP Selection

Dimension	Linguistic terms	Comparative importance of value $\tilde{s}_j$	Fuzzy coefficient $\tilde{k}_j$	Fuzzy weight $\tilde{q}_j$	Relative fuzzy weights $\tilde{w}_j$
Economic			(1; 1; 1)	(1; 1; 1)	(0.438; 0.462; 0.495)
Social	LI	(0.400; 0.500; 0.667)	(1.400; 1.500; 1.667)	(0.600; 0.667; 0.714)	(0.262; 0.308; 0.354)
Infrastructure	EI	(1.000; 1.000; 1.000)	(2.000; 2.000; 2.000)	(0.300; 0.333; 0.357)	(0.131; 0.154; 0.177)
Environmental	MI	(0.667; 1.000; 1.500)	(1.667; 2.000; 2.500)	(0.120; 0.167; 0.214)	(0.052; 0.077; 0.106)

Table 6. Fuzzy SWARA Results from Expert 1 for the Criteria of Sustainable 3PLSP Selection

Criteria	L Terms	Comparative importance of value $\tilde{s}_j$	Fuzzy coefficient $\tilde{k}_j$	Fuzzy weight $\tilde{q}_j$	Relative fuzzy weights $\tilde{w}_j$	Weighted $\tilde{w}_j$
ECO2			(1; 1; 1)	(1; 1; 1)	(0.498; 0.511; 0.524)	(0.218; 0.236; 0.259)
ECO4	EI	(1.000; 1.000; 1.000)	(2.000; 2.000; 2.000)	(0.500; 0.500; 0.500)	(0.249; 0.255; 0.262)	(0.109; 0.118; 0.130)
ECO1	EI	(1.000; 1.000; 1.000)	(2.000; 2.000; 2.000)	(0.250; 0.250; 0.250)	(0.125; 0.128; 0.131)	(0.054; 0.059; 0.065)
ECO3	MI	(0.667; 1.000; 1.500)	(1.667; 2.000; 2.500)	(0.100; 0.125; 0.150)	(0.050; 0.064; 0.079)	(0.022; 0.029; 0.039)
ECO5	LI	(0.400; 0.500; 0.667)	(1.400; 1.500; 1.667)	(0.060; 0.083; 0.107)	(0.030; 0.043; 0.056)	(0.013; 0.020; 0.028)
INF6			(1; 1; 1)	(1; 1; 1)	(0.376; 0.398; 0.425	(0.049; 0.061; 0.075)
INF2	VLI	(0.286; 0.333; 0.400)	(1.286; 1.333; 1.400)	(0.714; 0.750; 0.778)	(0.269; 0.299; 0.330)	(0.035; 0.046; 0.058)
INF1	EI	(1.000; 1.000; 1.000)	(2.000; 2.000; 2.000)	(0.357; 0.375; 0.389)	(0.134; 0.149; 0.165)	(0.018; 0.023; 0.029)
INF5	MI	(0.667; 1.000; 1.500)	(1.667; 2.000; 2.500)	(0.143; 0.188; 0.233)	(0.054; 0.075; 0.099)	(0.007; 0.011; 0.018)
INF7	EI	(1.000; 1.000; 1.000)	(2.000; 2.000; 2.000)	(0.071; 0.094; 0.117)	(0.027; 0.037; 0.050)	(0.004; 0.006; 0.009)
INF3	LI	(0.400; 0.500; 0.667)	(1.400; 1.500; 1.667)	(0.043; 0.063; 0.083)	(0.016; 0.025; 0.035)	(0.002; 0.004; 0.006)
INF4	LI	(0.400; 0.500; 0.667)	(1.400; 1.500; 1.667)	(0.026; 0.042; 0.059)	(0.010; 0.017; 0.025)	(0.001; 0.003; 0.004)
ENV1			(1; 1; 1)	(1; 1; 1)	(0.491; 0.500; 0.513)	(0.026; 0.038; 0.054)
ENV4	EI	(1.000; 1.000; 1.000)	(2.000; 2.000; 2.000)	(0.500; 0.500; 0.500)	(0.246; 0.250; 0.256)	(0.013; 0.019; 0.027)
ENV2	LI	(0.400; 0.500; 0.667)	(1.400; 1.500; 1.667)	(0.300; 0.333; 0.357)	(0.147; 0.167; 0.183)	(0.008; 0.013; 0.019)
ENV3	EI	(1.000; 1.000; 1.000)	(2.000; 2.000; 2.000)	(0.150; 0.167; 0.179)	(0.074; 0.083; 0.092)	(0.004; 0.006; 0.010)
SOC1			(1; 1; 1)	(1; 1; 1)	(0.397; 0.416; 0.438)	(0.104; 0.128; 0.155
SOC5	VLI	(0.286; 0.333; 0.400)	(1.286; 1.333; 1.400)	(0.714; 0.750; 0.778)	(0.284; 0.312; 0.340)	(0.075; 0.096; 0.120)
SOC4	EI	(1.000; 1.000; 1.000)	(2.000; 2.000; 2.000)	(0.357; 0.375; 0.389)	(0.142; 0.156; 0.170)	(0.037; 0.048; 0.060)
SOC2	MI	(0.667; 1.000; 1.500)	(1.667; 2.000; 2.500)	(0.143; 0.188; 0.233)	(0.057; 0.078; 0.102)	(0.015; 0.024; 0.036)
SOC3	EI	(1.000; 1.000; 1.000)	(2.000; 2.000; 2.000)	(0.071; 0.094; 0.117)	(0.028; 0.039; 0.051)	(0.007; 0.012; 0.018)

Finally, the final fuzzy criterion weights were calculated using the arithmetic average of the fuzzy criterion weights provided by each expert evaluation, as seen Table 7 and Table 8. The fuzzy weight values were defuzzified using Eq. 11.

Table 7. Final Fuzzy Weight Values for The Dimension

Dimension	Expert 1	Expert 2	Expert 3	Expert 4	Final Weights
Economic	(0.438; 0.462; 0.495)	(0.467; 0.533; 0.61)	(0.468; 0.48; 0.496)	(0.438; 0.462; 0.495)	(0.453; 0.484; 0.524)
Infrastructure	(0.131; 0.154; 0.177)	(0.075; 0.133; 0.219)	(0.14; 0.16; 0.177)	(0.131; 0.154; 0.177)	(0.119; 0.15; 0.188)
Environmental	(0.052; 0.077; 0.106)	(0.187; 0.267; 0.366)	(0.234; 0.24; 0.248)	(0.052; 0.077; 0.106)	(0.132; 0.165; 0.207)
Social	(0.262; 0.308; 0.354)	(0.037; 0.067; 0.11)	(0.1; 0.12; 0.138)	(0.262; 0.308; 0.354)	(0.166; 0.201; 0.239)

Table 8. Final Fuzzy Weight Values for the Criteria

Criteria Code	Expert 1	Expert 2	Expert 3	Expert 4	Average Weights	Final Weights
ECO1	(0.125; 0.128; 0.131)	(0.461; 0.516; 0.581)	(0.233; 0.25; 0.268)	(0.091; 0.128; 0.174)	(0.227; 0.255; 0.288)	(0.103; 0.124; 0.151)
ECO2	(0.498; 0.511; 0.524)	(0.018; 0.032; 0.052)	(0.093; 0.125; 0.161)	(0.453; 0.511; 0.579)	(0.266; 0.295; 0.329)	(0.12; 0.143; 0.172)
ECO3	(0.05; 0.064; 0.079)	(0.092; 0.129; 0.174)	(0.467; 0.5; 0.535)	(0.036; 0.064; 0.104)	(0.161; 0.189; 0.223)	(0.073; 0.092; 0.117)
ECO4	(0.249; 0.255; 0.262)	(0.184; 0.258; 0.349)	(0.056; 0.083; 0.115)	(0.181; 0.255; 0.347)	(0.168; 0.213; 0.268)	(0.076; 0.103; 0.141)
ECO5	(0.03; 0.043; 0.056)	(0.037; 0.065; 0.105)	(0.022; 0.042; 0.069)	(0.022; 0.043; 0.074)	(0.028; 0.048; 0.076)	(0.013; 0.023; 0.04)
INF1	(0.134; 0.149; 0.165)	(0.046; 0.074; 0.112)	(0.407; 0.435; 0.47)	(0.085; 0.121; 0.167)	(0.168; 0.195; 0.229)	(0.02; 0.029; 0.043)
INF2	(0.269; 0.299; 0.33)	(0.385; 0.444; 0.521)	(0.203; 0.218; 0.235)	(0.169; 0.242; 0.334)	(0.256; 0.301; 0.355)	(0.031; 0.045; 0.067)
INF3	(0.016; 0.025; 0.035)	(0.154; 0.222; 0.313)	(0.073; 0.097; 0.12)	(0.008; 0.02; 0.043)	(0.063; 0.091; 0.128)	(0.008; 0.014; 0.024)
INF4	(0.01; 0.017; 0.025)	(0.033; 0.056; 0.087)	(0.013; 0.024; 0.04)	(0.003; 0.01; 0.026)	(0.015; 0.027; 0.044)	(0.002; 0.004; 0.008)
INF5	(0.054; 0.075; 0.099)	(0.02; 0.037; 0.062)	(0.122; 0.145; 0.168)	(0.051; 0.081; 0.119)	(0.062; 0.084; 0.112)	(0.007; 0.013; 0.021)
INF6	(0.376; 0.398; 0.425)	(0.092; 0.148; 0.223)	(0.018; 0.032; 0.051)	(0.423; 0.485; 0.557)	(0.227; 0.266; 0.314)	(0.027; 0.04; 0.059)
INF7	(0.027; 0.037; 0.05)	(0.008; 0.019; 0.037)	(0.029; 0.048; 0.072)	(0.02; 0.04; 0.072)	(0.021; 0.036; 0.058)	(0.003; 0.005; 0.011)
ENV1	(0.491; 0.5; 0.513)	(0.37; 0.393; 0.428)	(0.248; 0.261; 0.275)	(0.48; 0.485; 0.491)	(0.397; 0.41; 0.427)	(0.052; 0.068; 0.088)
ENV2	(0.147; 0.167; 0.183)	(0.159; 0.197; 0.238)	(0.496; 0.522; 0.549)	(0.171; 0.182; 0.191)	(0.243; 0.267; 0.29)	(0.032; 0.044; 0.06)
ENV3	(0.074; 0.083; 0.092)	(0.222; 0.262; 0.306)	(0.06; 0.087; 0.118)	(0.086; 0.091; 0.095)	(0.11; 0.131; 0.153)	(0.015; 0.022; 0.032)
ENV4	(0.246; 0.25; 0.256)	(0.113; 0.148; 0.185)	(0.099; 0.13; 0.165)	(0.24; 0.242; 0.246)	(0.175; 0.193; 0.213)	(0.023; 0.032; 0.044)
SOC1	(0.397; 0.416; 0.438)	(0.364; 0.387; 0.422)	(0.157; 0.229; 0.321)	(0.353; 0.385; 0.422)	(0.318; 0.354; 0.401)	(0.053; 0.071; 0.096)
SOC2	(0.057; 0.078; 0.102)	(0.156; 0.194; 0.234)	(0.027; 0.057; 0.107)	(0.066; 0.103; 0.148)	(0.076; 0.108; 0.148)	(0.013; 0.022; 0.035)
SOC3	(0.028; 0.039; 0.051)	(0.078; 0.097; 0.117)	(0.045; 0.086; 0.15)	(0.033; 0.051; 0.074)	(0.046; 0.068; 0.098)	(0.008; 0.014; 0.023)
SOC4	(0.142; 0.156; 0.17)	(0.218; 0.258; 0.301)	(0.393; 0.457; 0.535)	(0.11; 0.154; 0.207)	(0.216; 0.256; 0.303)	(0.036; 0.051; 0.072)
SOC5	(0.284; 0.312; 0.34)	(0.047; 0.065; 0.084)	(0.112; 0.171; 0.25)	(0.274; 0.308; 0.346)	(0.179; 0.214; 0.255)	(0.03; 0.043; 0.061)

Table 9 shows the crisp weights and importance rankings of the criteria were determined. Table 7 shows that the most important dimension in selecting sustainable logistics service providers in the pharmaceutical industry is the Economy dimension, which has a weight value of 0.4944. This indicates that economic factors play a significant role in decision-making processes, highlighting the importance of cost-effectiveness and financial viability in logistics operations.

The environmental dimension ranked second, with a weight value of 0.1975. This rank suggests that environmental factors play a crucial role in the decision-making process, highlighting the need to prioritize sustainability and ecological considerations. As concerns about environmental sustainability continue to grow, these issues have become crucial criteria in the selection process for logistics service providers. However, despite the rising importance of sustainability, economic factors such as cost, service quality, flexibility, and responsiveness remain vital considerations (Ali et al, 2021:3).

Social dimension and infrastructure have similar weight values, ranked third and fourth, respectively. The social dimension refers to social responsibility, workforce equity, employee health, safety, and the voice of the customer, while infrastructure encompasses the physical systems and facilities that support logistic activities. Their close ranking underscores the need to consider both aspects when evaluating effectiveness.

Table 9. Rankings and Importance Weights for Criteria in Selecting Sustainable 3PLSPs

Dimension	Dimension weight	Dimension rank	Criteria	Criteria Code	Criteria local weight	Local rank	Criteria global weight	Global rank
Economic	0.4944	1	Logistics costs	**ECO1**	0.257	2	0.127	**2**
			Financial Situation and Stability	**ECO2**	0.296	1	0.147	**1**
			Service quality	**ECO3**	0.191	4	0.095	**4**
			Delivery reliability	**ECO4**	0.216	3	0.107	**3**
			Flexibility and responsiveness	**ECO5**	0.051	5	0.025	15
Infrastructure	0.1519	4	Physical resources and infrastructure	**INF1**	0.197	3	0.030	13
			Industry-specific knowledge and experience	**INF2**	0.304	1	0.046	**8**
			Geographic coverage/Distribution network capacity	**INF3**	0.094	4	0.014	17
			Range of services offered	**INF4**	0.029	7	0.004	21
			Establishing partnerships and long-term relationships	**INF5**	0.086	5	0.013	18
			Reputation and trust	**INF6**	0.269	2	0.041	10
			Ability to adapt to technology and IT systems integration	**INF7**	0.038	6	0.006	20
Environmental	0.1975	2	Environmental protection	**ENV1**	0.411	1	0.081	**5**
			Green warehousing	**ENV2**	0.267	2	0.053	**7**
			Recycling packaging materials and minimizing waste	**ENV3**	0.131	4	0.026	14
			Environmental management certificate	**ENV4**	0.193	3	0.038	11
Social	0.1662	3	Employee health and safety	**SOC1**	0.357	1	0.059	**6**
			Employee satisfaction	**SOC2**	0.111	4	0.018	16
			Workforce equality	**SOC3**	0.071	5	0.012	19
			Voice of customer	**SOC4**	0.258	2	0.043	9
			Social responsibility	**SOC5**	0.216	3	0.036	12

4.2. Evaluating Alternative Sustainable 3PLSPs Using the Fuzzy MAIRCA

In this section, alternatives for sustainable 3PLSPs are ranked using the fuzzy MAIRCA method, with criterion weights obtained through the fuzzy SWARA method as input. Following a brainstorming session and a review of past research, experts identified four sustainable 3PLSPs for evaluation in the pharmaceutical sector. These providers were selected based on their proven commitment to environmentally friendly practices, innovative supply chain solutions, and their ability to meet the specific needs of the pharmaceutical industry. To maintain confidentiality, the four logistics companies involved in the study were referred to as S3PL-1, S3PL-2, SPL-3, and SPL-4.

At the beginning of the fuzzy MAIRCA process, a second questionnaire was provided to the same four logistics experts in the pharmaceutical manufacturing company. Through this questionnaire, experts were asked to evaluate four sustainable logistics service providers according to the 21 criteria defined previously, using the linguistic terms in Table 3. The linguistic evaluations of the experts are shown in Table 10.

Table 10. Linguistic Evaluations of Sustainable 3PLSPs Based on Selection Criteria

Criteria	**Sustainable 3PLSPs**			
	S3PL-1	**S3PL-2**	**S3PL-3**	**S3PL-4**
ECO1	(P,P,MP,MP)	(P,P,P,F)	(F,F,G,F)	(G,G,VG,MG)
ECO2	(G,MP,G,MG)	(MG,MP,MG,MG)	(MP,F,MG,F)	(F,P,MG,MP)
ECO3	(G,G,MG,G)	(G,MG,F,MG)	(MG,MG,MG,F)	(MG,MP,MP,P)
ECO4	(MG,MG,MG,MG)	(MG,F,MG,F)	(F,F,F,F)	(MP,MP,MP,P)
ECO5	(G,G,G,MG)	(MG,MG,MG,MG)	(MP,MP,F,MP)	(MP,MP,P,P)
INF1	(MG,MG,MG,MG)	(MG,MG,MG,MP)	(F,F,F,MP)	(P,P,MP,P)
INF2	(MG,MG,MG,MG)	(MG,MG,MG,MP)	(F,F,F,MP)	(P,P,MP,P)
INF3	(MG,G,MG,MG)	(MG,F,VG,G)	(MG,F,F,G)	(MG,P,MG,F)
INF4	(G,VG,VG,G)	(G,G,MG,MG)	(F,MG,MG,MG)	(F,F,F,F)
INF5	(F,G,G,MG)	(F,F,VG,MG)	(MG,MG,F,MG)	(MP,MP,MP,VP)
INF6	(G,MG,MG,G)	(G,MG,MG,MG)	(G,F,G,MG)	(F,F,F,MP)
INF7	(VG,VG,MG,G)	(G,VG,G,G)	(MG,MG,G,MG)	(MP,MP,MP,F)
ENV1	(MG,G,G,MG)	(VG,G,VG,MG)	(F,F,F,MG)	(MP,MP,P,MG)
ENV2	(G,VG,MG,MG)	(G,G,F,MG)	(MG,MG,MG,MP)	(F,VP,MP,MP)
ENV3	(F,MG,MG,F)	(F,MG,G,MG)	(MG,F,F,G)	(MP,P,P,MP)
ENV4	(G,MG,G,G)	(G,MG,VG,MG)	(G,MG,G,MG)	(F,F,MP,F)
SOC1	(G,VG,MG,MG)	(G,G,VG,MP)	(MG,F,MG,MP)	(P,P,VP,MP)
SOC2	(MG,G,MG,MG)	(G,G,MG,MG)	(F,MG,F,MP)	(MP,MP,MP,P)
SOC3	(MG,VG,G,G)	(MG,G,G,MG)	(F,MG,F,F)	(F,F,F,MP)
SOC4	(G,VG,MG,G)	(G,VG,MG,G)	(MG,MG,F,G)	(MP,MG,MP,F)
SOC5	(G,VG,MG,G)	(G,G,G,MG)	(F,MG,F,MG)	(MP,MP,MP,MP)

After the linguistic expressions of the expert evaluations were converted into corresponding triangular fuzzy numbers, the fuzzy aggregated decision matrix was constructed using the arithmetic operator in Eq. 13. The resulting fuzzy aggregated decision matrix is presented in Table 11. Following this, the P_{A_i} value, indicating that each alternative can be chosen with equal probability, was calculated as 0.25 using Eq. 14.

Table 11. The Fuzzy Aggregated Decision Matrix

Criteria	Sustainable 3PLSPs			
	S3PL-1	**S3PL-2**	**S3PL-3**	**S3PL-4**
ECO1	(0.15,0.275,0.4)	(0.15,0.275,0.4)	(0.4,0.575,0.75)	(0.688,0.8,0.675)
ECO2	(0.525,0.65,0.775)	(0.425,0.575,0.725)	(0.325,0.5,0.675)	(0.275,0.425,0.575)
ECO3	(0.65,0.7625,0.875)	(0.5,0.65,0.8)	(0.45,0.6125,0.55)	(0.25,0.388,0.4)
ECO4	(0.5,0.65,0.8)	(0.4,0.575,0.75)	(0.3,0.5,0.7)	(0.175,0.313,0.45)
ECO5	(0.65,0.763,0.875)	(0.5,0.65,0.8)	(0.225,0.388,0.55)	(0.15,0.275,0.4)
INF1	(0.5,0.65,0.8)	(0.425,0.575,0.725)	(0.275,0.463,0.65)	(0.125,0.238,0.35)
INF2	(0.5,0.65,0.8)	(0.375,0.538,0.7)	(0.45,0.613,0.775)	(0.3,0.463,0.625)
INF3	(0.55,0.688,0.825)	(0.588,0.725,0.625)	(0.45,0.613,0.775)	(0.35,0.5,0.65)
INF4	(0.775,0.875,0.5)	(0.6,0.725,0.85)	(0.45,0.613,0.775)	(0.3,0.5,0.7)
INF5	(0.55,0.688,0.825)	(0.488,0.65,0.575)	(0.45,0.613,0.775)	(0.15,0.275,0.413)
INF6	(0.6,0.725,0.85)	(0.55,0.688,0.825)	(0.55,0.688,0.825)	(0.275,0.463,0.65)
INF7	(0.725,0.838,0.475)	(0.738,0.838,0.7)	(0.55,0.688,0.825)	(0.225,0.388,0.55)
ENV1	(0.6,0.725,0.85)	(0.725,0.838,0.475)	(0.35,0.538,0.725)	(0.25,0.388,0.525)
ENV2	(0.638,0.763,0.65)	(0.55,0.688,0.825)	(0.425,0.575,0.725)	(0.175,0.313,0.463)
ENV3	(0.4,0.575,0.75)	(0.5,0.65,0.8)	(0.45,0.613,0.775)	(0.15,0.275,0.4)
ENV4	(0.65,0.763,0.875)	(0.638,0.763,0.65)	(0.6,0.725,0.85)	(0.275,0.463,0.65)
SOC1	(0.638,0.763,0.65)	(0.6125,0.725,0.6)	(0.375,0.538,0.7)	(0.1,0.2,0.313)
SOC2	(0.55,0.688,0.825)	(0.6,0.725,0.85)	(0.325,0.5,0.675)	(0.175,0.313,0.45)
SOC3	(0.688,0.8,0.675)	(0.6,0.725,0.85)	(0.35,0.538,0.725)	(0.275,0.463,0.65)
SOC4	(0.688,0.8,0.675)	(0.688,0.8,0.675)	(0.5,0.65,0.8)	(0.3,0.463,0.625)
SOC5	(0.688,0.8,0.675)	(0.65,0.763,0.875)	(0.4,0.575,0.75)	(0.2,0.35,0.5)

Subsequently, the fuzzy theoretical ponder matrix displayed in Table 12 was obtained by multiplying this value with the fuzzy criterion weights obtained through fuzzy SWARA.

Table 12. The Fuzzy Theoretical Ponder Matrix

Criteria	Sustainable 3PL service providers			
	S3PL-1	**S3PL-2**	**S3PL-3**	**S3PL-4**
ECO1	(0.026,0.031,0.038)	(0.026,0.031,0.038)	(0.026,0.031,0.038)	(0.026,0.031,0.038)
ECO2	(0.03,0.036,0.043)	(0.03,0.036,0.043)	(0.03,0.036,0.043)	(0.03,0.036,0.043)
ECO3	(0.018,0.023,0.029)	(0.018,0.023,0.029)	(0.018,0.023,0.029)	(0.018,0.023,0.029)
ECO4	(0.019,0.026,0.035)	(0.019,0.026,0.035)	(0.019,0.026,0.035)	(0.019,0.026,0.035)
ECO5	(0.003,0.006,0.01)	(0.003,0.006,0.01)	(0.003,0.006,0.01)	(0.003,0.006,0.01)
INF1	(0.005,0.007,0.011)	(0.005,0.007,0.011)	(0.005,0.007,0.011)	(0.005,0.007,0.011)
INF2	(0.008,0.011,0.017)	(0.008,0.011,0.017)	(0.008,0.011,0.017)	(0.008,0.011,0.017)
INF3	(0.002,0.003,0.006)	(0.002,0.003,0.006)	(0.002,0.003,0.006)	(0.002,0.003,0.006)
INF4	(0,0.001,0.002)	(0,0.001,0.002)	(0,0.001,0.002)	(0,0.001,0.002)
INF5	(0.002,0.003,0.005)	(0.002,0.003,0.005)	(0.002,0.003,0.005)	(0.002,0.003,0.005)
INF6	(0.007,0.01,0.015)	(0.007,0.01,0.015)	(0.007,0.01,0.015)	(0.007,0.01,0.015)
INF7	(0.001,0.001,0.003)	(0.001,0.001,0.003)	(0.001,0.001,0.003)	(0.001,0.001,0.003)
ENV1	(0.013,0.017,0.022)	(0.013,0.017,0.022)	(0.013,0.017,0.022)	(0.013,0.017,0.022)
ENV2	(0.008,0.011,0.015)	(0.008,0.011,0.015)	(0.008,0.011,0.015)	(0.008,0.011,0.015)
ENV3	(0.004,0.005,0.008)	(0.004,0.005,0.008)	(0.004,0.005,0.008)	(0.004,0.005,0.008)
ENV4	(0.006,0.008,0.011)	(0.006,0.008,0.011)	(0.006,0.008,0.011)	(0.006,0.008,0.011)
SOC1	(0.013,0.018,0.024)	(0.013,0.018,0.024)	(0.013,0.018,0.024)	(0.013,0.018,0.024)
SOC2	(0.003,0.005,0.009)	(0.003,0.005,0.009)	(0.003,0.005,0.009)	(0.003,0.005,0.009)
SOC3	(0.002,0.003,0.006)	(0.002,0.003,0.006)	(0.002,0.003,0.006)	(0.002,0.003,0.006)
SOC4	(0.009,0.013,0.018)	(0.009,0.013,0.018)	(0.009,0.013,0.018)	(0.009,0.013,0.018)
SOC5	(0.007,0.011,0.015)	(0.007,0.011,0.015)	(0.007,0.011,0.015)	(0.007,0.011,0.015)

Next, the fuzzy normalized decision matrix was derived using Eq. 16, as shown in Table 13.

Table 13. The Fuzzy Normalized Decision Matrix

Criteria	Sustainable 3PLSPs			
	S3PL-1	S3PL-2	S3PL-3	S3PL-4
ECO1	(0.085,0.155,0.226)	(0.085,0.155,0.226)	(0.226,0.325,0.423)	(0.388,0.452,0.381)
ECO2	(0.272,0.336,0.401)	(0.22,0.298,0.375)	(0.168,0.259,0.349)	(0.142,0.22,0.298)
ECO3	(0.312,0.366,0.42)	(0.24,0.312,0.384)	(0.216,0.294,0.264)	(0.12,0.186,0.192)
ECO4	(0.266,0.346,0.426)	(0.213,0.306,0.399)	(0.16,0.266,0.373)	(0.093,0.166,0.24)
ECO5	(0.332,0.389,0.446)	(0.255,0.332,0.408)	(0.115,0.198,0.281)	(0.077,0.14,0.204)
INF1	(0.277,0.36,0.443)	(0.236,0.319,0.402)	(0.222,0.302,0.383)	(0.148,0.228,0.308)
INF2	(0.247,0.321,0.395)	(0.185,0.265,0.346)	(0.222,0.302,0.383)	(0.148,0.228,0.308)
INF3	(0.254,0.317,0.381)	(0.271,0.335,0.289)	(0.208,0.283,0.358)	(0.162,0.231,0.3)
INF4	(0.339,0.383,0.219)	(0.262,0.317,0.372)	(0.197,0.268,0.339)	(0.131,0.219,0.306)
INF5	(0.279,0.348,0.418)	(0.247,0.329,0.291)	(0.228,0.31,0.393)	(0.076,0.139,0.209)
INF6	(0.262,0.317,0.372)	(0.24,0.301,0.361)	(0.24,0.301,0.361)	(0.12,0.202,0.284)
INF7	(0.32,0.369,0.209)	(0.325,0.369,0.309)	(0.242,0.303,0.364)	(0.099,0.171,0.242)
ENV1	(0.283,0.342,0.401)	(0.342,0.395,0.224)	(0.165,0.254,0.342)	(0.118,0.183,0.248)
ENV2	(0.309,0.37,0.315)	(0.267,0.334,0.4)	(0.206,0.279,0.352)	(0.085,0.152,0.224)
ENV3	(0.205,0.295,0.385)	(0.256,0.333,0.41)	(0.231,0.314,0.397)	(0.077,0.141,0.205)
ENV4	(0.277,0.325,0.373)	(0.272,0.325,0.277)	(0.256,0.309,0.362)	(0.117,0.197,0.277)
SOC1	(0.33,0.394,0.336)	(0.317,0.375,0.31)	(0.194,0.278,0.362)	(0.052,0.103,0.162)
SOC2	(0.268,0.335,0.402)	(0.293,0.354,0.414)	(0.158,0.244,0.329)	(0.085,0.152,0.219)
SOC3	(0.313,0.364,0.307)	(0.273,0.33,0.387)	(0.159,0.245,0.33)	(0.125,0.211,0.296)
SOC4	(0.303,0.353,0.298)	(0.303,0.353,0.298)	(0.22,0.287,0.353)	(0.132,0.204,0.276)
SOC5	(0.314,0.365,0.308)	(0.297,0.348,0.399)	(0.183,0.262,0.342)	(0.091,0.16,0.228)

The fuzzy actual ponder matrix in Table 14 was obtained by multiplying the normalized decision matrix with the fuzzy theoretical ponder matrix.

Table 14. The Fuzzy Actual Ponder Matrix

Criteria	Sustainable 3PLSPs			
	S3PL-1	S3PL-2	S3PL-3	S3PL-4
ECO1	(0.002,0.005,0.009)	(0.002,0.005,0.009)	(0.006,0.01,0.016)	(0.01,0.014,0.014)
ECO2	(0.008,0.012,0.017)	(0.007,0.011,0.016)	(0.005,0.009,0.015)	(0.004,0.008,0.013)
ECO3	(0.006,0.008,0.012)	(0.004,0.007,0.011)	(0.004,0.007,0.008)	(0.002,0.004,0.006)
ECO4	(0.005,0.009,0.015)	(0.004,0.008,0.014)	(0.003,0.007,0.013)	(0.002,0.004,0.008)
ECO5	(0.001,0.002,0.004)	(0.001,0.002,0.004)	(0,0.001,0.003)	(0,0.001,0.002)
INF1	(0.001,0.003,0.005)	(0.001,0.002,0.004)	(0.002,0.003,0.006)	(0.001,0.003,0.005)
INF2	(0.002,0.004,0.007)	(0.001,0.003,0.006)	(0.002,0.003,0.006)	(0.001,0.003,0.005)
INF3	(0,0.001,0.002)	(0.001,0.001,0.002)	(0,0.001,0.002)	(0,0.001,0.002)
INF4	(0,0,0)	(0,0,0.001)	(0,0,0.001)	(0,0,0.001)
INF5	(0.001,0.001,0.002)	(0,0.001,0.002)	(0,0.001,0.002)	(0,0,0.001)
INF6	(0.002,0.003,0.005)	(0.002,0.003,0.005)	(0.002,0.003,0.005)	(0.001,0.002,0.004)
INF7	(0,0.001,0.001)	(0,0.001,0.001)	(0,0,0.001)	(0,0,0.001)
ENV1	(0.004,0.006,0.009)	(0.004,0.007,0.005)	(0.002,0.004,0.008)	(0.002,0.003,0.005)
ENV2	(0.002,0.004,0.005)	(0.002,0.004,0.006)	(0.002,0.003,0.005)	(0.001,0.002,0.003)
ENV3	(0.001,0.002,0.003)	(0.001,0.002,0.003)	(0.001,0.002,0.003)	(0,0.001,0.002)
ENV4	(0.002,0.003,0.004)	(0.002,0.003,0.003)	(0.001,0.002,0.004)	(0.001,0.002,0.003)
SOC1	(0.004,0.007,0.008)	(0.004,0.007,0.007)	(0.003,0.005,0.009)	(0.001,0.002,0.004)
SOC2	(0.001,0.002,0.004)	(0.001,0.002,0.004)	(0.001,0.001,0.003)	(0,0.001,0.002)
SOC3	(0.001,0.001,0.002)	(0.001,0.001,0.002)	(0,0.001,0.002)	(0,0.001,0.002)
SOC4	(0.003,0.005,0.005)	(0.003,0.005,0.005)	(0.002,0.004,0.006)	(0.001,0.003,0.005)
SOC5	(0.002,0.004,0.005)	(0.002,0.004,0.006)	(0.001,0.003,0.005)	(0.001,0.002,0.003)

After calculating the total gap matrix using Eq. 18, the total gap values for each alternative were determined as shown in Table 15. Finally, all alternatives were ranked in ascending order based on these gap values. As shown in Table 15, the optimal choice is S3PL-1. The alternatives are ranked in descending order as S3PL-1 > S3PL-2 > S3PL-3 > S3PL-4.

Table 15. Total Gap Matrix and The Sum of The Gap Values for Each Alternative

Criteria	Sustainable 3PLSPs			
	S3PL-1	**S3PL-2**	**S3PL-3**	**S3PL-4**
ECO1	0.026	0.026	0.021	0.019
ECO2	0.024	0.025	0.027	0.028
ECO3	0.015	0.016	0.018	0.020
ECO4	0.017	0.018	0.019	0.022
ECO5	0.004	0.004	0.005	0.006
INF1	0.005	0.005	0.006	0.007
INF2	0.008	0.009	0.008	0.009
INF3	0.003	0.003	0.003	0.003
INF4	0.001	0.001	0.001	0.001
INF5	0.002	0.003	0.002	0.003
INF6	0.007	0.007	0.007	0.008
INF7	0.001	0.001	0.001	0.001
ENV1	0.011	0.013	0.013	0.014
ENV2	0.008	0.008	0.008	0.010
ENV3	0.004	0.004	0.004	0.005
ENV4	0.006	0.006	0.006	0.007
SOC1	0.012	0.013	0.013	0.016
SOC2	0.004	0.004	0.004	0.005
SOC3	0.003	0.003	0.003	0.003
SOC4	0.009	0.009	0.009	0.011
SOC5	0.008	0.007	0.008	0.009
$\boldsymbol{Q_i}$	0.1784	0.1844	0.1862	0.2068
Rank	**1**	**2**	**3**	**4**

5. Results Discussion

In order to organize their supply chain sustainability, organizations must fully comprehend the role of 3PLSPs. Consequently, selecting the right 3PLSP is crucial to establishing a sustainable supply chain. Due to the subjective characteristics of service provider performance and inherent ambiguity, selecting the most suitable 3PLSP is complicated (Roy et al., 2020:669). Selecting a proficient and compatible 3PLSP involves considering numerous criteria and methods. The complexity of this decision and the multitude of criteria involved make MCDM approaches an appealing method for solving this problem (Raut et al., 2018:78).

The pharmaceutical supply chain involves a series of stages that contribute to the production, distribution, and accessibility of pharmaceutical products. After production, it depends on the success of the distribution channels to ensure the quality of the drug until it reaches the point of consumption. Therefore, selecting the right 3PLSP company is a critical step in the success of the pharmaceutical supply chain. The pharmaceutical industry has an immense need to determine and evaluate selection criteria for a sustainable 3PLSP. Selecting the ideal sustainable 3PLSP improves the overall supply chain's effectiveness and competitiveness (Qian et al., 2021:359). The current study addresses this critical need by presenting a robust decision-making framework tailored to the pharmaceutical industry's unique requirements.

This study presents a new MCDM framework based on fuzzy sets for selecting a sustainable third-party logistics company in the pharmaceutical industry. The proposed approach has been implemented in a pharmaceutical manufacturing facility in Türkiye. The fuzzy SWARA method was employed to determine the priority weights of main dimensions and their sub-criteria, while the fuzzy MAIRCA method was utilized to rank sustainable 3PLSPs.

In this study, 21 criteria for selecting sustainable logistics service providers were identified within four main dimensions in the context of the pharmaceutical industry based on literature review and expert opinions. Subsequently, the weights and importance rankings of these criteria were calculated using the fuzzy SWARA method, as presented in Table 9. According to the results of the fuzzy SWARA analysis, the sustainable 3PLSP selection dimensions are ranked as economic, environmental, social, and infrastructure, respectively, according to their importance weights. This ranking reflects the industry's emphasis on cost-effectiveness and operational continuity, which are critical for maintaining competitiveness in a regulated and resource-intensive sector.

Upon examining the global weight values of the criteria, "Financial situation and stability (ECO2)" was ranked first, with a weight value of 0.147. Financial stability is crucial for 3PLSPs, as it allows them to maintain operational continuity and invest in sustainable practices (Baah et al., 2021:47). A financially stable 3PLSP can ensure consistent service delivery, which is vital for businesses that depend on timely and efficient logistics operations. Financial stability not only supports operational reliability but also enables 3PLSPs to implement innovative and sustainable logistics practices. In addition, financial stability enables logistics providers to meet environmental regulations and social standards. According to Pagell and Wu (2009), financially secure firms are more inclined to adopt policies that promote fair labor practices, minimize waste, and encourage community involvement. The prioritization of financial stability also reflects its pivotal role in facilitating long-term partnerships between pharmaceutical companies and logistics providers, fostering mutual growth and resilience.

"Logistics costs (ECO1)" were ranked as the second-highest criterion, with a global weight of 0.127. Similarly, in the study by Khan et al. (2022:1814), cost reduction was the second most important outsourcing factor. Wang et al., (2021:14) in their research using the fuzzy AHP method, determined logistics costs as the third most impactful factor in selecting providers within the Vietnam 3PLSP market. Logistics costs are a primary consideration for companies when selecting a 3PLSP. Reducing these costs is often cited as the most important reason for outsourcing logistics functions (Ali et al, 2023:1; Khan et al., 2022:1514). Gupta et al. (2018b:130) note that organizations typically outsource logistics activities to focus on their core competencies, lower costs, and enhance overall deliverables. Although cost reduction continues to be a key reason for outsourcing, businesses should also take sustainability into account when making their selection. By adopting a comprehensive approach that balances both cost and sustainability, companies can improve their supply chain efficiency while also addressing the increasing expectations of stakeholders for environmentally responsible practices. This highlights the dual challenge for decision-makers: achieving cost efficiency without compromising sustainability.

"Delivery reliability (ECO4)" was ranked third, achieving a global weight value of 0.216. Delivery reliability is an essential criterion when selecting a sustainable logistics service provider. Gupta et al. (2018a:295) highlight that service quality and reliability are crucial factors that influence the selection of logistics service providers, ranking third in importance with a strong correlation to sustainability. Wang et al. (2021:14) stated reliability and delivery time as the most influential factor in logistics outsourcing in their study. Similarly, Rosano et al. (2022:4) highlighted that on-time delivery is one of the parameters frequently adopted to evaluate 3PLSP performance. Delivery reliability is crucial for selecting a sustainable 3PLSP. It impacts customer satisfaction, supply chain efficiency, and sustainability goals. By focusing on reliable delivery, businesses can enhance customer loyalty and reduce waste, aligning their logistics with sustainability objectives. In the pharmaceutical sector, where precision and timeliness are critical, delivery reliability directly impacts patient safety and regulatory compliance.

"Service quality (ECO3)" was designated as the fourth highest criterion, with a global weight of 0.095. Service quality is a crucial factor that significantly influences the overall performance of a business (Gupta, 2018a:296). In their study analyzing the selection criteria of third-party logistics in the pharmaceutical supply chain, Gardas et al. (2019:970) emphasized that service quality is one of the most crucial factors with a significant driving power. Many authors in the literature established the relationship between service quality and factors such as cost reduction, increased profitability, customer satisfaction, and enhanced customer loyalty (Gupta, 2018a:296). Furthermore, Ozbekler and Ozturkoglu (2020:1504) suggested that focusing on sustainability-oriented service quality can give logistics service providers a competitive edge. 3PLSP companies can improve their reputation and attract environmentally conscious clients by investing in sustainable practices while maintaining high service quality. This connection between service quality and sustainability benefits the providers and supports the overarching goals of sustainable supply chain management.

"Environmental protection (ENV1)" criterion, with a global weight value of 0.081, was ranked fifth. The logistics industry significantly contributes to air pollution, greenhouse gas emissions, and resource depletion, highlighting the need for a transition to eco-friendly practices (Zhang et al., 2020:2). Moreover, stakeholders cooperating with logistics companies are increasingly focused on the damage caused by activities of 3PLSPs such as transport, storage, and transloading (Lun et al., 2015:50). Hence, in the pharmaceutical industry, selecting logistics providers with robust environmental policies can help minimize emissions, manage waste efficiently, and reduce the industry's overall carbon footprint. The prioritization of environmental protection reflects an increasing recognition of the need for sustainable practices to combat climate change and adhere to international environmental standards.

In the social dimension, “Employee health and safety (SOC1)” emerged as the sixth most important criterion, with a global weight value of 0.059. According to Gardas et al. (2019:973), health and safety measures are among the essential criteria in selecting a 3PLSP. In a different study, health and safety practices were identified as the most crucial evaluation criterion in the selection of 3PLSPs (Roy et al., 2020, p.688). Furthermore, Mavi et al. (2017:2401) also highlighted the importance of health and safety, asserting that these aspects play a vital role in determining the suitability of a 3PLSP. This focus is essential for ensuring a safe working environment and promoting overall employee welfare. Also, implementing effective health and safety practices reduces the risks of accidents and damage in logistics operations. This helps protect workers while preventing financial losses and reputational harm to the logistics provider and the pharmaceutical company.

“Green warehousing (ENV2)” was ranked seventh with a global weight value of 0.053. Green warehousing practices are important for reducing the environmental impact of logistics operations. Warehousing activities significantly contribute to greenhouse gas emissions, representing a part of the overall carbon footprint in supply chains (Aldakhil et al., 2018:861). Logistics providers can significantly reduce emissions from warehousing operations by implementing energy-efficient technologies, optimizing space utilization, and using sustainable materials (Agyabeng-Mensah et al., 2020:549). A particularly impactful example of green warehousing is the implementation of renewable energy sources. By installing solar panels on warehouse rooftops, companies can generate their own electricity, significantly decreasing their reliance on fossil fuels. This switch not only contributes to lower greenhouse gas emissions but also results in reduced long-term operational costs, as highlighted by Boztepe and Çetin (2020:97). The global weight values of other sustainable criteria evaluated in the pharmaceutical sector, along with the importance rankings created based on these values, are presented in Table 9.

The fuzzy weights for the criteria for selecting sustainable 3PLSPs were established using the Fuzzy SWARA method. These weights were then utilized as inputs for the fuzzy MIRCA method, which was employed to determine the final rankings of four alternative sustainable 3PLSPs based on evaluation from the same experts. As a result of the fuzzy MAIRCA analysis, the alternative service providers were ranked in decreasing order as S3PL-1> S3PL-2> SPL-3>SPL-4. The S3PL-1 alternative received the highest ranking because of its remarkable flexibility in incorporating sustainable innovations. This adaptability allows it to respond effectively to changing market demands and environmental challenges. Additionally, it offers cost-effective solutions that not only meet economic objectives but also align with broader environmental goals. By balancing financial efficiency with sustainability, the S3PL-1 alternative stands out as a suitable choice for organizations in the pharmaceutical industry seeking to enhance their environmental performance while considering cost constraints.

6. Conclusion

Outsourcing logistics has become a crucial strategic choice for companies aiming to improve their operations in today's competitive environment. By collaborating with specialized logistics providers, businesses can notably reduce distribution and logistics costs, enabling them to allocate resources more effectively. On the other hand, the implementation of sustainable practices in the field of logistics outsourcing is of paramount importance, as it has a significant impact on the environmental, social, and economic outcomes of the supply chain. Given that activities such as transportation and warehousing contribute considerably to carbon emissions and resource utilization, the adoption of sustainable methodologies is imperative. Consequently, collaborating with 3PLSPs that prioritize sustainability will greatly assist businesses in achieving economic, social, and environmental sustainability objectives.

Selecting the sustainable 3PLSP in the pharmaceutical industry is crucial because of the sector's stringent regulatory requirements and the high standards for quality and reliability. Pharmaceuticals must be transported, stored, and distributed precisely to maintain product integrity and ensure patient safety. Additionally, as sustainability becomes more important across all industries, pharmaceutical companies must increasingly turn to 3PLSPs that align with their environmental goals. Therefore, decision-makers in the pharmaceutical industry should critically evaluate the resources, capabilities, financial status, environmental practices, and social initiatives of outsourcing partners when selecting a 3PLSP partner. However, there is a lack of adequate studies on the criteria and selection methods for determining sustainable 3PLSPs that fulfill the specific needs of this sector.

To address this gap, the current study presents a comprehensive framework for the selection of sustainable 3PLSPs using fuzzy SWARA and MAIRCA methods in an integrated manner to meet the unique demands of the pharmaceutical industry. By applying a novel MCDM approach grounded in fuzzy sets, this research contributes theoretically and practically to the complex problem of sustainable 3PLSP selection in the pharmaceutical industry in Türkiye. Initially, 21 criteria were determined under the economic, infrastructure, environmental, and social dimensions through a literature review and expert opinions regarding the selection criteria of sustainable 3PLSPs in the pharmaceutical sector. Next, the weight of each criterion was calculated using the fuzzy SWARA method. Then, using the criterion weight values as input, four alternatives sustainable 3PLSPs were ranked through the fuzzy MAIRCA method.

The results reveal that the economic dimension, represented by factors like "Financial situation and stability" and "Logistics cost," is prioritized, as it not only ensures operational continuity but also supports the adoption of sustainable practices. Additionally, "Delivery reliability" and "Service quality" emerged as crucial for maintaining supply chain effectiveness and customer satisfaction, underscoring the need for a balanced approach that addresses both service excellence and environmental responsibility. The "Environmental protection" criterion under the environmental dimension and the "Employee health and safety" under the social dimension have emerged as important factors that underline a holistic sustainability focus in the selection of logistics service providers.

The ranking computed by the fuzzy MAIRCA method reveals that the most appropriate sustainable 3PLSP, S3PL-1, not only demonstrates financial and operational competence but also has the ability to incorporate sustainable innovations. This adaptability positions S3PL-1 as a valuable partner for pharmaceutical companies aiming to achieve both economic and environmental goals in the face of evolving market and regulatory demands.

The primary contribution of this study is the development of an innovative decision-making framework designed to help organizations in the pharmaceutical industry select the most suitable logistics service provider with an emphasis on sustainability. This framework takes into account various factors related to environmental impact, social responsibility, infrastructure requirements, and economic viability, enabling companies to make informed choices that align with their sustainability goals. In the current global landscape, the significance of sustainability is rapidly increasing, with its scope expanding continually. The proposed framework tailored for the pharmaceutical sector is anticipated to serve as a valuable guide for other organizations within the industry.

In future research, studies focusing on the differences between countries can be conducted. Additionally, incorporating various MCDM methods with more advanced fuzzy sets, such as spherical fuzzy sets, picture fuzzy sets, and intuitionistic fuzzy sets, will help enhance the existing literature in this field.

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