

**SUSTAINABLE SUPPLIER SELECTION IN FUZZY ENVIRONMENT: A
CASE STUDY IN TURKEY**

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LIST OF SYMBOLS

SF-TOPSIS	: Spherical Fuzzy the Order of Preference by Similarity to the Ideal Solution
MCDM	: Multi Criteria Decision Making
TOPSIS	: Technique for Order of Preference by Similarity to Ideal Solution
UN	: United Nations
LNG	: Liquidified Natural Gas
US	: United States
USD	: United States Dollar
JKM	: Japan Korea Marker
DES	: Delivered Ex-Ship
TTF	: Title Transfer Facility
HH	: Henry Hub
MMBtu	: One Million British Thermal Unit
NG	: Natural Gas
IFS2	: Intuitionistic Fuzzy Sets of the Second Type
T2FS	: Type-2 Fuzzy Set
IFS	: Intuitionistic Fuzzy Sets
NS	: Neutrosophic Sets
HFS	: Hesitant Fuzzy Sets
AHP	: Analytic Hierarchy Process
BWM	: The Best-Worst Method
TODIM	: TOMada de Deciso Interativa e Multicritrio
AQM	: Alternative Queuing Method
FAHP	: Fuzzy Analytic Hierarchy Process
CoCoSo	: The Combined Compromise Solution
FTOPSIS	: Fuzzy the Order of Preference by Similarity to the Ideal Solution
LEF	: Luminance Enhancement Film
MCGP	: Multi-Choice Goal Programming
VIKOR	: Vlekriterijumsko KOMpromisno Rangiranje
SF-VIKOR	: Spherical Fuzzy Vlekriterijumsko KOMpromisno Rangiranje
IVSWAM	: The Interval-Valued Spherical Weighted Arithmetic Mean
DEMATEL	: Decision-Making Trial and Evaluation Laboratory
WASPAS	: Weighted Aggregated Sum Product Assessment
ANP	: Analytical Network Process
GRA	: Grey Regional Analysis
CSFRS	: Covering-Based Spherical Fuzzy Rough Set
DANP	: DEMATEL based ANP

CODAS	: COmbine Distance-based Assessment
AD	: Axiomatic Design
ANN	: Artificial Neural Network
MADA	: Multi-Attribute Decision Analysis
DEA	: Data Envelopment Analysis
DMU	: Decision-Making Units
SWAM	: Spherical Weighted Arithmetic Mean
SWGM	: Spherical Weighted Geometric Mean
DM	: Decision Maker / Decision Matrix
PIS	: Positive Ideal Solution
NIS	: Negative Ideal Solution
NDM	: Normalised Decision Matrix
WNDM	: Weighted Normalised Decision Matrix
SF-PIS	: Spherical Fuzzy Positive Ideal Solution
SF-NIS	: Spherical Fuzzy Negative Ideal Solution
PhD	: Philosophie Doctor

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ABSTRACT

In today's business world, the supply chain performances of companies determine their competitiveness. Companies seek sustainable suppliers to have a seamless supply chain management system. Especially, manufacturing companies that have to deal with enormous amounts of energy requirements need to concrete their position in terms of selecting the most sustainable supplier. Energy supply can be a tricky issue because it is highly related to world politics. Compared to the past, manufacturers must deal with both the customer's demands and the availability of energy suppliers.

To determine whether the supplier is sustainable or not, three main criteria of sustainability are taken into account which are called fiscal, environmental and social sustainability. A supplier which can give the best overall performance according to these criteria should be selected. However, the selection process of the suppliers is consisting of many linguistic terms and their evaluation contains abundant errors due to the human element. Most of the time, linguistic terms might cloud human judgment and make it challenging to select the most appropriate choice.

In this study, a sustainable supplier selection was carried out using the recently proposed Spherical Fuzzy the Order of Preference by Similarity to the Ideal Solution (SF-TOPSIS) Method based on the weights established by a chosen expert group of ten people who are supply chain professionals working for the same company and were tasked to determine the interdependencies of three main and fifteen sub-criteria. The objective of this study is to demonstrate that SF-TOPSIS is effective at reducing human error and can produce the best results by addressing a challenging sustainable supplier selection problem.

Decision makers' judgments are calculated by using SF-TOPSIS and Supplier 2 was determined as the best option in terms of being the most sustainable one for the needs of the manufacturing company. Supplier 3 is determined as the second-best supplier in terms of sustainability with a really close margin. Finally, Supplier 1 was the least sustainable supplier. Results are discussed with the decision-maker group and their previous selection in real life was in favor of Supplier 3. By seeing the result of this study, the new deal will be negotiated with the Supplier 2 to purchase Liquefied Natural Gas (LNG) for 3 factories in Southern Turkey.



ÖZET

Günümüz iş dünyasında şirketlerin tedarik zinciri performansları rekabet güçlerini belirlemektedir. Şirketler kesintisiz bir tedarik zinciri yönetim sistemine sahip olmak için sürdürülebilir tedarikçiler aramaktadırlar. Özellikle de muazzam miktarlarda enerji ihtiyacıyla uğraşmak zorunda olan üretim şirketlerinin en sürdürülebilir tedarikçiyi seçme konusunda konumlarını somutlaştırmaları gerekmektedir. Enerji tedariki, dünya siyasetiyle yakından ilişkili bir husus olduğundan, yönetilmesi zor bir konuya dönüşmektedir. Geçmişle kıyaslandığında, üreticiler için hem müşterilerin talepleriyle hem de enerji tedarikçilerinin mevcudiyetiyle ilgilenmek zorunluluğu doğmaktadır.

Tedarikçinin sürdürülebilir olup olmadığını belirlemek için mali, çevresel ve sosyal sürdürülebilirlik olarak adlandırılan üç ana sürdürülebilirlik kriteri dikkate alınır. Bu kriterlere göre en iyi genel performansı gösterebilecek tedarikçi seçilmelidir. Ancak tedarikçilerin seçim süreci birçok dilsel terimden oluşmakta ve bunların değerlendirilmesi insan unsurundan kaynaklanan çok sayıda hata içermektedir. Çoğu zaman, dilsel terimler insan muhakemesini bulanıklaştırabilir ve en uygun seçimin yapılmasını zorlaştırabilir.

Bu çalışmada, aynı şirket için çalışan tedarik zinciri profesyonellerinden oluşan on kişilik seçilmiş bir uzman grubunun üç ana ve on beş alt kriterin karşılıklı bağımlılıklarını belirlemek üzere görevlendirilmesiyle belirlenen ağırlıklara dayalı olarak yeni önerilen Küresel Bulanık İdeal Çözüme Benzerlik Bakımından Sıralama Performansı Tekniği (SF-TOPSIS) kullanılarak sürdürülebilir bir tedarikçi seçimi yapılmıştır. Bu çalışma, SF-TOPSIS'in insan hatasını en aza indirmede başarılı olduğunu ve karmaşık bir sürdürülebilir tedarikçi seçim problemini çözerek en iyi sonucu verebileceğini göstermeyi amaçlamaktadır.

Karar vericilerin yargıları SF-TOPSIS kullanılarak hesaplanmış ve Tedarikçi 2, üretim şirketinin ihtiyaçları için en sürdürülebilir seçenek olması açısından en iyi seçenek olarak belirlenmiştir. Tedarikçi 3, çok yakın bir farkla sürdürülebilirlik açısından en iyi ikinci tedarikçi olarak belirlenmiştir. Son olarak, Tedarikçi 1 en az sürdürülebilir tedarikçi olmuştur. Sonuçlar karar verici grup ile tartışılmış ve gerçek hayattaki önceki seçimlerinin Tedarikçi 3 lehine olduğu görülmüştür. Bu çalışmanın sonucunu görerek, Türkiye'nin güneyindeki 3 fabrika için Sıvılaştırılmış Doğal Gaz (LNG) satın almak üzere Tedarikçi 2 ile yeni bir anlaşma müzakere edilecektir.

1. INTRODUCTION

Nowadays, the increasing competition between brands and globalization phenomenon has revealed the concept of sustainability and has increased its importance day by day. Being sustainable became so important that companies that require suppliers started to seek and replace their regulars with sustainable suppliers. In the business world we live in now, sustainable or with another words green supplier selection has a critical effect on the competitiveness of the entire supply chain network (De Boer, et al., 2001).

In this study, three main sub-branches of sustainability are taken into account. First one is fiscal sustainability, which considers the economical frame of operations. Fiscal sustainability mainly focuses on financials of a company and evaluates whether monetary components used effectively. Second one is environmental sustainability. This aspect mainly focuses on companies' impact on the environment and evaluates the actions taken by the company to reduce its' negative impacts on surroundings. Finally, social sustainability is taken into account. It focuses on the impacts of companies actions on human element. All of these sub-branches are defined in detail in the following section.

This study aims to address the energy crisis caused by recent actions taken by the Russian Federation. It will primarily concentrate on introducing a newly proposed fuzzy logic mechanism known as Spherical Fuzzy, which is utilized in conjunction with a Multi-Criteria Decision Making method called TOPSIS. By incorporating these methodologies, the research seeks to provide a comprehensive understanding of the energy crisis and offer potential solutions. To gain a comprehensive understanding of this study, it is essential to provide definitions for certain terms and establish the timeline of the energy market outlook. Furthermore, the research will delve into a literature review encompassing decision-making and sustainability approaches. Subsequently, the study will introduce a model tailored explicitly for a large-scale manufacturing company that relies on LNG as its power source. This model incorporates three main criteria and fifteen sub-criteria to ascertain the most sustainable supplier among three available LNG suppliers.

The uniqueness of this study stems from the significance and practicality of the example at hand. As mentioned earlier, finding a sustainable energy supplier which can meet the requirements of both the customer and the manufacturer is a difficult challenge. The case study involved in this research revolves around the current issue faced by a large-scale manufacturing company in Turkey. The outcomes of this study will be utilized to determine the subsequent supplier selection.

Another notable aspect is the careful selection of specific sub-criteria tailored for this problem. By doing a broad literature review, it was discovered that some of the criteria did not fully capture the exact circumstances of the case study. To enhance the accuracy of the sub-criteria, their selection was conducted in collaboration with decision-makers who are professionals working within the same manufacturing company.

Additionally, the employment of SF-TOPSIS contributes to the originality of this study. A distinct SF-TOPSIS methodology is introduced, along with its application to the issue of sustainable supplier selection. By utilizing a linguistic assessment scale based on spherical fuzzy sets, SF-TOPSIS enables decision-makers to express their uncertainties independently throughout the decision-making process.

The remainder of this study is organized as follows, in chapter 2, necessary information about the term sustainability and its' sub-branches are given in detail along with the definition of supply chain management and process of selecting supplier. In the same chapter, definition of energy crisis, which is the main reason behind this study, is given with the necessary definition of LNG. On the last section of chapter 2, TOPSIS method, Fuzzy sets and Spherical Fuzzy are given under the decision making sub-heading. On chapter 3, conducted literature review about sustainable supplier selection problems, fuzzy TOPSIS and SF-TOPSIS studies are given with respect to each other. On chapter 4, selected technique, which is SF-TOPSIS, is defined step by step. Later on the chapter 5, evaluation of the model is given by detailing selected main and sub-criteria. On chapter 6, application of the problem and results are shared. Discussion and concluding remarks are given in Chapter 7 and 8 with respect to each other. Finally, references are shared in Chapter 9.

2. PRELIMINARY INFORMATION

Before diving deeper in the methodology and concept of the study, terms and necessary preliminary information about sustainability and its' subdivisions, definition of sustainable supplier selection methodologies and its' management must be defined. Besides these factors, global energy crisis and supplied product in this study is defined.

Finally, information about decision making processes and methods are given. The main subject of this study, which is spherical fuzzy logic and spherical fuzzy TOPSIS is given alongside other notable fuzzy approaches.

2.1. Defining Sustainability

Through time and developed business conducting methods, there are several explanations came up for the term called sustainability. In general, sustainability means being perpetual to provide continuity (Saban, et al., 2017). This term is used in many forms which compensates both inner and outer factors of a company. According to Brundtland Report, sustainability defined as “The ability of future generations to meet their current needs without compromising their capacity to meet their own needs” (Karcioğlu & Öztürk, 2021). By evaluating given definition, it can be seen as the term sustainability evolved during time and changed circumstances.

With that change in the term, researchers and business professionals also came up with broader definitions for the term sustainability. Researchers indicate that, in the long run sustainability of businesses is possible not only by managing economic factors, but also by managing social and environmental factors simultaneously (Dyllick & Hockerts, 2002). After this approach is brought in to the literature, researchers defined sustainability by adding term corporal before it. So, corporal sustainability refers that, in addition to the growth and profitability model, which is the traditional method of conducting business before, it requires consideration of social and environmental targets as well as economic targets (Wilson, 2003). It is clearly being said as a green or sustainable supplier is the one who fulfills all three requirement of the term called sustainability.

As it is stated before, there are three criteria, namely fiscal, environmental and social to evaluate whether a supplier is sustainable or not.

2.1.1. Fiscal Sustainability

For being fiscally sustainable, suppliers must be focusing on their financials. Fiscal or economic sustainability is defined by several conventional criteria, which are determined by researchers that work on supply chain management, which includes transaction cost economics and resource based approach on business management. So, for the most of the time, it is considered as having maximum profit would make the company fiscally sustainable, that cause researchers develop an incomplete assumption stating that price is the most important criterion (Baskaran, et al., 2012).

Literature contains several fiscal sustainability definitions that are way broaden than only taking price into account. Fiscal sustainability covers concern like the methodical management of the company's resources, cost-cutting, boosting employee enthusiasm to boost productivity, and bringing in new investors (Jamali, 2006).

An alternative definition for fiscal sustainability is given as economic growth that has no detrimental effects on social or environmental aspects is said to be sustainable. Consequently, the rise in economic capital shouldn't result in a decline in the capital of the environment and society (Gedik, 2020).

2.1.2. Environmental Sustainability

Prior to dissecting the components of Environmental Sustainability, it is important to establish a clear definition. Typically, the term "environmental" pertains to the effects of human activities and human-created elements on nature and natural systems. In broad terms, environmental sustainability refers to the notion of meeting the current generation's requirements while ensuring that future generations can fulfill their own needs. It also entails addressing the resource and service demands of both present and future generations while safeguarding the well-being of the ecosystems that provide these resources.

The phenomenon can be more precisely characterized as a dynamic equilibrium, characterized by the ability of human society to effectively fulfill its requirements while simultaneously preserving the regenerative capacity of the underlying ecosystems. This delicate balance ensures the perpetuation of essential ecosystem services necessary to meet societal needs while safeguarding against the detrimental consequences of anthropogenic activities that may result in biodiversity loss (Morelli, 2011).

Environmental criteria are consisting of so many aspects which are determined by researchers. Until recent years, this criterion was not among the favorites of the researchers. However, with the increased environmental awareness of the public and business, more and more researchers started to take environmental aspects into consideration (Handfield, et al., 2002).

This aspect branch is mainly consisting of pollution and management based. To fulfill the requirements, suppliers should be able to minimize their pollutants and/or find a way to manage their waste. To do that, they can implement ecological design methods while building facilities or determining cleaner routes for their logistics. Also using recycled materials or biofuels might help them become environmentally sustainable.

In this research, another aspect of being environmentally sustainable will be taken into account which is suppliers' impact on biodiversity. As a term, biodiversity refers to all of the different types of life forms living in a certain area, which are the variety of animals, plants, fungi and even microorganisms. Biodiversity, supports everything in nature that we require to survive, so that it is extremely important (Hancock, 2023).

2.1.3. Social Sustainability

Last criterion is being socially sustainable. McKenzie identifies social sustainability as a desirable state for communities to be in, as well as a procedure for achieving that state in communities (2004). This definition is supported by several principles which are listed;

- Equal access for all members of the society to essential services,
- Equality between genders and generations,
- Citizens' active participation to political activity and decisions, especially on local levels,
- Showing value and respect to all cultures and nations in the community,
- A belonging sentiment to community among members,

Another definition for social sustainability is made by Barron and Gauntlett (2002) as official and informal institutions, structures, connections, and processes actively promoting future generations' abilities to build livable and healthy communities.

Communities that are socially sustainable are fair, varied, connected, democratic, and offer a high standard of living.

On the corporate level, these principles manifest themselves in a refined manner. In the context of manufacturing enterprises, it becomes imperative for companies to exhibit not only fiscal and environmental sustainability, but also social sustainability, in order to foster continuous growth and endure in the market over a prolonged period. Prominent facets of social sustainability at the corporate level encompass the preservation of workers' well-being, safeguarding human rights, ensuring equitable practices, embracing diversity, and addressing various socio-security concerns, among others. (Sutherland, et al., 2016).

2.2. Defining Supply Chain Management

Supply chain management may be thought of as a long-term management strategy that helps businesses stay alive and stay one step ahead of their rivals in an environment where competition is on the rise. It can also be described as a network that consists of information systems for identifying the source of raw materials, the production and assembly process, storage, order flow, management, and control of the delivery process to the final customer, starting with the product's raw material state and ending with the final customer (Mentzer, et al., 2001).

The goal of supply chain management is to effectively integrate suppliers, manufacturers, warehouses, and retail outlets so that goods are produced and distributed in the appropriate quantities, at the appropriate times, and in the correct locations in order to reduce system costs and meet service level requirements (Simchi-Levi, et al., 2008).

In order to build up a successful supply chain management mechanism, selection process of the supplier must be conducted seamlessly. There are many recent studies in the

literature about sustainable supplier selection. Within the realm of sustainable supplier selection, extensive efforts have been undertaken to establish a systematic groundwork. However, the aspect of selecting and delineating the appropriate array of evaluation criteria has received comparatively inadequate scrutiny. Consequently, prevailing practices involve solely relying on insights garnered from experts and decision-makers for constructing models. Nevertheless, in the pursuit of devising a robust framework for addressing supplier selection quandaries, it becomes imperative to construct a sophisticated knowledge repository, as exemplified in Figure 2. 1.

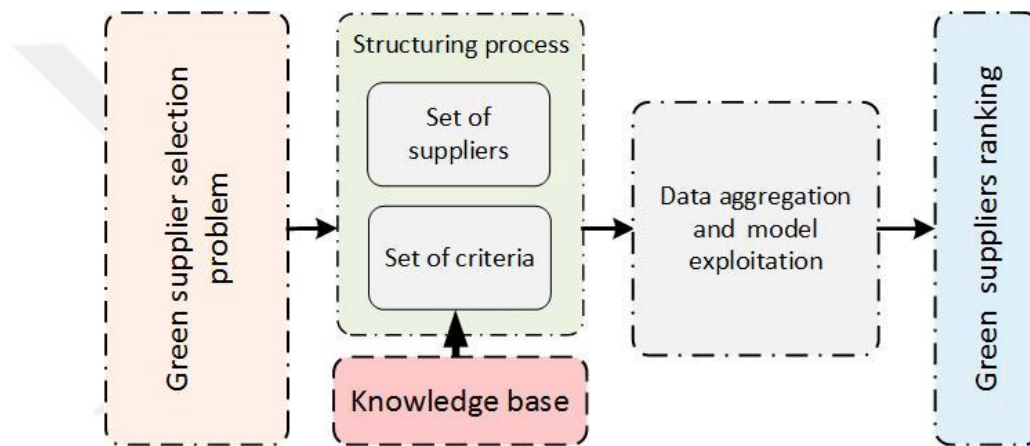


Figure 2.1. Conceptual Framework for Green Supplier Selection (Konys, 2019)

In this study, knowledge base is designed as a combination of opinions of professionals and deep dive literature review about sustainable supplier selection studies. While picking the studies, problems with different scales and different criteria sets are taken into account to broaden the criteria pool for this study.

After defining problem and criteria sets, data evaluation process is handled by using SF-TOPSIS and finally, ranking is given and discussed.

2.3. Energy Crisis

Selecting a sustainable supplier is recommended for the most of the companies. However, for the ones who are dealing with energy market, working with sustainable suppliers is becoming a necessity. The energy crisis issue became the driving force behind this study.

In the 20th century, the world met with a new concept called energy crisis. It is defined as a shortfall in or interruption to the provision of energy supplies (Collins Dictionary, 2023). It can also be defined as an energy shortage which is a significant bottleneck in the supply of energy products. At first, the world has witnessed shortages of petroleum due to wars and embargoes around the world. After few years and new petroleum based energy crises, Russian Federations' invasion to Ukraine in February 2022 started a new crisis in the world.

Numerous nations, including the United States and some of the European states, advocated for a prompt cessation of military hostilities following Russia's invasion of Ukraine. While resorting to military intervention often serves as a customary response to such acts of aggression, the intricate challenge lies in countering Russia due to its possession of nuclear capabilities, as there exists a tangible risk of instigating a fresh global conflict. Moreover, the presence of Russia as a permanent member within the United Nations Security Council impedes the UN's ability to oversee and mediate the Russia-Ukraine conflict. Consequently, rather than direct involvement, the United States, Europe, and Japan have assumed the forefront in implementing economic measures aimed at exerting pressure. Notably, these measures encompass the imposition of a blockade on Russia's fuel exports, particularly natural gas, to curtail its acquisition of foreign currencies, and the imposition of import restrictions to impede Russian domestic revenue generation. (Hosoe, 2023). The aforementioned circumstances have instigated a progressive series of effects on the pricing dynamics within the natural gas market. Noteworthy instances of these effects, denoted in Figure 2.2 and quantified in US Dollars per million British thermal units (USD/MMBtu), are attributable to Russia's strategic response of refraining from supplying natural gas to its European counterparts. (Shell Global, 2023).

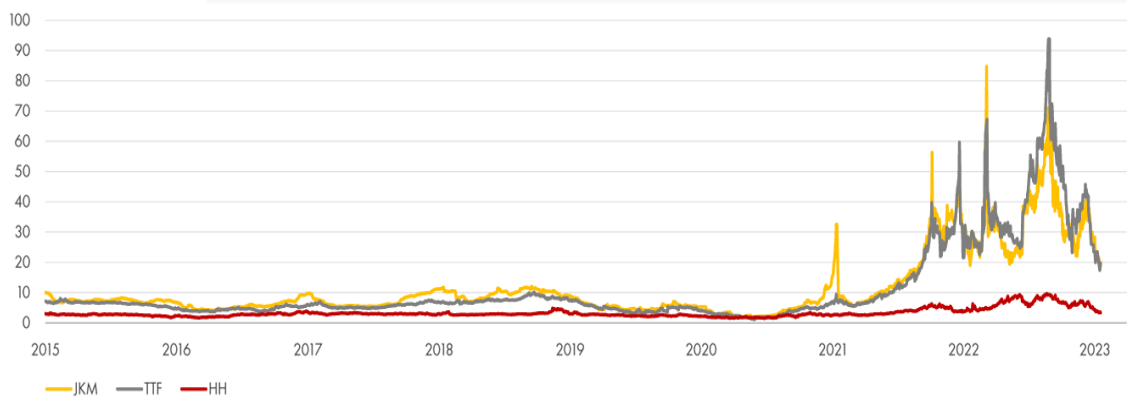


Figure 2.2. Global Gas Prices (Shell Global, 2023)

The global markets encompassing Japan Korea Marker (JKM), recognized as the benchmark price assessment for spot-priced physical liquefied natural gas (LNG) cargoes, hold significant prominence. JKM serves as a reference point in spot transactions, tenders, and contracts of various durations, including short-term, medium-term, and long-term agreements, in Northeast Asia and other geographical regions. Its valuation reflects the prevailing market rate for LNG shipments delivered ex-ship (DES) to China, Taiwan, South Korea, and Japan, regions that collectively represent a substantial portion of global LNG demand (S&P Global, 2023). Notably, as depicted in Figure 1.2, the JKM price has undergone a remarkable surge, soaring from 12 USD per MMBtu to 84 USD per MMBtu. As it is seen the Figure 1.2. JKM price has rocketed up from 12 USD per MMBtu to 84 USD per MMBtu.

An additional index highlighted in the aforementioned figure is the Title Transfer Facility (TTF) index. The contracts traded on this market pertain to the physical conveyance of natural gas. TTF functions as a Virtual Trading Port overseen by Gasunie Transport Services, a Netherlands-based transmission operator. Initially, TTF index prices closely mirrored those of the JKM index. However, in the wake of the diminished supply of natural gas from Russia, TTF prices have experienced a substantial surge, ascending to levels as elevated as 95 USD per MMBtu (Intercontinental Exchange, 2023).

Undoubtedly, The Henry Hub (HH) stands out as the pre-eminent natural gas trading hub within North America. Situated in close proximity to Erath, Louisiana, this pipeline interchange functions as a conduit for gas sourced from diverse regions across the US Gulf Coast, facilitated by the operational infrastructure administered by Sabine Pipe Line, a subsidiary of Chevron Corporation. Notably, the HH price holds remarkable significance due to its resilience against the Russian-induced market impacts. This can be attributed to the United States of America's prominent stature as one of the largest producers and suppliers of LNG globally. Consequently, even amidst widespread scarcity of LNG supplies in various markets, the US market remained adequately equipped to meet the demand, thereby maintaining a balanced pricing equilibrium (S&P Global, 2023).

Within the scope of this study, the focal point revolves around a manufacturer exhibiting substantial reliance on energy-intensive operations. Following the emergence of supply shortages induced by Russia's actions, the manufacturer now faces the imperative task of identifying a supplier capable of fortifying its supply chain against unforeseen disruptions of this nature. It is precisely this compelling rationale that underscores the necessity and relevance of the present study.

2.4. Defining Liquefied Natural Gas

The utilization of NG as a fuel for energy generation has gained popularity in recent decades. This is possible since it is abundant, inexpensive, and produces less emissions than other fossil fuels (Bucknall & Attah, 2015). Nonetheless, owing to its gaseous state, the transportation of NG to regions of demand presents inherent challenges. Consequently, predominant modes of transmission involve interconnecting pipelines that bridge nations with limited supplies and their neighboring counterparts. However, the escalating demand for energy in remote and inaccessible regions necessitated the advent of LNG transportation, which originated in the 1960s. In numerous scenarios, the construction of pipelines proved either technologically unfeasible or economically impractical. (Khalilpour & Karimi, 2011).

As previously mentioned, NG exists in a gaseous state at standard room temperature. However, this characteristic poses a challenge when it comes to long-distance transportation, as the transportation of large volumes of gaseous NG requires extensive pipelines or oversized container vessels, which are not economically viable. To address this concern, LNG has emerged as a solution. By subjecting natural gas to a cooling process, known as liquefaction, processors can convert it into a denser fluid form, achieved by chilling it to a temperature as low as -259 degrees Fahrenheit. This LNG is then stored in specialized oceangoing containers, resembling colossal spheres atop the vessel's deck. To ensure the LNG remains in a cool and liquid state throughout the extensive maritime journey, transporters employ a sophisticated approach. As the LNG nears its condensation point of -259 degrees Fahrenheit, it is loaded into the vessel. During the voyage, the ambient air transfers heat to the storage containers, causing small portions of the LNG to transition back into a gaseous state. These regasified molecules are directed from the storage space to the vessel's engines, where they serve as the propellant. However, the majority of the LNG remains in liquid form until it reaches its final destination, where it undergoes a regasification process and is transmitted via pipelines to the end customers (NRDC, 2022). LNG process chain is stated below to clarify the process.

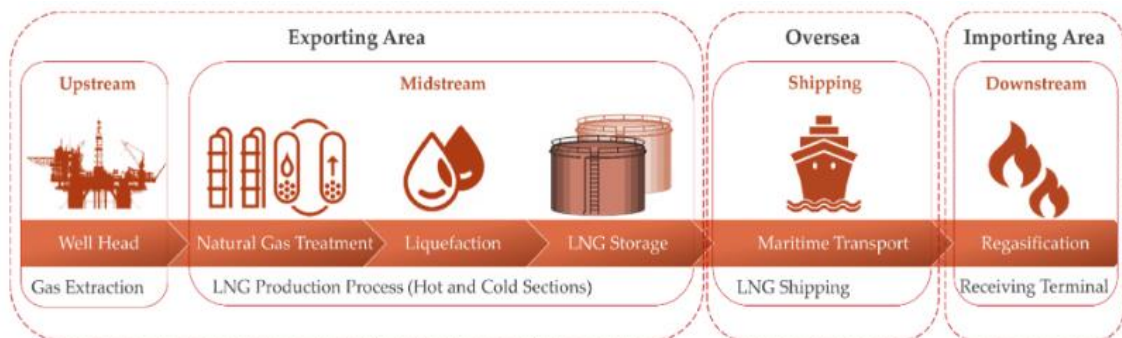


Figure 2.3. LNG Process Chain (Al-Yafei, et al., 2021)

Up to roughly 2000 kilometers, pipelines are favored for the transmission of gas. After that point, the prices rise noticeably more quickly than the expenses of shipping liquid gas (Dobrota, Branko, & Komar, 2013). The worldwide commerce in LNG will account

for around half of all gas handled by 2035, up from 32% now, growing seven times faster than that of pipeline gas. Environmental advantages of using LNG as an alternative fuel include the environmentally friendly combustion of natural gas, which produces 99% fewer emissions of particulate matter (PM), sulfur oxide (SO_x), nitrogen oxides (NO_x), and carbon dioxide (CO₂) as opposed to diesel (Pfooser, et al., 2018).

Within the framework of this research endeavor, the manufacturer under scrutiny exhibits a substantial demand for NG owing to its energy-intensive operations. In light of the challenges elucidated in both the current and preceding sections, the utilization of LNG has become an imperative requirement, prompting a comprehensive exploration of potential LNG suppliers. Prior to embarking upon this particular case study, the manufacturer had been engaging with various LNG suppliers in a non-algorithmic and methodologically unguided manner throughout their decision-making processes.

2.5. Decision Making

Within this section, the elucidation of the algorithms employed in this research takes precedence. Initially, the TOPSIS methodology, renowned for its widespread application in decision-making, will be introduced. Subsequently, a comprehensive overview of existing fuzzy set approaches, as well as the introduction of the novel concept of spherical fuzzy sets, will be presented.

2.5.1. TOPSIS Method

When faced with the task of selecting among alternatives that are categorized based on a hierarchical list of criteria, MCDM methods can be employed. One such method, as described and exemplified, is the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). This method was initially proposed by Hwang and Yoon as a means to address MCDM problems effectively. (1981). After this proposal, him and other researchers work on TOPSIS to improve the original idea. In 1987, Yoon published an

upgraded version of TOPSIS (1987). After Yoon, further developments continued and in 1993, Hwang et.al., published final form of TOPSIS algorithm (1993). All these researches and developments made TOPSIS a widely used MCDM algorithm.

2.5.2. Fuzzy Sets and Spherical Fuzzy Sets

Following Zadeh's exposition of common fuzzy sets, they have gained immense acceptance across practically all scientific disciplines. Numerous academics have created a number of expansions to regular fuzzy sets (Zadeh, 1965). In recent years, numerous researchers have utilized these extensions to address multi-criteria decision-making challenges. Various fuzzy extensions have emerged, leading to the categorization of several recent research papers in the following manner.

Zadeh introduced the concept of a type-2 fuzzy set (T2FS) as an extension of the conventional type-1 fuzzy set. Type-2 fuzzy sets are essentially type-1 fuzzy sets with membership grades represented as fuzzy sets themselves. They prove to be particularly valuable in scenarios where it becomes difficult to precisely define a membership function for a fuzzy set (Zadeh, 1975).

In 1986, Atanassov introduced the concept of intuitionistic fuzzy sets (IFS), which enables the specification of both membership and non-membership degrees of an element within a fuzzy set (Atanassov, 1986). Another contribution by Atanassov is the notion of type-2 intuitionistic fuzzy sets. These sets, known as Atanassov's intuitionistic fuzzy sets of the second type (IFS2), represent a generalization of IFS. They are characterized by a membership degree and a non-membership degree that satisfy the condition that the sum of their squares is equal to or less than one. The introduction of IFS2 is motivated by the recognition that in real-world decision-making scenarios, the square sum of the membership degree and non-membership degree for an alternative meeting a decision maker's specified criterion may be less than or equal to 1, while their sum may exceed 1 (Atanassov, 1999). The hesitancy degree, which constitutes the third dimension of IFS2,

can be determined using various techniques. Over the past few years, IFS2 has been utilized to address challenges associated with multi-criteria decision-making (Ren, et. al, 2016).

Smarandache expanded intuitionistic fuzzy sets by creating neutrosophic sets (NSs) and neutrosophic logic. A degree of truthiness, indeterminacy, and falsehood is assigned to each element of the universe in the neutrosophic set (Smarandache, 1998).

A new type of fuzzy sets was introduced after NSs', which are named Hesitant Fuzzy Sets (HFS). Hesitant fuzzy sets are useful tools that provide a variety of possible degrees of membership for an element in a collection. These fuzzy sets require that an element's membership degree only take potential values between zero and one (Torra, 2010).

The membership, non-membership, and hesitation parameters compose the fuzzy membership functions for intuitionistic and IFS2 systems and they can be calculated by using following formulas; with respect to each other (Kutlu Gündoğdu & Kahraman, 2019).

$$\pi_I = 1 - \mu_I - \vartheta_I \quad (1)$$

or

$$(1 - \mu_p^2(u) - v_p^2(u))^{1/2} \quad (2)$$

Neutrosophic membership functions utilize three parameters, truthiness, falsity, and indeterminacy, which collectively range from 0 to 3, with individual values varying between 0 and 1. In contrast, in spherical fuzzy sets, the squared sum of membership,

non-membership, and hesitancy parameters can range from 0 to 1, while each parameter can be independently determined between 0 and 1. Figure 1.5.2. illustrates the distinctions between PFS, NS, IFS, SFS (Kutlu Gündoğdu & Kahraman, 2019).

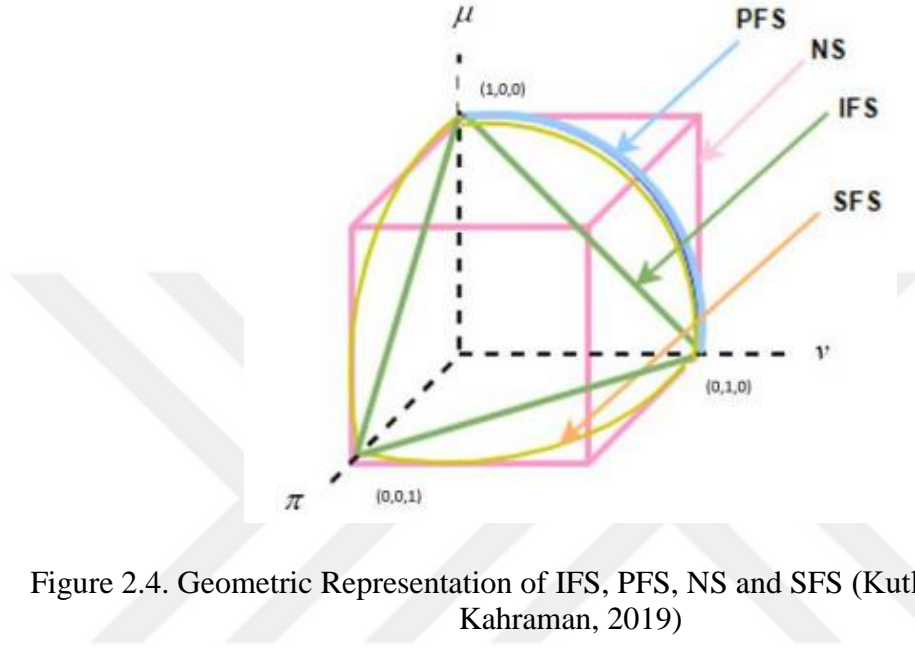


Figure 2.4. Geometric Representation of IFS, PFS, NS and SFS (Kutlu Gündoğdu & Kahraman, 2019)

To define Spherical Fuzzy Set \tilde{A}_S of the universe of discourse is given below as;

$$\tilde{A}_S = \left\{ \left\langle u, \left(\mu_{\tilde{A}_S}(u), \nu_{\tilde{A}_S}(u), \pi_{\tilde{A}_S}(u) \right) \mid u \in U \right\} \right. \quad (2)$$

where

$$\mu_{\tilde{A}_S}: U \rightarrow [0, 1], \nu_{\tilde{A}_S}(u): U \rightarrow [0, 1], \pi_{\tilde{A}_S}: U \rightarrow [0, 1], \quad (3)$$

and

$$0 \leq \mu_{\tilde{A}_S}^2(u) + v_{\tilde{A}_S}^2(u) + \pi_{\tilde{A}_S}^2(u) \leq 1 \quad \forall u \in U \quad (4)$$

For each u , the numbers $\mu_{\tilde{A}_S}(u)$, $v_{\tilde{A}_S}(u)$ and $\pi_{\tilde{A}_S}(u)$ are degree of membership, degree of non-membership and hesitancy of u to \tilde{A}_S with respect to each other (Kutlu Gündoğdu & Kahraman, 2019).

2.5.3. Geometric Representation of Spherical Fuzzy Sets

Spherical distance between \tilde{A}_S and \tilde{B}_S on the surface of the sphere is shown in the Figure 1.5.3. and explained with following formula (Kutlu Gündoğdu & Kahraman, 2019).

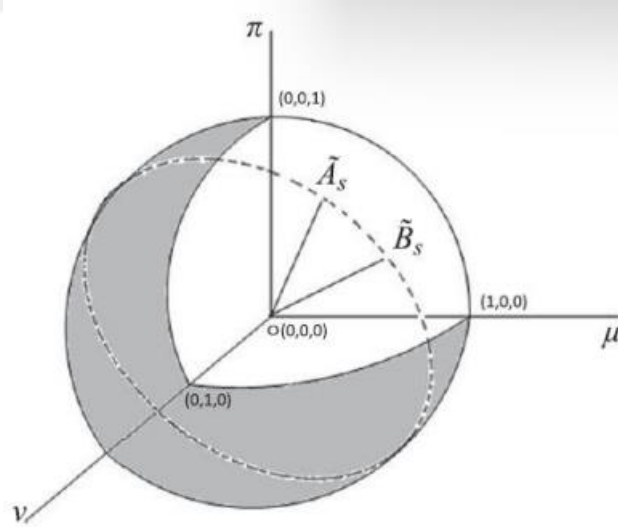


Figure 2.5. Geometric Representation of Spherical Fuzzy Sets (Kutlu Gündoğdu & Kahraman, 2019)

$$dis(\tilde{A}_S, \tilde{B}_S) = \cos^{-1} \left\{ 1 - \frac{1}{2} \left((\mu_{\tilde{A}_S} - \mu_{\tilde{B}_S})^2 + (v_{\tilde{A}_S} - v_{\tilde{B}_S})^2 + (\pi_{\tilde{A}_S} - \pi_{\tilde{B}_S})^2 \right) \right\} \quad (5)$$

The following formula may be used to determine the spherical distance between two spherical fuzzy sets:

$$dis(\tilde{A}_S, \tilde{B}_S) = \frac{2}{\pi} \sum_{i=1}^n \cos^{-1} \left\{ 1 - \frac{1}{2} \left((\mu_{\tilde{A}_S} - \mu_{\tilde{B}_S})^2 + (v_{\tilde{A}_S} - v_{\tilde{B}_S})^2 + (\pi_{\tilde{A}_S} - \pi_{\tilde{B}_S})^2 \right) \right\} \quad (6)$$

Where the factor $\frac{2}{\pi}$ is defined to get distance values in the range of $[0, 1]$ instead of $\left[0, \frac{\pi}{2}\right]$. Because $\mu_{\tilde{A}_S}^2(u) + v_{\tilde{A}_S}^2(u) + \pi_{\tilde{A}_S}^2(u) = 1$, so the distance can be calculated as follows,

$$dis(\tilde{A}_S, \tilde{B}_S) = \frac{2}{\pi} \sum_{i=1}^n \cos^{-1} \left(\mu_{\tilde{A}_S}(u_i) * \mu_{\tilde{B}_S}(u_i) + v_{\tilde{A}_S}(u_i) * v_{\tilde{B}_S}(u_i) + \pi_{\tilde{A}_S}(u_i) * \pi_{\tilde{B}_S}(u_i) \right) \quad (7)$$

Normalized spherical distance between \tilde{A}_S and \tilde{B}_S on the surface of a sphere;

$$dis(\tilde{A}_S, \tilde{B}_S) = \frac{2}{n\pi} \sum_{i=1}^n \cos^{-1} \left(\mu_{\tilde{A}_S}(u_i) * \mu_{\tilde{B}_S}(u_i) + v_{\tilde{A}_S}(u_i) * v_{\tilde{B}_S}(u_i) + \pi_{\tilde{A}_S}(u_i) * \pi_{\tilde{B}_S}(u_i) \right) \quad (8)$$

Evidently, we obtain these equivalencies $0 \leq dis(\tilde{A}_S, \tilde{B}_S) \leq n$ and $0 \leq dis_n(\tilde{A}_S, \tilde{B}_S) \leq 1$ (Kutlu Gündoğdu & Kahraman, 2019).

3. LITERATURE REVIEW

The imperative of attaining sustainability, particularly at the industrial level, is unequivocally emphasized. However, navigating the path of sustainable practices has become increasingly challenging compared to previous times. To mitigate risks and optimize decision-making processes, researchers are diligently employing various MCDM methods to tackle the complex problems confronting professionals in the business domain. This section presents a collection of studies gleaned from the existing literature, exemplifying the application of MCDM methodologies.

This comprehensive study encompasses various dimensions within the realm of MCDM and sustainability, necessitating the division of the literature review section into distinct subheadings representing the different areas explored in this research. The initial subheading delves into the realm of sustainable supplier selection, providing a comprehensive listing and explication of relevant studies. Notably, the studies are presented without grouping them based on the MCDM method employed, ensuring a comprehensive portrayal of diverse research efforts utilizing distinct MCDM methodologies. The subsequent section of the literature review focuses on research pertaining to Fuzzy TOPSIS, presenting an array of studies that emphasize the methodology itself without explicitly considering the specific problem context. Lastly, the literature review incorporates research centered on SF-TOPSIS, following the same approach as the preceding section, while shedding light on studies incorporating this novel concept.

3.1.Sustainable Supplier Selection

The process of supplier selection carries substantial significance within the domain of business professionals. However, decision-makers, who themselves possess business expertise, frequently encounter obstacles that can impede their judgment when engaging in the selection process. In an effort to tackle this issue, the ensuing research endeavors to provide a solution that showcases the potential to mitigate human error and discern the most favorable alternative during supplier selection.

An empirical investigation conducted in India demonstrated the implementation of the Analytic Hierarchy Process (AHP) as a means to effectively select a socially sustainable supplier. This study sheds light on the practical utilization of social sustainability considerations by manufacturers in developing countries when making supplier choices. Three distinct case studies were incorporated, focusing on the electrical, automotive, and construction sectors. The research not only scrutinizes the outcomes derived from employing the AHP methodology but also examines the trade-offs made by supply chain managers in these three case studies. The findings of this research unequivocally indicate that leveraging the AHP enables the identification of the most optimal alternative in terms of social sustainability. By recognizing the relevance of social factors in supplier selection and making them a requisite consideration, attention is drawn to social circumstances and stakeholders alike (Mani, et al., 2014).

Another notable study incorporating social sustainability criteria is evaluated. Within the evaluated research, researchers introduce a comprehensive grey-based multi-criteria decision-support tool, which synergistically integrates the best-worst method (BWM) and TOMada de Decisão Interativa e Multicritério (TODIM). In this context, the grey-BWM technique is employed to determine the weights associated with social sustainability attributes, while the grey-TODIM method is utilized to rank suppliers accordingly. To empirically validate the applicability and efficacy of the proposed social sustainability decision framework, researchers leverage a case study involving an Iranian manufacturing business as an illustrative example (Bai, et al., 2019).

The intricacies of sustainable supplier selection problems are not universally transparent in every instance. Some cases may suffer from incomplete information or various uncertainties that have the potential to obscure the judgment of decision-makers. However, notable research has demonstrated the capacity to address these uncertainties. Within a multi-person decision-making framework characterized by imperfect preference relations, the study introduces a novel technique founded on the fuzzy Analytical Network Process (ANP). By leveraging the provided preference information, this approach not only facilitates comprehensive assessments but also upholds the integrity of evaluation consistency. To substantiate the efficacy of the proposed evaluation approach, the research undertakes an investigation of supplier sustainability in a real-world context (Büyüközkan & Çifçi, 2011).

Another research focused on uncertain linguistic environments, presenting an innovative MCDM model for selecting sustainable suppliers using the BWM and Alternative Queuing Method (AQM) has been evaluated. This study employed interval-valued intuitionistic uncertain linguistic sets, which allow for the representation of the vague and ambiguous judgments of decision-makers. To showcase the practicality and effectiveness of proposed sustainable supplier selection strategy, researchers conducted a case study involving a watch manufacturer (Hu-Chen, et al., 2019).

An additional empirical investigation was conducted, entailing the integration of the concept of fuzziness. Within this research endeavor, the scholars developed a composite model that synergistically incorporated Triple Bottom Line Metrics, the FAHP methodology, and the Combined Compromise Solution (CoCoSo) algorithm. The primary aim of their study was to discern the most optimal supplier for their raw material procurement challenge (Van Thanh & Thi Kim Lan, 2022).

An additional scholarly investigation has been examined, focusing on the utilization of fuzzy MCDM techniques in the context of a supplier selection problem within the garment industry, which has experienced adverse effects following the COVID-19 pandemic. The study adopts FAHP and Weighted Aggregated Sum Product Assessment (WASPAS) methodologies to support decision-makers in minimizing human errors during the decision-making process. The overarching objective of their research article is to offer a decision-making tool that aids decision-makers in selecting the most suitable supplier in the clothing sector amidst an uncertain and ambiguous environment (Kao, Chia-Nan, & Viet Tinh, 2022).

Büyüközkan (2011) conducted a research study with a central focus on the environmental dimensions of sustainable supplier selection, employing the principles of fuzzy logic. The primary objective of the study was to assess potential suppliers from an environmental sustainability perspective, utilizing an integrated approach that incorporates a fuzzy group decision-making technique. More specifically, the study employed a fuzzy group decision-making technique grounded in axiomatic design (AD) to rank suppliers in terms of their environmental sustainability, while the FAHP was employed to ascertain the relative weights of the assessment criteria. To ascertain the effectiveness of the proposed methodology, a case study was conducted, providing empirical validation of its compatibility and accuracy.

An additional research investigation pertaining to decision-making based on environmental sustainability criteria is examined. The primary focus of the researchers is on the concept of sustainable supply chain management, whereby they incorporate both fiscal and environmental criteria to propose a sustainable supplier selection model. To address the interdependencies among the criteria, the researchers suggest the use of the ANP, while they enhance the conventional Grey Relational Analysis (GRA) to better handle the uncertainties inherent in supplier selection decisions. By utilizing ANP and the improved GRA in tandem, the researchers determine the weight of the criteria and rank the sustainable suppliers. This innovative approach empowers decision-makers to actively participate in the evaluation process and employ linguistic evaluation when

choosing sustainable suppliers. To demonstrate the efficacy of their proposed strategy, the researchers present a case study from the automobile sector (Hashemi, et al., 2015).

At this juncture, the aforementioned studies predominantly utilized AHP-based MCDM methods. However, a recent publication focused on a case study concerning sustainable supplier selection for an electronics company introduces a research study that primarily relies on the Decision-Making Trial and Evaluation Laboratory (DEMATEL) in conjunction with the ANP method, known as DANP. These techniques are employed to establish the causal relationships among them and determine the significance of assessment criteria in the supplier selection process. Subsequently, the environmental performances of suppliers are evaluated using the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) technique, which aids in identifying a solution for each assessment criterion (Kuo, et al., 2015).

The final study discussed in this section regarding sustainable supplier selection employs a hybrid method that combines various MCDM techniques. These techniques include the artificial neural network (ANN) and two multi-attribute decision analysis (MADA) methods: data envelopment analysis (DEA) and the ANP. The hybrid method developed by the researchers is referred to as the ANN-MADA method. It considers both environmental standards and the practicality of conventional supplier selection criteria, which primarily revolve around economic aspects. The researchers emphasize that their model overcomes limitations related to the number of decision-making units (DMUs) and data accuracy encountered in typical DEA approaches. Through a case study conducted on an internationally renowned camera manufacturer, the researchers demonstrate that the ANN-MADA hybrid technique outperforms both the ANN-DEA and ANP-DEA hybrid methods in terms of its results (Kuo, et al., 2010).

3.2.Fuzzy TOPSIS

Yıldızbaşı et al., (2021) undertook a study focused on the selection of a socially sustainable supplier within the automotive industry. They developed a model for a case study conducted in Turkey, employing two distinct MCDM methods: the FAHP and the FTOPSIS. Through this approach, the researchers assessed the social sustainability status of automotive industry companies in Turkey, providing a comprehensive evaluation and offering suggestions for improvement to enrich the existing literature on the subject.

Chen et al., (2019) conducted a research focusing on the selection of sustainable suppliers, taking into account both economic and environmental aspects. To address the complexities inherent in supplier selection, they employed a fuzzy MCDM approach. The study employed the FAHP to establish the relative importance of the criteria and subsequently employed FTOPSIS to finalize the model. To demonstrate the feasibility and effectiveness of their proposed methodology, a case study within the Luminance Enhancement Film (LEF) industry was conducted, providing real-world context and practical insights.

Another study that includes Fuzzy TOPSIS method is conducted in Iran by using a case study that includes a supplier selection problem for a pharmaceutical company. Mehralian et al., (2012) stated that the majority of the advancements achieved in supply chain operations over the years have been on strategies to cut costs and increase scale efficiency. Professionals may need to weigh additional risks, nevertheless, in order to choose the finest source. Their research depends on the results of a review of the literature, the consultation of experts in the field of statistical analysis, and the application of MCDM models to data from numerous dispersed investigations. By using FTOPSIS with the gathered data, researchers showed that delivery risk, which is a common economic criterion in supplier selection problems, may significantly reduce the risk in the pharmaceutical sector (Mehralian, et al., 2012).

Awathi et al., (2010) conducted a research study with the primary objective of assessing the environmental sustainability performances of suppliers. To achieve this goal, they employed the FTOPSIS method, which is a fuzzy MCDM approach. The selection of this approach was driven by the rationale of incorporating linguistic variables in the research, thereby enabling a more comprehensive evaluation of environmental sustainability. Moreover, the incorporation of linguistic variables in the research conducted by Awathi et al., (2010) enabled the researchers to effectively capture the qualitative dimensions inherent in environmental sustainability, which are often intricate to quantify. By integrating fuzzy logic into their analysis, the study successfully addressed the inherent uncertainties and vagueness that accompany assessments of environmental sustainability. The utilization of the FTOPSIS method provided a systematic framework for evaluating suppliers' environmental performance, encompassing multiple criteria and their corresponding importance weights. This comprehensive evaluation approach not only yielded valuable insights into the environmental sustainability practices of suppliers but also facilitated informed decision-making processes targeted at fostering sustainability within supply chain management. In summary, the findings of Awathi et al., (2010) substantiated the effectiveness of the fuzzy MCDM approach in evaluating and comparing the environmental sustainability performances of suppliers.

The combined utilization of FTOPSIS and FAHP has gained significant prominence in current literature, particularly in the context of effective supplier selection. A recent study sought to address this issue within the pharmaceutical industry by integrating these two approaches. In collaboration with hospital pharmacy managers, the researchers identified a comprehensive set of field-specific criteria and alternatives within the commercial sector. Through the FAHP and FTOPSIS procedures, decision-makers were actively involved in determining the weights assigned to the criteria and sub-criteria, enabling a rigorous analysis and ranking of the available options. The primary objective of the study was to optimize the overall efficiency of the pharmacy by comparing and contrasting the outcomes obtained from the FAHP and FTOPSIS methodologies, ultimately leading to the selection of the most suitable supplier (Palanisamy & Ranganathan, 2017).

The following study explores the integration of the FTOPSIS and Multi-Choice Goal Programming (MCGP) methods to address a MCDM problem. Rouyendegh and Saputro (2014) aim to demonstrate the effectiveness of this integrated approach in the supplier selection and order assignment process. By incorporating proximity coefficients derived from the MCGP model, the study generates a final decision on supplier selection and order distribution. A numerical example is included in the study to illustrate and provide a detailed explanation of the key findings and outcomes of this proposed approach.

3.3.Spherical Fuzzy and Spherical Fuzzy TOPSIS

Following its introduction by Gündoğdu and Kahraman, the SF-TOPSIS method has gained significant attention among researchers studying location selection problems. One noteworthy application of this MCDM method is demonstrated by the method's founders in the context of hospital location selection. The researchers implemented their proposed spherical fuzzy methodology to address a hospital selection problem consisting of five criteria and five alternative locations. The adoption of TOPSIS with fuzzy logic stems from its ability to effectively group criteria into distinct categories, such as cost and benefit, with the objective of maximizing performance in both groups. The utilization of spherical fuzzy aims to transform qualitative data into quantitative form, thereby facilitating the decision-making process. Through this study, the researchers successfully showcased the practicality and suitability of the SF-TOPSIS method for addressing location selection problems (Kahraman, et al., 2019).

Kutlu Gündoğdu and Kahraman (2019), the pioneers of Spherical Fuzzy Logic, published a research article focusing on the field of site selection. In their study, they introduced a novel method called Spherical Fuzzy VIKOR (SF-VIKOR), which integrates the VIKOR method with Spherical Fuzzy logic. The primary objective of their research was to enhance the traditional VIKOR method by developing the SF-VIKOR method and evaluating its practicality and reliability using a concrete example. Furthermore, they conducted a comparative analysis between the SF-VIKOR and SF-TOPSIS methods. To

demonstrate the efficacy of the proposed SF-VIKOR technique, they examined a warehouse location selection problem encompassing four alternatives and four criteria.

Kutlu Gündoğdu and Kahraman (2021) published another study about location selection by using Spherical Fuzzy TOPSIS. In their study, the aim was to find out the best location to place an electric vehicle charging station. To validate the devised technique and show its viability and efficacy, they designed a multi-criteria selection issue for the best location of an electric car charging station. In addition to that, a comparison using the single-valued spherical fuzzy COmbine Distance-based Assessment (CODAS) approach is carried out in their study.

To simultaneously address the ambiguity in subjective data and the uncertainty in objective data, Sharaf (2023), conducted a research by using both SF-TOPSIS and SF-VIKOR in the evaluation of hydrogen storage systems. The suggested approaches by Sharaf are demonstrated by two real-world examples. The first example addresses the issue of choosing a warehouse site. The second example uses several forms of data (crisp, linguistic variables, type 1 fuzzy sets) to assess hydrogen storage systems for vehicles. To provide a more thorough examination, Sharaf converted these data to SFSs. To clarify the suitability of the suggested approaches and the consistency of the outcomes, a comparison with older versions of TOPSIS and VIKOR is made.

MCDM techniques are widely used especially in the logistics area, when making decisions become more difficult and unclear. Jaller and Otay (2021), conducted a study that includes evaluating sustainable vehicle technologies on large scale logistics. The researchers stated that there are many alternative technologies on freight transportation, however, all of them has their limitations and most of the time these factors cloud the judgements of decision makers. Their study suggests using the AHP and the TOPSIS based on spherical fuzzy sets to compare different sustainable vehicle technology possibilities for transporting cargo based on a variety of criteria. Because they can better account for uncertainty by defining membership functions on a spherical surface and encompassing a wider domain, spherical fuzzy sets are gaining popularity. In particular,

the authors assess the options based on twenty-one sub-criteria and five main criteria: financial, business and market-related, environmental and legal, repair and service accessibility, and safety and vehicle efficiency. Additionally, the researchers carried out a sensitivity analysis.

The SF-TOPSIS method has garnered attention from researchers, who have been exploring ways to enhance and extend its capabilities. Mathej, et al., (2020), conducted a study that employed both SF-TOPSIS and Spherical Fuzzy AHP to determine the rankings of alternatives and criteria weights in relation to each other. In their research, they proposed a novel formula for calculating spherical fuzzy criterion weights, utilizing an entirely new eleven-point spherical fuzzy linguistic word scale to measure preference. The study focused on an advanced manufacturing system selection problem with six assessment criteria and four options, using the suggested approach. The researchers found that the Spherical Fuzzy AHP-TOPSIS method effectively manages uncertainty in decision-making and generates reliable and competitive outcomes, outperforming contemporary MCDM methods in dealing with uncertainty.

As previously discussed, the applications of spherical fuzzy logic and SF-TOPSIS span diverse sectors and contexts. In a research endeavor, investigators proposed a tailored design problem specific to a marble manufacturing facility. In addition to the established dimensions of severity, incidence, and detection, the SF-TOPSIS approach introduced three supplementary parameters: cost, prevention, and efficacy. The weights associated with these parameters were determined through the utilization of the interval-valued spherical weighted arithmetic mean (IVSWAM) operator. To showcase the practical implementation of this pioneering model, a case study was presented, focusing on a marble manufacturing plant. The outcomes underscored the importance of the factory's repair and maintenance procedures, as well as the absence of regular technical inspections for hoisting equipment in instances of crane breakdowns, as the most critical breakdown modes. To assess the reliability and effectiveness of the technique, a series of comparative and validation tests were conducted (Gul & Ak, 2021).

As a final example found in the literature, Zeng et al., (2019), proposed a hybrid SF-TOPSIS method to enhance the accuracy of decision-making processes. Researchers developed a comprehensive framework to address decision-making challenges that involve strong perspectives in favor of, neutral towards, or opposed to specific initiatives, businesses, or strategies. To integrate spherical fuzzy sets with the concept of rough set wrapping, they introduced a novel technique called covering-based spherical fuzzy rough set (CSFRS) models, which utilize spherical fuzzy neighborhoods (SF-neighborhoods). The TOPSIS technique was then applied using CSFRS models with SF-neighborhoods to incorporate the notion of TOPSIS within the spherical fuzzy context. By employing the SF-TOPSIS approach, a multi-attribute decision-making problem was formulated in an SF environment. This paradigm proves to be more effective in handling vagueness and uncertainty compared to intuitionistic fuzzy sets and image fuzzy sets. The suggested strategy was further illustrated with a real-world example to demonstrate its application in resolving decision-making challenges.

4. METHODOLOGY

As it is stated in the previous chapters, large-scale manufacturers, especially if they are energy intensive, require sustainable suppliers in the critical aspects of the supply chain. To keep their manufacturing schedule on track, they require a seamless flow of energy. However, the energy sector is fragile enough to get affected negatively by most of the political events in the world which increases the importance of selecting a sustainable supplier for large-scale manufacturers.

The chosen case study for this research is selected from a real-life problem which is stated as selecting a sustainable LNG supplier for a glass manufacturer company in Turkey. An extensive literature review was undertaken to identify the most precise criteria sets for this problem. These sets are divided into three groups which are defined as fiscal, environmental, and social sustainability criteria. Each criterion is divided into five sub-criteria. Some of the sub-criteria are redefined for this study that's because not all criteria correspond with the literature and defines the case study sufficiently enough to examine.

As of the data evaluation and ranking section of this study, a new proposed SF-TOPSIS method is used. An immense literature review about both Spherical Fuzzy and SF-TOPSIS has been conducted. Studies that include applications of SF-TOPSIS are investigated without making any distinction in terms of the business area of the case studies.

In this section, necessary spherical fuzzy operations and SF-TOPSIS method will be introduced step by step with respect to each other in order to clarify the concept.

4.1.Spherical Fuzzy Operations

In their study, Kutlu Gündoğdu and Kahraman defined six major operations which are addition, multiplication, multiplication by a scalar, exponentiation of SFSs, Union and Intersection of SFSs. In this study, only major operation that will be utilized is the multiplication of two Spherical Fuzzy Sets, which given in the following Equation (9) (Kutlu Gündoğdu & Kahraman, 2019). This equation will also be used for calculation of global weights.

Let two SFSs be $\tilde{A}_S = (\mu_{\tilde{A}_S}, \nu_{\tilde{A}_S}, \pi_{\tilde{A}_S})$ and $\tilde{B}_S = (\mu_{\tilde{B}_S}, \nu_{\tilde{B}_S}, \pi_{\tilde{B}_S})$

- Multiplication of two Spherical Fuzzy Sets:

$$\tilde{A}_S \otimes \tilde{B}_S = \left\{ \begin{array}{l} \mu_{\tilde{A}_S} \mu_{\tilde{B}_S}, (v_{\tilde{A}_S}^2 + v_{\tilde{B}_S}^2 - v_{\tilde{A}_S}^2 v_{\tilde{B}_S}^2)^{1/2}, \\ \left(((1 - v_{\tilde{B}_S}^2) \pi_{\tilde{A}_S}^2 + (1 - v_{\tilde{A}_S}^2) \pi_{\tilde{B}_S}^2 - \pi_{\tilde{A}_S}^2 \pi_{\tilde{B}_S}^2)^{1/2} \right) \end{array} \right\} \quad (9)$$

After explaining the multiplication operation, the following formula is included in this study to introduce the SWAM operation that will be used during this research as mentioned in Equation (10) (Kutlu Gündoğdu & Kahraman, 2019).

- Spherical Weighted Arithmetic Mean (SWAM)

$$w = (w_1, w_2, \dots, w_n); w_i \in [0,1];$$

$$SWAM_w(A_{S_1}, \dots, A_{S_n}) = w_1 A_{S_1} + w_2 A_{S_2} + \dots + w_n A_{S_n}$$

$$= \left\{ \begin{array}{l} \left[1 - \prod_{i=1}^n (1 - \mu_{A_{S_i}}^2)^{w_i} \right]^{1/2}, \\ \prod_{i=1}^n v_{A_{S_i}}^{w_i} \left[\prod_{i=1}^n (1 - \mu_{A_{S_i}}^2)^{w_i} - \prod_{i=1}^n (1 - \mu_{A_{S_i}}^2 - \pi_{A_{S_i}}^2)^{w_i} \right]^{1/2} \end{array} \right\} \quad (10)$$

4.2. Defining Selected Technique

The realm of sustainable supplier selection problems offers a range of methodologies, including the one adopted in this study. The viability of these methodologies has been demonstrated through an extensive review of existing literature and research. In this particular study, a novel MCDM method known as the SF-TOPSIS technique will be employed to assess and identify the optimal choice among a set of alternatives. The evaluation process will involve considering three primary criteria and fifteen sub-criteria to determine the most sustainable option. The selection of three main criteria and fifteen sub-criteria demonstrates the comprehensive nature of the evaluation, considering various aspects of sustainability. The findings of this study will not only inform practitioners and decision-makers but also pave the way for future research in the field of sustainable supplier selection.

4.2.1. Application of Spherical Fuzzy the Order of Preference by Similarity to Ideal Solution (SF-TOPSIS) Method

Step 1: Defining Criteria and Necessary Vectors

Consider a discrete set of m alternatives denoted as $X = \{x_1, x_2, \dots, x_m\}$ where ($m \geq 2$) and $C = \{C_1, C_2, \dots, C_n\}$ be a finite set of criteria and $w = \{w_1, w_2, \dots, w_n\}$ represent the weight vector assigned to each criterion which are denoted as $0 \leq w_j \leq 1$ and the sum of all weights is equal to 1, denoted as $\sum_{j=1}^n w_j = 1$ (Kutlu Gündoğdu & Kahraman, 2019).

Step 2: The evaluation of criteria is conducted by Decision Makers using linguistic terms provided in various tables (Sharaf, 2022). For this study, Table 3.4 has been chosen and adapted to align with the research requirements (Kutlu Gündoğdu & Kahraman, 2019).

Table 4.1. Linguistic Terms and Their SF numbers – 5 Scale (Kutlu Gündoğdu & Kahraman, 2019)

Linguistic Terms	(μ, ν, π)
Very Good	(0.9, 0.1, 0.1)
Good	(0.7, 0.3, 0.3)
Fair	(0.5, 0.5, 0.5)
Poor	(0.3, 0.7, 0.3)
Very Poor	(0.1, 0.9, 0.1)

Table 4.2. Linguistic Terms and Their SF numbers – 7 Scale (Kutlu Gündoğdu & Kahraman, 2019)

Linguistic Terms	(μ, ν, π)
Extremely Good	(0.9, 0.1, 0.1)
Very Good	(0.8, 0.2, 0.2)
Good	(0.7, 0.3, 0.3)
Fair	(0.5, 0.5, 0.5)
Poor	(0.3, 0.7, 0.3)
Very Poor	(0.2, 0.8, 0.2)
Extremely Poor	(0.1, 0.9, 0.1)

Table 4.3. Linguistic Terms and Their SF numbers - 9 Scale (Kutlu Gündoğdu & Kahraman, 2019)

Linguistic Terms	(μ, ν, π)
Superior	(0.9, 0.1, 0.1)
Extremely Good	(0.8, 0.2, 0.2)
Very Good	(0.7, 0.3, 0.3)
Good	(0.6, 0.4, 0.4)
Fair	(0.5, 0.5, 0.5)
Poor	(0.4, 0.6, 0.4)
Very Poor	(0.3, 0.7, 0.3)
Extremely Poor	(0.2, 0.8, 0.2)
Inferior	(0.1, 0.9, 0.1)

Table 4.4. Linguistic Terms and Their SF numbers

Linguistic Terms	(μ, ν, π)
Absolutely Important (AI)	(0.9, 0.1, 0.1)
More Important (MI)	(0.8, 0.2, 0.2)
Important (I)	(0.7, 0.3, 0.3)
Slightly Important (SI)	(0.6, 0.4, 0.4)
Equally Important (EI)	(0.5, 0.5, 0.5)
Slightly Unimportant (SU)	(0.4, 0.6, 0.4)
Unimportant (U)	(0.3, 0.7, 0.3)
Strongly Unimportant (STU)	(0.2, 0.8, 0.2)
Absolutely Unimportant (AU)	(0.1, 0.9, 0.1)

Step 3: Aggregate the judgments of Decision Makers using the Spherical Weighted Arithmetic Mean (SWAM) or the Spherical Weighted Geometric Mean (SWGM), as defined in Equation 10 and Equation 11 (Kutlu Gündoğdu & Kahraman, 2019).

The Spherical Weighted Geometric Mean (SWGM) is defined as follows;

where $w = (w_1, w_2, \dots, w_n)$;

$$w_i \in [0,1]; \sum_{i=1}^n w_i = 1;$$

$$SWGM_w(A_1, \dots, A_n) = A_{S_1}^{w_1} + A_{S_2}^{w_2} + \dots + A_{S_n}^{w_n}$$

$$= \left\{ \begin{array}{l} \prod_{i=1}^n \mu_{A_{S_i}}^{w_i}, \left[1 - \prod_{i=1}^n (1 - v_{A_{S_i}}^2)^{w_i} \right]^{1/2}, \\ \left[\prod_{i=1}^n (1 - v_{A_{S_i}}^2)^{w_i} - \prod_{i=1}^n (1 - \mu_{A_{S_i}}^2 - \pi_{A_{S_i}}^2)^{w_i} \right]^{1/2} \end{array} \right\} \quad (11)$$

Step 4: Aggregated Spherical Decision Matrix must be constructed by using the opinions provided by Decision Makers (Kutlu Gündoğdu & Kahraman, 2019).

Score and Accuracy Functions are defined;

$$Score(\tilde{A}_S) = (\mu_{\tilde{A}_S} - \pi_{\tilde{A}_S})^2 - (v_{\tilde{A}_S} - \pi_{\tilde{A}_S})^2 \quad (12)$$

$$Accuracy(\tilde{A}_S) = \mu_{\tilde{A}_S}^2 + v_{\tilde{A}_S}^2 + \pi_{\tilde{A}_S}^2 \quad (13)$$

It should be considered that $\tilde{A}_S < \tilde{B}_S$ if and only if;

$$Accuracy(\tilde{A}_S) < Accuracy(\tilde{B}_S) \quad (14)$$

Denote the evaluation values of Alternative $X_i (i = 1, 2, \dots, m)$ with respect to criterion $C_j (j = 1, 2, \dots, n)$ by $C_j(X_j) = (\mu_{ij}, v_{ij}, \pi_{ij})$ and $D = (C_{ij}(X_{ij}))_{m \times n}$ should be constructed according to Equation 15 given below (Kutlu Gündoğdu & Kahraman, 2019).

$$\begin{aligned}
\text{Decision Matrix } (D) &= \left(C_j(X_i) \right)_{m \times n} \\
&= \begin{pmatrix} \mu_{11}, v_{11}, \pi_{11} & \dots & \mu_{1n}, v_{1n}, \pi_{1n} \\ \dots & \dots & \dots \\ \mu_{m1}, v_{m1}, \pi_{m1} & \dots & \mu_{mn}, v_{mn}, \pi_{mn} \end{pmatrix} \quad (15)
\end{aligned}$$

Step 5: In this step, it is necessary to construct the Aggregated Spherical Fuzzy Matrix. After determining the weights of the criteria and the ratings of the alternatives, the Aggregated Weighted Spherical Fuzzy Decision Matrix is created using Equation 16 as provided below. The Aggregated Weighted Spherical Fuzzy Decision Matrix can be defined as follows (Kutlu Gündoğdu & Kahraman, 2019):

$$\tilde{A}_S \otimes \tilde{B}_S = \left\{ \begin{array}{l} \mu_{\tilde{A}_S} \mu_{\tilde{B}_S}, (v_{\tilde{A}_S}^2 + v_{\tilde{B}_S}^2 - v_{\tilde{A}_S}^2 v_{\tilde{B}_S}^2)^{1/2} \\ \left((1 - v_{\tilde{B}_S}^2) \pi_{\tilde{A}_S}^2 + (1 - v_{\tilde{A}_S}^2) \pi_{\tilde{B}_S}^2 - \pi_{\tilde{A}_S}^2 \pi_{\tilde{B}_S}^2 \right)^{1/2} \end{array} \right\} \quad (16)$$

$$\begin{aligned}
\text{Weighted Decision Matrix } (D) &= \left(C_j(X_{iw}) \right)_{m \times n} \\
&= \begin{pmatrix} (\mu_{11w}, v_{11w}, \pi_{11w}) & \dots & (\mu_{1nw}, v_{1nw}, \pi_{1nw}) \\ \dots & \dots & \dots \\ (\mu_{m1w}, v_{m1w}, \pi_{m1w}) & \dots & (\mu_{mnw}, v_{mnw}, \pi_{mnw}) \end{pmatrix} \quad (17)
\end{aligned}$$

Step 6: To obtain a crisp decision from the Weighted Decision Matrix, defuzzification is required. This can be achieved by applying Equation 12, which has been modified and presented below as Equation 18 (Kutlu Gündoğdu & Kahraman, 2019).

$$\text{Score } \left(C_j(X_{iw}) \right) = (\mu_{ijw} - \pi_{ijw})^2 - (v_{ijw} - \pi_{ijw})^2 \quad (18)$$

Step 7: In the preceding step, the Score values are determined, and they are used to calculate the Spherical Fuzzy Positive Ideal Solution (SF-PIS) and Spherical Fuzzy Negative Ideal Solution (SF-NIS) using Equation 19 and Equation 20, respectively (Kutlu Gündoğdu & Kahraman, 2019).

For SF-PIS:

$$X^* = \{C_j, \max_i \langle \text{Score} (C_j(X_{iw})) \rangle \mid j = 1, 2, \dots, n\}$$

$$X^* = \{\langle C_1, (\mu_1^*, \nu_1^*, \pi_1^*) \rangle, \langle C_2, (\mu_2^*, \nu_2^*, \pi_2^*) \rangle, \dots, \langle C_n, (\mu_n^*, \nu_n^*, \pi_n^*) \rangle\} \quad (19)$$

For SF-NIS:

$$X^* = \{C_j, \min_i \langle \text{Score} (C_j(X_{iw})) \rangle \mid j = 1, 2, \dots, n\}$$

$$X^* = \{\langle C_1, (\mu_1^-, \nu_1^-, \pi_1^-) \rangle, \langle C_2, (\mu_2^-, \nu_2^-, \pi_2^-) \rangle, \dots, \langle C_n, (\mu_n^-, \nu_n^-, \pi_n^-) \rangle\} \quad (20)$$

Step 8: To calculate the distances between each alternative X_i and the SF-PIS and SF-NIS, the Normalized Euclidean Distance is recommended. Equations 21 and 22, provided below, can be used for this calculation. (Kutlu Gündoğdu & Kahraman, 2019).

For SF-PIS:

$$D(X_i, X^*) = \sqrt{\frac{1}{2n} \sum_{i=1}^n \left((\mu_{X_i} - \mu_{X^*})^2 + (v_{X_i} - v_{X^*})^2 + (\pi_{X_i} - \pi_{X^*})^2 \right)} \quad (21)$$

For SF-NIS:

$$D(X_i, X^-) = \sqrt{\frac{1}{2n} \sum_{i=1}^n \left((\mu_{X_i} - \mu_{X^-})^2 + (v_{X_i} - v_{X^-})^2 + (\pi_{X_i} - \pi_{X^-})^2 \right)} \quad (22)$$

Step 9: Maximum distance between SF-NIS and Alternative Set and minimum distance between SF-PIS and Alternative Set must be determined by using Equations 23 and 24 (Kutlu Gündoğdu & Kahraman, 2019).

$$D_{max}(X_i, X^-) = \max_{1 \leq i \leq m} D(X_i, X^-) \quad (23)$$

$$D_{min}(X_i, X^*) = \min_{1 \leq i \leq m} D(X_i, X^*) \quad (24)$$

Step 10: Calculation of the revised closeness ratio can be done using Equations 23 and 24 (Zhang & Xu, 2014). However, Gündoğdu and Kahraman modified revised closeness ratio equation to address the issue of obtaining zero or negative outcomes. The modified equation, referred to as Equation 25, allows for the possibility of obtaining a zero or positive outcome by adjusting the elements on both sides of the minus sign (Kutlu Gündoğdu & Kahraman, 2019).

$$\xi(X_i) = \frac{D(X_i, X^*)}{D_{min}(X_i, X^*)} - \frac{D(X_i, X^-)}{D_{max}(X_i, X^-)} \quad (25)$$

Step 11: To identify the optimal alternative, relative closeness ratio that is stated above will be used. Ranking will be done according to increasing order to the relative closeness ratio. The alternative with the smallest ratio value will be the best one (Kutlu Gündoğdu & Kahraman, 2019).



5. EVALUATION MODEL

In this section, the other key elements of this study which are main and sub-criteria will be shown in detail. To determine the best supplier, professionals used the fiscal criteria group as the most important one for the vast majority of the time (Vasiljevic, et al., 2018). That was the regular supplier selection methodology. Nowadays, sustainable supplier selection demands fiscal, environmental and social criteria to be taken into account when making a selection of a supplier. The reason behind taking them all into account is to enable the organizations' long-term business sustainability and maintain their position in a highly competitive market (Sen, et al., 2018). In this research, all of these three criteria are used and they are defined in the following section.

5.1.1. Fiscal Criteria

The first criteria group is fiscal criteria which can also be called economic or cost criteria. The main object of this criterion is to keep it as low as possible while not diminishing the capability of doing necessary work. By reducing these costs, which can be done by selecting suitable suppliers, companies can have a competitive advantage against their rivals to keep or develop their position in the market (Ghodsypour & O'Brien, 2001).

The fiscal criteria have been subdivided into five distinct sub-criteria to conduct a comprehensive analysis. To ensure clarity and avoid potential ambiguity, each sub-criterion has been assigned a unique code, as presented in Table 5.1. The overarching fiscal criterion has been designated with the code "FC0" to provide a concise and standardized reference throughout the study.

Table 5.1. Fiscal Sub-Criteria's and Their Codes

Sub-Criteria Code	Name of the Sub-Criteria
FC01	Logistics Expenses
FC02	Financial Stability
FC03	Daily Delivery Capacity
FC04	Infrastructure Expenses
FC05	Maintenance Expenses of Infrastructure

5.1.1.1. Logistics Expenses

The primary sub-criterion within the fiscal criteria category is identified as FC01, specifically referring to Logistics Expenses. This particular sub-criterion holds substantial significance within the broader fiscal group, primarily attributed to the extensive scope of logistics, particularly in the context of larger companies being investigated in this research. Logistics encompasses a multitude of sub-branches, thus making it an encompassing sub-criterion within the fiscal group. Its multifaceted nature and wide-ranging interpretations contribute to the comprehensive understanding and assessment of logistics within the context of this study.

Initially coined by military officials, the term "logistics" has acquired a more comprehensive definition with the rapid growth of industrialization and globalization. It now represents a professional concept known as a crucial component of supply chain management. Logistics can be described as the discipline concerned with the strategic

planning, execution, and supervision of the smooth and efficient flow of goods, services, and associated information in both forward and reverse directions, from the point of origin to the point of consumption, aiming to fulfill customer demands effectively and efficiently (Council of Supply Chain Management Professionals, 2014).

In this study, the assessment of Logistics Expenses encompasses resource acquisition costs, product distribution costs, and notably, regasification costs, which are unique to this research. These costs are examined collectively as part of the Logistics Expenses category. However, it is important to note that the costs associated with the import and customs clearance of the supplied product, specifically LNG in this case, are not considered within this sub-criterion. This exclusion is due to the fact that these costs are applicable to all suppliers, as highlighted in the previous sections. The focus here is on the specific expenses directly related to logistics within the region of interest.

Additionally, it is crucial to analyze the resource acquisition costs within the context of logistics expenses, as these costs encompass the procurement and sourcing of necessary resources for the operations. Product distribution costs play a significant role in logistics, as they involve the transportation and delivery of goods to various destinations. The inclusion of regasification costs in this research is of particular importance, as it pertains to the specialized process of converting LNG back into its gaseous form.

Although the supplied product, LNG, is not domestically available in the subject region of Turkey, it is imported from foreign countries and subsequently delivered within the region. However, it is worth noting that the expenses associated with the import and customs clearance process are not considered as part of this specific sub-criterion. These costs are typically applicable to all suppliers and are not specific to the logistics expenses associated with a particular supplier.

By focusing on the distinct logistics expenses related to resource acquisition, product distribution, and regasification, this research aims to provide a comprehensive evaluation of the fiscal criteria within the context of sustainable supplier selection.

5.1.1.2. Financial Stability

The second sub-criterion falling under the Fiscal category is denoted as Financial Stability, assigned the code FC02. This criterion holds particular significance within the context of this research, as the magnitude of the supply involved is of an exceptionally large scale, rendering not all regional suppliers capable of meeting the required capacity. While financial stability is a widely applicable concept encompassing various economic systems such as companies, enterprises, and governments, a universal definition suffices for our research. Financial stability refers to a monetary system's capacity to effectively support and enhance economic processes, manage risks, and absorb shocks. It is important to note that financial stability is a dynamic concept, subject to change over time and adaptable to different configurations of fundamental financial components (Schinasi, 2004).

Additionally, financial stability plays a crucial role in establishing long-term partnerships with suppliers, as it ensures a reliable and consistent supply chain. Therefore, evaluating the financial stability of suppliers is an essential aspect of sustainable supplier selection, contributing to the overall resilience and effectiveness of the supply chain management process. Through this research, the aim is to identify suppliers with a solid financial footing capable of meeting the demands and challenges of the supply operation at hand.

As previously mentioned, the primary focus of this research pertains to the supply operation conducted on a considerable scale. Hence, it is imperative for all the alternative suppliers under investigation to effectively handle this substantial workload, necessitating the presence of a financially secure operation.

5.1.1.3. Daily Delivery Capacity

This particular sub-criterion, denoted as FC03, holds unique significance within the context of this research. Unlike most literature on supply chain management discussed in the literature review section, this criterion is often not explicitly considered. Typically, it is encompassed within the broader categories of delivery quality or delivery time. The existing literature highlights the importance for businesses to establish an efficient supply chain, collaborating with suppliers capable of meeting their demands in terms of timing, location, conditions, and service, thereby satisfying the customer-driven market dynamics (Wisner et al., 2022).

Nonetheless, within the scope of this research, the delivery quantity assumes a critical dimension. As elucidated, LNG suppliers with specific carrying capacities rely on truck transportation for domestic product distribution. Simultaneously, an uninterrupted power supply is imperative for the smooth operation of factories, with LNG serving as the primary energy source. Consequently, this criterion encompasses evaluating the number of transport vehicles at the disposal of each supplier, as it directly impacts their ability to meet the required delivery quantities. Given the finite capacity of transport vehicles, the number of available vehicles directly influences the supplier's capability to deliver the required quantities of LNG to meet the factory's demand. A sufficient fleet of transport vehicles is crucial to ensure uninterrupted supply, minimize potential disruptions, and maintain the operational efficiency of the recipient facility.

By incorporating this criterion into the sustainable supplier selection process, the research aims to identify suppliers equipped with an adequate number of transport vehicles to meet the delivery quantity requirements effectively. This comprehensive evaluation ensures that suppliers possess the necessary logistical capabilities to fulfill the demands of the recipient facility, promoting a reliable and efficient supply chain for the continuous provision of LNG as a vital energy source.

5.1.1.4. Infrastructure Expenses

The fourth criterion within the fiscal criteria section is denoted as FC04 and pertains to infrastructure expenses. This criterion holds significance within the research due to the specialized requirements associated with the loading, storing, and handling of the supply product, as elaborated in prior sections. Notably, this criterion serves as a distinguishing factor in this case study, as all suppliers can provide the requisite infrastructures, which must be constructed within the facility, albeit at varying timeframes and cost levels.

In infrastructure quality, standardization of LNG handling infrastructure types ensures consistent infrastructure quality among all suppliers. This standardization brings all suppliers to an equivalent grade in terms of infrastructure quality, thereby facilitating fair and objective comparisons in the evaluation process. Including infrastructure expenses as a distinct criterion contributes to the comprehensive assessment of suppliers, considering their ability to provide the necessary infrastructure components for efficient and secure handling of LNG within the facility.

Moreover, evaluating infrastructure expenses provides insights into the suppliers' long-term planning and commitment to infrastructure development. Suppliers capable of delivering the required infrastructure components demonstrate a proactive approach to meeting the facility's specific needs. This criterion serves as a vital determinant in selecting suppliers who can effectively support the facility's operations and contribute to the overall success of the supply chain management process.

5.1.1.5. Maintenance Expenses of Infrastructure

The fifth sub-criterion within the Fiscal Criteria category is identified as FC05 and focuses on the maintenance expenses associated with infrastructure. While this sub-criterion is connected to infrastructure expenses, it possesses unique characteristics that differentiate it from others in this case study. Suppliers adopt diverse approaches towards

this aspect, emphasizing the importance of self-assumed maintenance responsibilities to ensure reliable performance and mitigate unforeseen mechanical failures for customers. This strategic choice is driven by suppliers' delivery capacities, which are carefully aligned with predetermined order quantities. Any infrastructure breakdown could disrupt suppliers' and customers' operational plans, underscoring the significance of evaluating the maintenance costs incurred by suppliers for their provided infrastructures (AYGAZ, 2021).

In this case study, the evaluation of maintenance expenses allows for a comprehensive assessment of suppliers' commitment to infrastructure upkeep. By considering the costs associated with maintenance, the study aims to identify suppliers who prioritize proactive maintenance practices and allocate adequate resources to ensure the uninterrupted functioning of the infrastructure. This criterion provides valuable insights into the suppliers' dedication to providing reliable and well-maintained infrastructure, which is crucial for the seamless flow of operations in the supply chain.

5.1.2. Environmental Criteria

The environmental criteria, denoted as EC0, constitute this study's second group of criteria. Its primary objective is to evaluate the environmental implications arising from both the operation itself and the actions of the suppliers, aiming to minimize their adverse effects by selecting suitable suppliers. Companies can cultivate an environmentally responsible image through this approach, enhance their reputation, and bolster their operational capabilities among discerning customers. Consequently, this fosters a competitive advantage within the market, enabling companies to thrive while prioritizing sustainable practices (Morelli, 2011).

By considering suppliers' environmental performance, companies can contribute to preserving natural resources, mitigating pollution, and promoting a greener supply chain. This comprehensive approach takes care of the current environmental issues while laying

the groundwork for long-term resilience and sustainable development amid changing consumer demands and environmental legislation.

To examine in detail, environmental criteria have been divided into five sub-criteria, and to prevent any confusion, all of them are assigned codes, which are given in Table 5.2.

Table 5.2. Environmental Sub-Criteria's and Their Codes

Sub-Criteria Code	Name of the Sub-Criteria
EC01	Proximity to Supplier's Depot to Companies' Facilities
EC02	Zero Waste Goals
EC03	Carbon Emissions
EC04	Share of Renewable Energy in Total Consumption
EC05	Impact on Biodiversity

5.1.2.1. Proximity to Supplier's Depot to Companies' Facilities

The initial sub-criterion within the environmental criteria domain is the Proximity of the Supplier's Depot to the Companies' Facilities, denoted as EC01. While this sub-criterion could have been categorized as a logistics expense under the fiscal criteria section, this study specifically focuses on the environmental implications arising from a distance between suppliers' and companies' facilities. As discussed in the section on Daily Delivery Capacity, suppliers rely on trucks to transport LNG to their customers. Consequently, a significant concern emerges in terms of emissions. By minimizing this distance, the emissions resulting from highway transport can be effectively reduced. It is worth noting that with the rapid advancements in electric-powered truck manufacturing, researchers anticipate that this criterion may become obsolete in future studies.

By considering the environmental impact of the supplier's depot location, companies can demonstrate their commitment to environmental responsibility and contribute to mitigating the adverse effects of transportation-related emissions. This enhances their reputation among environmentally conscious customers and positions them as leaders in sustainable supply chain management practices.

5.1.2.2. Zero Waste Goals

The second sub-criterion within the environmental criteria is termed Zero Waste Goals, denoted by the code EC02, which is distinctive to this particular research. While the literature review primarily addresses the concept of pollution control, the notion of zero waste goals emerges as a novel perspective. While pollution control aims to minimize pollutants, zero waste goals strive to eliminate them entirely, representing an elevated and ultimate approach. This concept embraces sustainable production and consumption practices, prioritizes recycling and resource recovery, and restricts mass incineration and landfilling. The zero-waste concept has garnered legislative support due to its potential to foster environmental sustainability (Zaman, 2015).

Furthermore, zero waste goals promote the efficient utilization of resources, minimizing the depletion of natural reserves and reducing the overall environmental footprint. By implementing a zero-waste strategy, businesses may improve their environmental performance and show stakeholders and consumers that they are committed to sustainability. This sub-criterion assesses how suppliers, including waste reduction plans, recycling programs, and the use of circular economy activities, correspond with zero waste principles in their operations. Achieving zero waste targets promotes innovation and the creation of sustainable business models, in addition to helping to create a cleaner and healthier environment. As environmental concerns continue to gain significance, incorporating zero waste goals into supplier selection processes becomes crucial for organizations aiming to create a greener and more sustainable supply chain.

In this study, suppliers will be evaluated by their zero waste commitment, which is obtained from their evaluation by independent evaluators.

5.1.2.3. Carbon Emissions

The third sub-criterion within the environmental criteria category is Carbon Emissions, denoted by the code EC03. Since natural gas burning produces non-toxic gases, setting it apart from traditional fossil fuels, using LNG as an energy source provides a workable solution for reducing carbon emissions. Nevertheless, liquefaction, regasification, transportation, odorization, and power consumption within suppliers' facilities generate carbon emissions. This sub-criterion evaluates the extent of carbon emissions resulting from these stages of the LNG supply chain. Organizations can advance their environmental sustainability objectives by assessing and minimizing carbon emissions and aligning with global efforts to mitigate climate change (AYGAZ, 2021).

Integrating carbon emissions as a sub-criterion in the supplier selection process enables companies to prioritize suppliers who actively work towards minimizing their environmental impact. This demonstrates a commitment to ecological responsibility and enhances the company's reputation and competitiveness in an increasingly eco-conscious market. Additionally, adopting cleaner and more energy-efficient technologies, such as renewable energy sources and low-carbon transportation methods, can reduce carbon emissions throughout the supply chain.

This sub-criterion evaluates the total emission amount of suppliers in one calendar year and tries to minimize its impact on the environment.

5.1.2.4.Share of Renewable Energy in Total Consumption

The fourth sub-criterion within the environmental criteria category is the Proportion of Renewable Energy in Total Consumption, denoted by the code EC04. This particular sub-criterion pertains to the power sources utilized by suppliers and their impact on carbon emissions. However, the objective of this sub-criterion is not to minimize the quantity of energy consumed but to maximize the use of renewable energy sources to determine which supplier incorporates sustainable energy practices. This approach aligns with the overarching goal of this study, which is to identify the most environmentally sustainable supplier. A higher proportion of suppliers' renewable energy utilization signifies their commitment to sustainability principles (Malik, et al., 2016).

Furthermore, adding the Share of Renewable Energy in the Total Consumption sub-criteria recognizes the importance of switching to clean and renewable energy sources. This research intends to promote the worldwide transition toward a more sustainable and carbon-neutral future by encouraging suppliers to embrace and grow their reliance on renewable energy. In addition to reducing greenhouse gas emissions, using renewable energy promotes energy independence, diversification, and a reduction in dependency on fossil fuels. In addition, evaluating the proportion of renewable energy in overall consumption offers insightful information about suppliers' environmental consciousness and long-term sustainability objectives, enabling well-versed supplier selection decisions.

5.1.2.5.Impact on Biodiversity

The concluding sub-criterion, denoted as EC05, pertains to the influence of suppliers on biodiversity. Its principal objective is to mitigate the adverse effects of suppliers on biodiversity. While previous research often encompasses biodiversity impact within the context of pollution control or eco-design, this study seeks to appraise reports compiled by impartial evaluators regarding the suppliers' ecological footprint on biodiversity.

Such evaluations encompass the extent to which suppliers consider the environmental repercussions of their investment choices, the degree to which their operations disrupt the local ecosystem, and their contributions to conserving regional biodiversity (Puska, et al., 2021).

Furthermore, evaluating suppliers' impact on biodiversity extends beyond merely assessing their compliance with environmental regulations. It delves into a deeper understanding of how their business practices align with conservation efforts and sustainable development goals. This sub-criterion highlights the significance of suppliers' commitment to biodiversity preservation, emphasizing the need for proactive measures and responsible decision-making in their operations. By incorporating this criterion, the study aims to promote greater awareness and accountability among suppliers regarding preserving biodiversity and ecological balance. Through rigorous evaluation and analysis, the research identifies suppliers who demonstrate a genuine commitment to sustainable practices and contribute positively to biodiversity protection.

5.1.3. Social Criteria

The third and ultimate group of criteria is denoted as Social Criteria, identified by the code SC0. The primary focus of this criteria group is to identify the supplier that strongly emphasizes human-centered practices, encompassing both customer relations and internal company dynamics. Existing research extensively incorporates stakeholders within the framework of social sustainability criteria, as companies are obliged to address activities that have the potential to impact their corporate image and value (Mani, et al., 2014). However, it is essential to note that this research does not consider stakeholders, as it explicitly examines a customer's perspective without any direct connection to the supplier's stakeholders. Nonetheless, it should be acknowledged that this study indirectly impacts stakeholders, as it demonstrates the significance of social sustainability as a valued criterion among prominent enterprises, including the one under investigation.

The social criteria have been subdivided into five distinct sub-criteria to conduct a comprehensive analysis. Each sub-criterion has been assigned unique codes to ensure clarity and avoid potential ambiguity, as outlined in Table 5.3.

Table 5.3. Social Sub-Criteria's and Their Codes

Sub-Criteria Code	Name of the Sub-Criteria
SC01	Customer Service
SC02	Past Experience
SC03	Company Image
SC04	Diversity Among Employees
SC05	Health and Safety Regulations

5.1.3.1. Customer Service

Within the framework of the social criteria, the initial sub-criterion to be examined is Customer Service, denoted by the code SC01. Previous studies in the literature have primarily focused on evaluating customer satisfaction and happiness through interviews and questionnaires. These assessments provide insights into the performance of both individuals and organizations (Hussain, et al., 2018). However, for the purpose of this specific research, experts' opinions have guided the selection of this sub-criterion.

It is important to note that, in this study, Customer Service goes beyond the conventional notion of post-purchase assistance. Rather, it encompasses the provision of professional engineering solutions by suppliers when customers encounter specific needs. This can involve the deployment of engineering expertise in response to infrastructure failures or troubleshooting issues related to the utilization of LNG. By broadening the scope of this sub-criterion, a more comprehensive assessment of suppliers' capabilities in addressing customer requirements can be achieved.

5.1.3.2.Past Experience

The second sub-criterion within the social criteria is Past Experience, identified by the code SC02. This particular sub-criterion can be approached from two distinct perspectives.

The first approach involves assessing suppliers' competence in the relevant field by considering their previous work. It has been observed that companies become more competitive through their experience in the field. To evaluate this aspect, the Past Experience criterion considers the volume and scale of the work undertaken by the company. This includes considering whether the company has been involved in large-scale projects requiring significant manpower and resources or smaller-scale endeavors that can be managed by most suppliers operating in the same domain.

By examining the past experience of suppliers, valuable insights can be gained regarding their proficiency and ability to handle similar tasks. This sub-criterion is a quantitative measure to gauge the level of expertise accumulated by suppliers over time, contributing to the overall assessment of their capabilities in the given field (Suopajarvi, et al., 2016).

The second approach involves considering customers' previous experiences working with the supplier. This aspect considers the insights and opinions of experts such as procurement professionals and senior-level management associates. These individuals are crucial in evaluating their past working relationships with suppliers. Factors such as their professional backgrounds, extensive networks, and the company's overarching approach to supplier relations can all contribute to a contagion effect that shapes the nature of the actual supplier interactions.

By incorporating the perspectives of these experts, a comprehensive assessment of the supplier's track record in terms of customer satisfaction and relationship management can

be achieved. This sub-criterion provides qualitative insights into the supplier's ability to foster positive and enduring partnerships with customers, highlighting the significance of past experiences in shaping current and future business dynamics (Kamann & Bakker, 2004).

In the context of this research, the adopted interpretation of the past experience concept pertains specifically to the expertise and knowledge gained by professionals through their prior interactions with suppliers. This definition focuses on the firsthand experiences and insights garnered from past business engagements. By emphasizing the professionals' familiarity with suppliers based on their previous collaborations, this study prioritizes the significance of practical encounters and the valuable lessons learned from them.

5.1.3.3. Company Image

The third sub-criterion within the social criteria domain is Company Image, denoted by the code SC03. In the existing literature, alternative terms such as reputation or credibility are employed to describe this aspect. Company Image is closely connected to the preceding sub-criterion, Past Experience, but focuses on the overall perception of the supplier company by the general public.

Company Image, also referred to as company reputation, can be defined as the perceptual representation of a company's overall appeal in relation to its key stakeholders when compared to other prominent competitors. It encompasses the collective impressions and evaluations formed by various stakeholders regarding the company's standing and desirability (Fombrun, 1996).

In this research, the assessment of company image is based on the perspectives of industry professionals rather than the general public. This approach is adopted because the suppliers under investigation primarily cater to large-scale industrial operations and do

not directly serve the public. Therefore, the evaluation of company image relies on the insights and judgments provided by experts within the relevant field.

5.1.3.4. Diversity Among Employees

The fourth sub-criterion within the social criteria framework is labeled as Diversity Among Employees, denoted by the code SC04. The concept of diversity in this context pertains to the gender composition within the workforce and is examined in relation to employee rights and inclusivity (Marzouk & Sabbah, 2021).

While most studies primarily consider the gender ratio when referring to the term "diversity among employees", this research adopts a broader perspective by incorporating additional dimensions within the definition of this concept. In addition to gender, this study expands the scope to include ethnicity and religious background as analysis factors. The diversity assessment is conducted by professionals who have collaborated with the suppliers under consideration as alternative options in this study.

5.1.3.5. Health and Safety Regulations

The final sub-criterion within the social criteria domain is Health and Safety Regulations, designated by the code SC05. This specific sub-criterion holds considerable significance within research investigations about social sustainability criteria. It encompasses the comprehensive implementation of measures and protocols to ensure the preservation of employee health and well-being, primarily focusing on their protection and enhancement of overall quality of life (Stevic, et al., 2020).

In this research, the decision-makers analyze quantitative metrics and the company's commitment to established regulations. The evaluation encompasses the company's conformity to global health and safety standards and the presence of compulsory and

voluntary certifications in this domain. Additionally, the occurrence of accidents and occupational hazards encountered by the company in the preceding calendar year is also considered in the assessment.

5.2. Defining Demographics of Experts

As it is stated in the previous sections, criteria weights, which will be decided by their relative importance, must be calculated before beginning to use SF-TOPSIS Method. In order to do that, twenty experts, picked from relative department of the same company, are selected and to be subjected to a survey to gather their opinions. They have selected based on their job description. Their demographic information is given in Table 5.4. The survey was conducted during the period from December 20th, 2022 to February 15th, 2023. All of the experts were informed about the research and given necessary information about the model. After that they were tasked to determine the interdependencies of fifteen total sub criteria and three main criteria as they are explained above.

Table 5.4. Demographic Information of Experts

Demographic Information		Frequency	Percentage
Age	25-31	2	20
	32-38	3	30
	39-45	3	30
	45+	2	20
Education	Bachelor	4	40
	Master's	4	40
	PhD	2	20
Experience in Relative Field	1-3 years	2	20
	3-10 years	3	30
	10+ years	5	50

The selected panel of experts comprises ten individuals exclusively employed in a single company's Supply Chain department.

The age range of the experts spans from 25 to 52 years, encompassing a diverse spectrum of experience. Notably, the age group of 32 to 45 represents the majority, accounting for 60 percent of the experts.

Regarding their educational background, 40 percent of the experts hold a Bachelor's Degree in fields directly related to the supply chain discipline. Merely 20 percent of the experts possess the highest attainable level of education, which is a Ph.D.

Regarding professional experience in the relevant field, nearly all expert group members have accrued a minimum of 3 years of practical involvement. Only 20 percent of the professionals have expertise of less than three years. It is significant to emphasize that to qualify as an expert, each participant must have at least one year of relevant experience, and all members satisfy this requirement.

5.3. Weights of Decision Makers

As discussed in the section above, the decision-makers who participated in this study had various backgrounds and expertise that impacted their decision-making abilities. People with substantial education and experience hold critical positions within the hierarchical structure within the professional environment surrounding the manufacturer firm under evaluation in this case study. Therefore, they must participate in the decision-making processes. These experts have been given certain weights to consider their importance; these weights were chosen based on their contributions to the allocation mechanism. Table 5.5 presents these allocated weights and indicates their respective relevance.

Table 5.5. Weights of Decision Makers

DM's	DM1	DM2	DM3	DM4	DM5
Weight	0,220	0,220	0,120	0,120	0,120
DM's	DM6	DM7	DM8	DM9	DM10
Weight	0,080	0,040	0,040	0,020	0,020

5.4.Characteristics of Predetermined Suppliers

For the purposes of this research, three distinct suppliers were selected for evaluation based on the predetermined criteria outlined in the preceding section. In order to maintain confidentiality, the specific names of these suppliers have not been disclosed. However, to provide a contextual understanding of these suppliers, their fundamental characteristics have been presented in Table 5.6. To avoid any potential ambiguity, each supplier has been assigned a unique code, which is also indicated in Table 5.6.

Table 5.6. Basic Characteristics of Predetermined Suppliers

Suppliers' Codes	Basic Characteristics		
	Foundation (Date)	Operation	Known Attribute
SP1	1961	Works under highly respected holding company.	Known by their experience in energy providing
SP2	1960's	Recently acquired by highly respected holding company.	Known by their competitiveness in alternative fuel market
SP3	1993	Operating locally and has many service facilities	Known by their flexibility in price and delivery options.

6. APPLICATION OF THE PROBLEM and RESULTS

To begin the process of determining the positive and negative ideal distances, it is necessary to evaluate and assign weights to the criteria and sub-criteria. Initially, decision makers provide their evaluations of the main criteria in linguistic form, which are then compiled and presented in Table 6.1. The linguistic parameters and their corresponding spherical fuzzy values are defined in Table 4.4. Using the SWAM operator, as described in Equation 10, the spherical fuzzy equivalents of the linguistic evaluations are calculated based on the weights assigned by the decision makers, which are provided in Table 5.5. The resulting spherical fuzzy evaluations are then shared in Table 6.2.

Table 6.1. Evaluations of DM's in Linguistic Variable Form

	In Linguistic Variables									
Criteria	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10
FS0	MI	I	I	MI	SI	EI	EI	I	AI	EI
ES0	I	MI	SI	I	EI	SU	SU	EI	STU	EI
SS0	SI	EI	SI	SI	EI	U	U	I	AU	SI

Table 6.2. Evaluations of DM's in Spherical Fuzzy Form by Using SWAM Operator

	SF Format		
Criteria	μ	ν	π
FS0	0,720	0,284	0,300
ES0	0,664	0,345	0,336
SS0	0,544	0,464	0,425

After obtaining spherical fuzzy equivalents of DM's judgements of weights of the main criteria, DMs are tasked to evaluate sub-criteria in order to determine their weights by using SWAM operator which is given in Equation 10. Evaluation of sub-criteria for weight calculation is given in the following Table 6.3.

Table 6.3. Evaluation of Sub-Criteria in Linguistic Form

Criteria	In Linguistic Variables									
	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10
FS01	MI	MI	I	I	SI	I	I	I	MI	SI
FS02	I	SI	SI	I	SI	I	I	I	MI	SI
FS03	AI	MI	I	I	I	EI	SI	I	AI	EI
FS04	EI	EI	I	SI	SI	EI	EI	SI	I	EI
FS05	AU	STU	SI	U	U	U	STU	U	EI	U
ES01	I	I	I	EI	I	EI	EI	I	EI	I
ES02	EI	EI	EI	I	EI	EI	I	EI	U	SU
ES03	I	I	EI	I	EI	SU	EI	I	SU	SU
ES04	SU	EI	SU	EI	SU	SU	SU	SU	EI	SU
ES05	SU	EI	EI	I	EI	SU	SU	EI	STU	EI
SC01	SU	EI	EI	EI	SU	SU	SU	EI	AU	SU
SC02	MI	AI	I	I	SI	EI	EI	I	I	I
SC03	SI	SI	EI	SI	EI	EI	I	EI	STU	SI
SC04	STU	U	U	EI	SU	STU	U	SU	AU	U
SC05	MI	MI	SI	SI	I	SI	U	EI	EI	SI

DMs' judgements are given in linguistic form, their spherical fuzzy equivalents are shared in the following tables, starting from judgements of DM1-DM2 with Table 6.4. until Table 6.8. which includes judgements of DM9-DM10.

Table 6.4. Judgements of DM1-DM2 for all Sub-Criteria

Sub-Criteria	DM1			DM2		
	μ	ν	π	μ	ν	π
FC01	0,8	0,2	0,2	0,8	0,2	0,2
FC02	0,7	0,3	0,3	0,6	0,4	0,4
FC03	0,9	0,1	0,1	0,8	0,2	0,2
FC04	0,5	0,5	0,5	0,5	0,5	0,5
FC05	0,1	0,9	0,1	0,2	0,8	0,2
EC01	0,7	0,3	0,3	0,7	0,3	0,3
EC02	0,5	0,5	0,5	0,5	0,5	0,5
EC03	0,7	0,3	0,3	0,7	0,3	0,3
EC04	0,4	0,6	0,4	0,5	0,5	0,5
EC05	0,4	0,6	0,4	0,5	0,5	0,5
SC01	0,4	0,6	0,4	0,5	0,5	0,5
SC02	0,8	0,2	0,2	0,9	0,1	0,1
SC03	0,6	0,4	0,4	0,6	0,4	0,4
SC04	0,2	0,8	0,2	0,3	0,7	0,3
SC05	0,8	0,2	0,2	0,8	0,2	0,2

Table 6.5. Judgements of DM3-DM4 for all Sub-Criteria

Sub-Criteria	DM3			DM4		
	μ	ν	π	μ	ν	Π
FC01	0,7	0,3	0,3	0,7	0,3	0,3
FC02	0,6	0,4	0,4	0,7	0,3	0,3
FC03	0,7	0,3	0,3	0,7	0,3	0,3
FC04	0,7	0,3	0,3	0,6	0,4	0,4
FC05	0,6	0,4	0,4	0,3	0,7	0,3
EC01	0,7	0,3	0,3	0,5	0,5	0,5
EC02	0,5	0,5	0,5	0,7	0,3	0,3
EC03	0,5	0,5	0,5	0,7	0,3	0,3
EC04	0,4	0,6	0,4	0,5	0,5	0,5
EC05	0,5	0,5	0,5	0,7	0,3	0,3
SC01	0,5	0,5	0,5	0,5	0,5	0,5
SC02	0,7	0,3	0,3	0,7	0,3	0,3
SC03	0,5	0,5	0,5	0,6	0,4	0,4
SC04	0,3	0,7	0,3	0,5	0,5	0,5
SC05	0,6	0,4	0,4	0,6	0,4	0,4

Table 6.6. Judgements of DM5-DM6 for all Sub-Criteria

Sub-Criteria	DM5			DM6		
	μ	ν	π	μ	ν	π
FC01	0,6	0,4	0,4	0,7	0,3	0,3
FC02	0,6	0,4	0,4	0,7	0,3	0,3
FC03	0,7	0,3	0,3	0,5	0,5	0,5
FC04	0,6	0,4	0,4	0,5	0,5	0,5
FC05	0,3	0,7	0,3	0,3	0,7	0,3
EC01	0,7	0,3	0,3	0,5	0,5	0,5
EC02	0,5	0,5	0,5	0,5	0,5	0,5
EC03	0,5	0,5	0,5	0,4	0,6	0,4
EC04	0,2	0,8	0,2	0,4	0,6	0,4
EC05	0,5	0,5	0,5	0,4	0,6	0,4
SC01	0,2	0,8	0,2	0,4	0,6	0,4
SC02	0,6	0,4	0,4	0,5	0,5	0,5
SC03	0,5	0,5	0,5	0,5	0,5	0,5
SC04	0,2	0,8	0,2	0,2	0,8	0,2
SC05	0,7	0,3	0,3	0,6	0,4	0,4

Table 6.7. Judgements of DM7-DM8 for all Sub-Criteria

Sub-Criteria	DM7			DM8		
	μ	ν	π	μ	ν	Π
FC01	0,7	0,3	0,3	0,7	0,3	0,3
FC02	0,7	0,3	0,3	0,7	0,3	0,3
FC03	0,6	0,4	0,4	0,7	0,3	0,3
FC04	0,5	0,5	0,5	0,6	0,4	0,4
FC05	0,2	0,8	0,2	0,3	0,7	0,3
EC01	0,5	0,5	0,5	0,7	0,3	0,3
EC02	0,7	0,3	0,3	0,5	0,5	0,5
EC03	0,5	0,5	0,5	0,7	0,3	0,3
EC04	0,4	0,6	0,4	0,4	0,6	0,4
EC05	0,4	0,6	0,4	0,5	0,5	0,5
SC01	0,4	0,6	0,4	0,5	0,5	0,5
SC02	0,5	0,5	0,5	0,7	0,3	0,3
SC03	0,7	0,3	0,3	0,5	0,5	0,5
SC04	0,3	0,7	0,3	0,4	0,6	0,4
SC05	0,3	0,7	0,3	0,5	0,5	0,5

Table 6.8. Judgements of DM9-DM10 for all Sub-Criteria

Sub-Criteria	DM9			DM10		
	μ	ν	π	μ	ν	π
FC01	0,8	0,2	0,2	0,6	0,4	0,4
FC02	0,8	0,2	0,2	0,6	0,4	0,4
FC03	0,9	0,1	0,1	0,5	0,5	0,5
FC04	0,7	0,3	0,3	0,5	0,5	0,5
FC05	0,5	0,5	0,5	0,3	0,7	0,3
EC01	0,5	0,5	0,5	0,7	0,3	0,3
EC02	0,3	0,7	0,3	0,4	0,6	0,4
EC03	0,4	0,6	0,4	0,4	0,6	0,4
EC04	0,5	0,5	0,5	0,4	0,6	0,4
EC05	0,2	0,8	0,2	0,5	0,5	0,5
SC01	0,1	0,9	0,1	0,4	0,6	0,4
SC02	0,7	0,3	0,3	0,7	0,3	0,3
SC03	0,2	0,8	0,2	0,6	0,4	0,4
SC04	0,1	0,9	0,1	0,3	0,7	0,3
SC05	0,5	0,5	0,5	0,6	0,4	0,4

After obtaining spherical fuzzy equivalents of DMs' judgements on all sub-criteria, their weights are calculated in spherical fuzzy form by using weights of decision makers' that are given in Table 5.5. and Equation 10, which is defined as SWAM operator. Obtained weights are presented the following Table 6.9.

Table 6.9. Weights of Sub-Criteria by SWAM Operator

Sub-Criteria	Weights		
	μ	ν	π
FC01	0,743	0,259	0,266
FC02	0,660	0,342	0,346
FC03	0,780	0,224	0,246
FC04	0,566	0,437	0,444
FC05	0,320	0,711	0,286
EC01	0,660	0,343	0,353
EC02	0,539	0,466	0,464
EC03	0,630	0,376	0,369
EC04	0,425	0,582	0,434
EC05	0,502	0,505	0,445
SC01	0,437	0,572	0,447
SC02	0,769	0,237	0,262
SC03	0,568	0,434	0,431
SC04	0,303	0,710	0,316
SC05	0,711	0,295	0,301

Prior to constructing the decision matrix, it is essential to calculate the global weights for the sub-criteria. This can be achieved by applying Equation 16, which involves simple spherical fuzzy multiplication. The data provided in Table 6.2 is multiplied by the corresponding data from Table 6.9, resulting in the determination of the global weights for the sub-criteria. These global weights are then presented in Table 6.10.

Table 6.10. Global Weights of Sub-Criteria

Sub-Criteria	Global Weight		
	μ	ν	π
FC01	0,53	0,38	0,38
FC02	0,47	0,43	0,42
FC03	0,56	0,36	0,37
FC04	0,41	0,51	0,49
FC05	0,23	0,74	0,33
EC01	0,44	0,47	0,44
EC02	0,36	0,56	0,50
EC03	0,42	0,49	0,45
EC04	0,28	0,65	0,47
EC05	0,33	0,59	0,49
SC01	0,24	0,69	0,49
SC02	0,42	0,51	0,46
SC03	0,31	0,60	0,51
SC04	0,16	0,78	0,39
SC05	0,39	0,53	0,47

After obtaining global weights of sub-criteria, judgements about alternatives and sub-criteria must be done by decision makers.

DM's judgements of alternatives and sub-criteria are given in linguistic form which is presented in three separate tables. At first, alternative evaluation by using fiscal sub-criteria are presented in Table 6.11.

Table 6.11. Alternate Evaluation by Using Fiscal Sub-Criteria

Alternatives	FS01	FS02	FS03	FS04	FS05	Decision Maker
S1	MI	I	AI	I	AU	DM1
S2	I	I	MI	EI	U	
S3	EI	SI	AI	EI	STU	
S1	AI	MI	AI	EI	STU	DM2
S2	MI	I	I	EI	STU	
S3	I	EI	EI	EI	U	
S1	MI	EI	MI	I	AU	DM3
S2	I	SI	I	I	AU	
S3	I	MI	EI	SI	AU	
S1	I	I	MI	EI	U	DM4
S2	MI	I	MI	SI	U	
S3	I	I	MI	SI	STU	
S1	SI	MI	I	SI	SU	DM5
S2	EI	I	I	SI	SU	
S3	I	EI	MI	I	EI	
S1	SI	SI	SI	I	SU	DM6
S2	I	SI	EI	SI	U	
S3	I	I	SI	EI	EI	
S1	I	I	MI	EI	EI	DM7
S2	I	MI	I	EI	EI	
S3	I	MI	SI	EI	EI	
S1	MI	I	EI	SI	STU	DM8
S2	I	SI	SI	SI	SU	
S3	MI	I	MI	EI	U	
S1	EI	AI	I	EI	AU	DM9
S2	SI	MI	I	SI	STU	
S3	I	I	MI	SI	U	
S1	MI	AI	MI	EI	AU	DM10
S2	MI	MI	MI	I	U	
S3	MI	I	MI	I	U	

Secondly, alternative evaluation by using environmental sub-criteria are presented in Table 6.12.

Table 6.12. Alternate Evaluation by Using Environmental Sub-Criteria

Alternatives	EC01	EC02	EC03	EC04	EC05	Decision Maker
S1	I	EI	I	EI	U	DM1
S2	I	EI	I	EI	U	
S3	I	I	SI	SU	SU	
S1	EI	EI	I	SU	SU	DM2
S2	I	I	SI	U	U	
S3	EI	I	SI	U	U	
S1	EI	I	EI	U	SU	DM3
S2	EI	SI	SI	U	SU	
S3	I	SI	SI	U	SU	
S1	I	SI	I	SU	EI	DM4
S2	SI	I	I	SU	U	
S3	I	I	I	U	EI	
S1	SI	EI	EI	U	EI	DM5
S2	EI	EI	EI	U	EI	
S3	I	SI	SI	U	EI	
S1	SI	SU	SI	SU	EI	DM6
S2	EI	U	SI	U	SU	
S3	SU	SU	I	SU	SU	
S1	EI	SU	MI	EI	STU	DM7
S2	EI	EI	I	SU	U	
S3	SU	EI	MI	EI	U	
S1	EI	I	SI	EI	STU	DM8
S2	EI	I	EI	U	STU	
S3	SI	SU	SI	U	EI	
S1	SI	SU	EI	U	U	DM9
S2	I	SU	SI	U	U	
S3	SI	SU	SU	EI	STU	
S1	I	EI	SU	SU	AU	DM10
S2	EI	SU	U	EI	U	
S3	SI	U	U	U	AU	

In the final step, the Social Sub-Criteria are considered to evaluate the Alternatives. The evaluation results for the Alternatives are presented in Table 6.13.

Table 6.13. Alternate Evaluation by Using Social Sub-Criteria

Alternatives	SC01	SC02	SC03	SC04	SC05	Decision Maker
S1	EI	I	EI	U	I	DM1
S2	EI	I	EI	U	I	
S3	SI	MI	SI	U	I	
S1	SI	MI	SI	SU	I	DM2
S2	SI	MI	EI	U	MI	
S3	EI	MI	EI	STU	MI	
S1	MI	I	SU	STU	I	DM3
S2	SI	MI	SU	AU	AI	
S3	EI	I	U	STU	MI	
S1	U	AI	U	U	EI	DM4
S2	EI	AI	U	U	EI	
S3	SU	MI	U	SU	SI	
S1	SU	SI	U	STU	SI	DM5
S2	EI	EI	SU	STU	I	
S3	I	SI	STU	AU	SI	
S1	I	SI	EI	AU	SI	DM6
S2	EI	I	U	STU	I	
S3	SU	SI	U	U	MI	
S1	SU	MI	U	U	I	DM7
S2	U	I	EI	EI	MI	
S3	U	SI	SU	SU	MI	
S1	U	SI	STU	SU	I	DM8
S2	U	I	AU	EI	SI	
S3	U	MI	STU	EI	MI	
S1	U	SI	U	SU	SI	DM9
S2	EI	I	EI	EI	EI	
S3	EI	EI	U	STU	EI	
S1	EI	EI	EI	U	EI	DM10
S2	SI	I	STU	U	MI	
S3	SI	I	U	STU	SI	

Decision matrix is constructed by using SWAM operator which is given in Equation 10. Decision matrix is presented in the following Table 6.14. in transpose form and with spherical fuzzy values, as the combination of the data from Table 6.11., Table 6.12. and Table 6.13.

Table 6.14. Decision Matrix by Using SWAM Operator

Sub-Criteria	Alternatives		
	S1 (μ, ν, π)	S2 (μ, ν, π)	S3 (μ, ν, π)
FC01	(0,79, 0,21, 0,23)	(0,73, 0,28, 0,29)	(0,68, 0,33, 0,34)
FC02	(0,73, 0,27, 0,29)	(0,69, 0,31, 0,32)	(0,65, 0,36, 0,37)
FC03	(0,83, 0,17, 0,19)	(0,73, 0,27, 0,28)	(0,76, 0,25, 0,29)
FC04	(0,61, 0,39, 0,40)	(0,58, 0,43, 0,43)	(0,56, 0,44, 0,45)
FC05	(0,26, 0,76, 0,28)	(0,30, 0,72, 0,30)	(0,33, 0,70, 0,35)
EC01	(0,61, 0,40, 0,41)	(0,62, 0,38, 0,40)	(0,63, 0,37, 0,36)
EC02	(0,55, 0,46, 0,46)	(0,59, 0,41, 0,40)	(0,64, 0,37, 0,35)
EC03	(0,65, 0,35, 0,36)	(0,63, 0,38, 0,38)	(0,63, 0,37, 0,37)
EC04	(0,41, 0,59, 0,42)	(0,38, 0,63, 0,39)	(0,35, 0,66, 0,35)
EC05	(0,40, 0,61, 0,41)	(0,35, 0,66, 0,36)	(0,41, 0,60, 0,41)
SC01	(0,57, 0,45, 0,38)	(0,53, 0,47, 0,45)	(0,53, 0,47, 0,42)
SC02	(0,75, 0,26, 0,27)	(0,76, 0,24, 0,26)	(0,75, 0,25, 0,27)
SC03	(0,46, 0,55, 0,57)	(0,43, 0,58, 0,60)	(0,43, 0,58, 0,62)
SC04	(0,30, 0,71, 0,73)	(0,30, 0,72, 0,74)	(0,28, 0,73, 0,75)
SC05	(0,66, 0,34, 0,35)	(0,75, 0,26, 0,27)	(0,74, 0,27, 0,28)

The next step in the SF-TOPSIS method involves calculating the Weighted Decision Matrix. To do this, the previously obtained decision matrix is multiplied by the Global Weight data, as shown in Table 6.12. This calculation is performed using the SWAM Operator, as presented in Equation 10. The resulting weighted Decision Matrix is calculated and displayed in Table 6.15.

Table 6.15. Weighted Decision Matrix Based on SWAM Operator

Sub-Criteria	Alternatives (μ, v, π)		
	S1	S2	S3
FC01	(0,42, 0,43, 0,42)	(0,39, 0,46, 0,44)	(0,36, 0,48, 0,46)
FC02	(0,35, 0,50, 0,47)	(0,33, 0,52, 0,47)	(0,31, 0,54, 0,49)
FC03	(0,47, 0,39, 0,40)	(0,41, 0,44, 0,43)	(0,43, 0,43, 0,43)
FC04	(0,25, 0,61, 0,53)	(0,23, 0,63, 0,54)	(0,23, 0,63, 0,54)
FC05	(0,06, 0,90, 0,27)	(0,07, 0,88, 0,29)	(0,08, 0,88, 0,31)
EC01	(0,27, 0,59, 0,51)	(0,27, 0,58, 0,51)	(0,28, 0,58, 0,50)
EC02	(0,20, 0,68, 0,54)	(0,21, 0,65, 0,53)	(0,23, 0,64, 0,52)
EC03	(0,27, 0,58, 0,50)	(0,26, 0,59, 0,50)	(0,26, 0,59, 0,50)
EC04	(0,12, 0,79, 0,46)	(0,11, 0,81, 0,43)	(0,10, 0,82, 0,41)
EC05	(0,13, 0,76, 0,47)	(0,12, 0,79, 0,43)	(0,14, 0,76, 0,47)
SC01	(0,13, 0,76, 0,49)	(0,13, 0,77, 0,50)	(0,13, 0,77, 0,49)
SC02	(0,31, 0,56, 0,49)	(0,32, 0,55, 0,49)	(0,31, 0,55, 0,49)
SC03	(0,14, 0,74, 0,50)	(0,13, 0,76, 0,50)	(0,13, 0,76, 0,48)
SC04	(0,05, 0,90, 0,31)	(0,5, 0,90, 0,31)	(0,05, 0,90, 0,30)
SC05	(0,25, 0,61, 0,50)	(0,29, 0,57, 0,49)	(0,28, 0,58, 0,49)

In the subsequent stage of the SF-TOPSIS method, score functions need to be computed using the data from the Weighted Decision Matrix, as shown in Table 6.15. Score functions are solely calculated to determine SF-PIS and SF-NIS values, and they will not be utilized for any other purpose. The calculation of score functions is carried out using Equation 18. The resulting score function data is presented in Table 6.16.

Table 6.16. Score Functions Based on SWAM Operator

Sub-Criteria	Alternatives		
	S1	S2	S3
FC01	0,356	0,254	0,178
FC02	0,143	0,097	0,051
FC03	0,508	0,319	0,358
FC04	-0,062	-0,088	-0,095
FC05	-0,585	-0,542	-0,516
EC01	-0,033	-0,023	-0,013
EC02	-0,150	-0,127	-0,102
EC03	-0,024	-0,041	-0,041
EC04	-0,314	-0,347	-0,372
EC05	-0,279	-0,329	-0,276
SC01	-0,267	-0,270	-0,274
SC02	0,048	0,060	0,049
SC03	-0,245	-0,260	-0,273
SC04	-0,545	-0,553	-0,566
SC05	-0,059	0,003	-0,006

Once the Score Function values have been obtained, the next step is to calculate the SF-PIS and SF-NIS values. SF-PIS can be calculated using Equation 19 with the Score Function data provided in Table 6.16. SF-PIS represents the highest-scored values in the weighted decision matrix, which is also presented in Table 6.15. On the other hand, SF-NIS values correspond to the lowest-scored equivalents in the same data set and can be calculated using Equation 20. The SF-PIS and SF-NIS values are displayed in Table 6.17. Instead of X notation, letter S is used.

Table 6.17. SF-PIS and SF-NIS Values

	FC01			FC02			FC03		
	μ	ν	π	μ	ν	π	μ	ν	π
S^*	0,42	0,43	0,42	0,35	0,50	0,47	0,47	0,39	0,40
S^-	0,36	0,48	0,46	0,31	0,54	0,49	0,41	0,44	0,43
	FC04			FC05			EC01		
	μ	ν	π	μ	ν	π	μ	ν	π
S^*	0,25	0,61	0,53	0,08	0,88	0,31	0,28	0,58	0,50
S^-	0,23	0,63	0,54	0,06	0,90	0,27	0,27	0,59	0,51
	EC02			EC03			EC04		
	μ	ν	π	μ	ν	π	μ	ν	π
S^*	0,23	0,64	0,52	0,27	0,58	0,50	0,12	0,79	0,46
S^-	0,20	0,68	0,54	0,26	0,59	0,50	0,10	0,82	0,41
	EC05			SC01			SC02		
	μ	ν	π	μ	ν	π	μ	ν	π
S^*	0,14	0,76	0,47	0,13	0,76	0,49	0,32	0,55	0,49
S^-	0,12	0,79	0,43	0,13	0,77	0,50	0,31	0,56	0,49
	SC03			SC04			SC05		
	μ	ν	Π	μ	ν	π	μ	ν	π
S^*	0,14	0,74	0,50	0,05	0,90	0,31	0,29	0,57	0,49
S^-	0,13	0,76	0,50	0,05	0,90	0,30	0,25	0,61	0,50

Once the Positive and Negative Ideal Solutions have been determined, the next step involves calculating the distances between these solutions and the values in the weighted decision matrix, as presented in Table 6.15. The positive distances can be calculated using Equation 21, while the negative distances can be calculated using Equation 22. The resulting distance data is provided in Table 6.18.

Table 6.18. Distances to SF-PIS and SF-NIS

Alternatives	$D(X_i, X^*)$	$D(X_i, X')$
S1	0,446	0,257
S2	0,248	0,348
S3	0,294	0,412

To rank these three alternatives, Closeness Ratio must be calculated by using Equation 23 must be used. Closeness Ratios and Final Ranking is given in the following Table 6.19.

Table 6.19. Final Ranking

Alternatives	Closeness Ratio	Rank
S1	1,158	3
S2	0,186	1
S3	0,220	2

Ranking is deduced by ordering alternatives starting from the smallest closeness ratio to largest one. Final ranking is obtained as $S_2 > S_3 > S_1$.

7. DISCUSSION

As is shown in this study, MCDM algorithms make decision-makers' jobs easier and let them decide more accurately according to their criteria weighting. However, MCDM algorithms cannot eliminate the human element, which might cause human error even if it is a slight possibility.

In this study, ten decision-makers are used, which are professionals in the same company. This dynamic presented another factor: collaboration among decision-makers led to converging thinking patterns. It is worth noting that the convergence of thinking patterns among decision-makers can have advantages and disadvantages. On the positive side, shared perspectives and experiences can promote cohesion and facilitate effective communication within the decision-making process. However, it also introduces the potential risk of groupthink, where dissenting opinions and alternative viewpoints may be overlooked.

The study used strong validation processes to reduce the potential effect of human error by comparing the outcomes of the MCDM algorithms with professional judgments and assuring agreement among the decision-makers. The study aims to increase the validity and reliability of the decision-making process by using such strong approaches.

To investigate the concepts of human error and groupthink in decision-making processes by employing the standard method and the SF-TOPSIS method. Both methods are utilized on the same dataset to facilitate a comprehensive comparison. In TOPSIS, spherical fuzzy weighted evaluations values are employed after defuzzification. The study findings, presented in the appendix, reveal a reversed ranking outcome in TOPSIS, which can be attributed to technical differences between the two methods.

The standard TOPSIS method involves the calculation of normalized decision matrix and determination of the PIS and the NIS. Spherical fuzzy weighted evaluations are used after defuzzification to assess the distance of each alternative to PIS and NIS, ultimately leading to ranking results.

In contrast, SF-TOPSIS utilizes the original spherical fuzzy weighted evaluations to form the normalized decision matrix. The SF-PIS and SF-NIS are determined to evaluate the distance of each alternative to these ideal solutions. Subsequently, ranking is achieved through the relative closeness coefficient computation.

Upon comparing the ranking results from both methods, it is evident that TOPSIS produces a reversed ranking order. This discrepancy can be attributed to the absence of uncertainty consideration in the standard TOPSIS method, which SF-TOPSIS is specifically designed to address.

Furthermore, in a groupthink scenario, where decision-makers may conform or manipulate results based on their predetermined choices, the decision-making mechanism becomes susceptible to biases and individual preferences. Some decision-makers with higher weights can exert greater influence on the final outcomes, potentially leading to skewed results.

The research highlights the significance of addressing human error and groupthink in decision-making processes. SF-TOPSIS proves advantageous over standard TOPSIS in considering uncertainties through spherical fuzzy evaluations. Additionally, awareness of the influence of individual decision-makers' weights is vital to ensure a more transparent and unbiased decision-making process. These findings contribute valuable insights for enhancing decision-making methodologies in complex real-world situations. The detailed steps and results are provided in the appendix for further reference.

While MCDM algorithms offer valuable support in decision-making, they should be viewed as complementary tools rather than replacements for human judgment. Integrating human expertise, critical thinking, and considering multiple perspectives remains indispensable in ensuring well-informed and sound decision-making outcomes.

8. CONCLUSION

In this research, an assessment is undertaken to identify a sustainable LNG supplier for a prominent global glass manufacturing company. Ten highly qualified decision-makers with extensive industry knowledge actively participate in the selection process. Through thoughtful consideration, a comprehensive set of criteria comprising three main criteria and fifteen distinct sub-criteria is determined. These selection criteria serve as essential guidelines in determining the most suitable LNG supplier to meet the sustainability objectives of the glass manufacturer. According to decision makers, the overall ranking of the suppliers is determined as $S_2 > S_3 > S_1$.

8.1. Thesis Contribution

This research has several notable elements that considerably enrich the literature. Firstly, it employs a recently introduced novel method called SF-TOPSIS, which offers a distinct approach to decision-making processes. Secondly, it focuses on selecting LNG as the specific supply type, presenting a unique perspective within the research domain. The selection of LNG as the focal point of this study holds significant importance in the context of sustainable supplier selection.

In comparison to conventional fossil fuels, LNG is a useful alternative energy source since it has fewer environmental effects and lower greenhouse gas emissions. Its application in large-scale industrial processes, including the production of glass, is consistent with the shift to cleaner energy sources and the rising worldwide emphasis on environmental sustainability. Furthermore, this study addresses a real-life challenge involving the identification of the most sustainable LNG supplier for one of the world's largest glass manufacturing companies.

Notably, the sustainable supplier selection process incorporates specific sub-criteria for this study. While previous research predominantly focuses on generic sustainability criteria, this study takes a more tailored approach by incorporating industry-specific factors that directly impact the sustainability performance of LNG suppliers in the glass manufacturing sector. These specific sub-criteria are carefully selected by industry professionals, drawing upon their expertise and insights to ensure the relevance and applicability of the evaluation process. Through the utilization of these distinctive sub-criteria, this study offers a comprehensive and industry-tailored viewpoint when it comes to selecting the most sustainable LNG supplier. The study recognizes the challenges faced by large-scale glass manufacturers and highlights the need for a specific evaluation framework that takes into account their specific requirements and sustainability objectives. This technique is beneficial in addressing the unique complexities of the industry.

Another objective of this study is to demonstrate the applicability of the SF-TOPSIS method in tackling complex, large-scale problems such as this one. By leveraging linguistic variables and an extensive range of corresponding fuzzy numbers associated with these linguistic terms, the SF-TOPSIS method effectively mitigates potential errors stemming from human subjectivity.

8.2.Limitations and Future Works

Similar to other research endeavors, this study is not exempt from limitations. Firstly, the exclusive reliance on a single methodology for evaluating the optimal choice may not offer an ideal scenario. Incorporating supplementary methods could offer comparative insights, enabling a more nuanced understanding of the strengths and limitations inherent in various MCDM approaches. Secondly, it is essential to acknowledge that decision-makers' judgments can evolve over time as they accumulate experience and encounter evolving circumstances within their professional domain. Therefore, for practical application, this study necessitates periodic review and adaptation to ensure its relevance and efficacy in real-life contexts, which constitutes its primary objective.

An additional notable observation is the tendency of decision makers with shared backgrounds to yield comparable assessments for both main and sub-criteria. To mitigate this issue, it is imperative to incorporate diverse decision-maker groups within the same industry but across distinct organizations.

The recent energy crisis has served as a stark reminder that the global economy and supply chains of major corporations are ill-prepared to handle unforeseen shortages. Hence, companies operating at such a magnitude should proactively adopt alternative energy sources, including renewable options, to safeguard their energy supplies against adverse external impacts.

Finally, for further research, other techniques such as AHP, TOPSIS, VIKOR, PROMETHEE, etc. can be used in this problem to compare their performances. Also, other Spherical Fuzzy MCDM methods can be applied to this problem such as Interval Values SF-TOPSIS, SF-VIKOR, and SF-WASPAS.

REFERENCES

- Al-Yafei, H., Aseel, S., Kucukvar, M., Onat, N., Al-Sulaiti, A., & Al-Hajri, A. (2021). A Systematic Review for Sustainability of Global Liquefied Natural Gas. *Energy Strategy Reviews*, 38.
- Atanassov, K. (1986). Intuitionistic Fuzzy Sets. *Fuzzy Sets and Systems*, 87-96.
- Atanassov, K. (1999). Other Extensions of Intuitionistic Fuzzy Sets. *Studies in Fuzziness and Soft Computing*, 35, 179-198.
- Awathi, A., Goyal, S., & Chauhan, S. (2010). A Fuzzy Multicriteria Approach for Evaluating Environmental Performance of Suppliers. *International Journal of Production Economics*, 126(2), 370-378.
- AYGAZ. (2021). *AYGAZ Sürdürülebilirlik Raporu*. Istanbul: AYGAZ.
- Bai, C., Kusi-Sarpong, S., Badri Ahmadi, H., & Sarkis, J. (2019). Social Sustainable Supplier Evaluation and Selection: A Group Decision-Support Approach. *International Journal of Production Research*, 1-22.
- Barron, L., & Gauntlett, E. (2002). *Stage 1 Report - Model of Social Sustainability. Housing and Sustainable Communities. Indicators Project*. Perth: Murdoch University.
- Baskaran, V., Nachiappan, S., & Rahman, S. (2012). Indian textile suppliers' sustainability evaluation using the Grey approach. *Int. J. Prod. Econ.* 135, 647-658.
- Bucknall, R., & Attah, E. (2015). An Analysis of the Energy Efficiency of LNG Ships Powering Options Using the EEDI. *Ocean Engineering*, 110.

- Büyüközkan, G. (2011). An Integrated Fuzzy Multi-Criteria Group Decision-Making Approach for Green Supplier Evaluation. *International Journal of Production Research*, 2892-2909.
- Büyüközkan, G., & Çifçi, G. (2011). A Novel Fuzzy Multi-Criteria Decision Framework for Sustainable Supplier Selection with Incomplete Information. *Computers in Industry*, 62(2), 164-174.
- Collins Dictionary. (2023, January 15). *Collins Dictionary*. Collins Dictionary Website: from <https://www.collinsdictionary.com/dictionary/english/energy-crisis>
- Council of Supply Chain Management Professionals. (2014, September 19). *CSCMP Supply Chain Management*. CSCMPC Web Site: from <http://cscmp.org/about-us/supply-chain-management-definitions>
- De Boer, L., Labro, E., & Morlacchi, P. (2001). A review of methods supporting supplier selection. *Eur. J. Purch. Supply Manag.* 7, 75-89.
- Dobrota, Đ., Branko, L., & Komar, I. (2013). Problem of Boil-Off in LNG Supply Chain. *Transactions on Maritime Science*, 2(2), 91-100.
- Dyllick, R., & Hockerts, K. (2002). Beyond the business case for corporate sustainability. *Business Strategy and the Environment*, 11(2), 130-141.
- Fombrun, C. (1996). *Reputation: Realizing Value from the Corporate Image*. Boston: Harvard Business School Press.
- Gedik, Y. (2020). Sustainability and Sustainable Development with Social, Economic and Environmental Dimensions. *International Journal of Economics, Politics, Humanities & Social Sciences*, 3(3), 196-215.
- Ghodsypour, S. H., & O'Brien, C. (2001). The total cost of logistics in supplier selection, under conditions of multiple sourcing, multiple criteria and capacity constraint. *International Journal of Production Economics*, 15-27.
- Gul, M., & Ak, M. (2021). A Modified Failure Modes and Effects Analysis Using Interval-Valued Spherical Fuzzy Extension of TOPSIS Method: Case Study in a Marble Manufacturing Facility. *Soft Computing*, 25(8), 6157-6178.

- Hancock, L. (2023, February 1). *World Wild Life*. World Wild Life Organization Website: from <https://www.worldwildlife.org/pages/what-is-biodiversity>
- Handfield, R., Walton, S., Sroufe, R., & Melnyk, S. (2002). Applying environmental criteria to supplier assessment: a study in the application of the Analytical Hierarchy Process. *Eur. J. Oper. Res.* 141, 70-87.
- Hashemi, S., Karimi, A., & Tavana, M. (2015). An Integrated Green Supplier Selection Approach with Analytic Network Process and Improved Grey Relational Analysis. *International Journal of Production Economics*, 178-191.
- Hosoe, N. (2023). The Cost of War: Impact of Sanctions on Russia following the Invasion of Ukraine. *Jornal of Policy Modelling*, 45(2), 305-319.
- Hu-Chen, L., Mei-Yun, Q., ZhiWu, L., & Ze-Ling, W. (2019). A New Integrated MCDM Model for Sustainable Supplier Selection Under Interval-Valued Intuitionistic Uncertain Linguistic Environment. *Information Sciences*, 486, 254-270.
- Hussain, M., Ajmal, M. M., Gunasekaran, A., & Khan, M. (2018). Exploration of Social Sustainability in Healthcare Supply Chain. *ournal of Cleaner Production*, 203, 977-989.
- Hwang, C.-L., & Yoon, K. (1981). Methods and Applications A State-of-the-Art Survey. *Multiple Attribute Decision Making*. içinde Heidelberg: Springer Berlin.
- Hwang, C.-L., Lai, Y., & Liu, T. (1993). A new approach for multiple objective decision making. *Computers and Operational Research*, 20(8), 889-899.
- Intercontinental Exchange. (2023, May 21). *ICE Endex Dutch TTF Natural Gas Futures*. ICE: <https://www.ice.com/products/27996665/Dutch-TTF-Natural-Gas-Futures>
adresinden alındı
- Jaller, M., & Otay, İ. (2021). Evaluating Sustainable Vehicle Technologies for Freight Transportation Using Spherical Fuzzy AHP and TOPSIS. *Intelligent and Fuzzy Techniques: Smart and Innovative Solutions* (s. 118-126). Springer International Publishing.
- Jamali, D. (2006). Insights into Triple Bottom Line Integration from a Learning Organization Perspective. *Business Process Management Journal*, 12, 809-821.

- Kahraman, C., Kutlu Gundogdu, F., Cevik Onar, S., & Oztaysi, B. (2019). Hospital Location Selection Using Spherical Fuzzy TOPSIS. *Proceedings of the 11th Conference of the European Society for Fuzzy Logic and Technology (EUSFLAT 2019)* (s. 77-82). Atlantis Press.
- Kamann, D.-J. F., & Bakker, E. F. (2004). Changing Supplier Selection and Relationship Practices: A Contagion Process. *Journal of Purchasing and Supply Management*, 10(2), 55-64.
- Kao, J.-C., Chia-Nan, W., & Viet Tinh, N. (2022). A Fuzzy MCDM Model of Supplier Selection in Supply Chain Management. *Intelligent Automation & Soft Computing*, 1451-1466.
- Karcioğlu, R., & Öztürk, S. (2021). *Sürdürülebilirlik muhasebesi ve raporlaması*. Gazi Kitabevi.
- Khalilpour, K., & Karimi, I. (2011). Selection of Liquefied Natural Gas (LNG) Contracts for Minimizing Procurement Cost. *Industrial & Engineering Chemistry Research*, 50, 10298-10312.
- Konys, A. (2019). Green Supplier Selection Criteria: From a Literature Review to a Comprehensive Knowledge Base. *Sustainability*, 11(15), 2.
- Kuo, R., Wang, Y., & Tien, F. (2010). Integration of Artificial Neural Network and MADA Methods for Green Supplier Selection. *Journal of Cleaner Production*, 1161-1170.
- Kuo, T., Hsu, C.-W., & Li, J. (2015). Developing a Green Supplier Selection Model by Using the DANP with VIKOR. *Sustainability*, 1-29.
- Kutlu Gundogdu, F., & Kahraman, C. (2019). A Novel VIKOR Method Using Spherical Fuzzy Sets and Its Application to Warehouse Site Selection. *Journal of Intelligent & Fuzzy Systems*, 37(1), 1197-1211.
- Kutlu Gündoğdu, F., & Kahraman, C. (2019). Spherical fuzzy sets and spherical fuzzy TOPSIS method. *Journal of Intelligent & Fuzzy Systems*, 36, 337-352.
- Kutlu Gündoğdu, F., & Kahraman, C. (2021). Optimal Site Selection of Electric Vehicle Charging Station by Using Spherical Fuzzy TOPSIS Method. *Decision Making*

with Spherical Fuzzy Sets: Theory and Applications (s. 201-216). içinde Springer International Publishing.

- Malik, M., Abdallah, S., & Hussain, M. (2016). Assessing supplier environmental performance: Applying Analytical Hierarchical Process in the United Arab Emirates healthcare chain. *Renewable and Sustainable Energy Reviews*, 55, 1313-1321.
- Mani, V., Agrawal, R., & Sharma, V. (2014). Supplier selection using social sustainability: AHP based approach in India. *International Strategic Management Review*, 2(2), 98-112.
- Marzouk, M., & Sabbah, M. (2021). AHP-TOPSIS Social Sustainability Approach for Selecting Supplier in Construction Supply Chain. *Cleaner Environmental Systems* 2.
- Mathej, M., Chakraborty, R., & Ryan, M. (2020). A Novel Approach Integrating AHP and TOPSIS Under Spherical Fuzzy Sets for Advanced Manufacturing System Selection. *Engineering Applications of Artificial Intelligence*, 96.
- McKenzie, S. (2004). Social Sustainability: Towards Some Definitions. *Hawke Research Institute Working Paper Series* 27 .
- Mehralian, G., Gatari, A., Morakabati, M., & Vatanpour, H. (2012). Developing a Suitable Model for Supplier Selection Based on Supply Chain Risks: an Empirical Study from Iranian Pharmaceutical Companies. *Iranian Journal of Pharmaceutical Research*, 209-219.
- Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining Supply Chain Management. *Journal of Business Logistics*, 22(2), 1-25.
- Morelli, J. (2011). Environmental Sustainability: A Definition for Environmental Professionals. *Journal of Environmental Sustainability: Vol. 1: Iss. 1, Article 2*.
- NRDC. (2022, January 4). *NRDC Liquefied Natural Gas 101*. NRDC Web Site: from <https://www.nrdc.org/stories/liquefied-natural-gas-101#whatis>

- Palanisamy, M., & Ranganathan, R. (2017). An Efficient supplier selection Model for Hospital Pharmacy through Fuzzy AHP and Fuzzy TOPSIS. *International Journal of Services and Operations Management*, 33(4).
- Pfoser, S., Schauer, O., & Costa, Y. (2018). Acceptance of LNG as an Alternative Fuel: Determinants and Policy Implications. *Energy Policy*, 120, 259-267.
- Puska, A., Stevic, Z., & Stojanovic, I. (2021). Selection of Sustainable Suppliers Using the Fuzzy MARCOS Method. *Current Chinese Science, Volume 1, Number 2*, 218-229.
- Ren, P., Xu, Z., & Gou, X. (2016). Pythagorean Fuzzy TODIM Approach to Multi-Criteria Decision Making. *Applied Soft Computing*, 246-259.
- Rouyendegh, B., & Saputro, T. (2014). Supplier Selection Using Integrated Fuzzy TOPSIS and MCGP: A Case Study. *Procedia - Social and Behavioral Sciences*, 3957-3970.
- S&P Global. (2023, June 5). *S&P Global Commodity Insights*. S&P Global: from <https://www.spglobal.com/commodityinsights/en/our-methodology/price-assessments/lng/jkm-japan-korea-marker-gas-price-assessments>
- S&P Global. (2023, May 21). *S&P Global Commodity Insights*. S&P Global Web Site: from <https://www.spglobal.com/commodityinsights/en/our-methodology/price-assessments/natural-gas/henry-hub-natural-gas-price-assessments#>
- Saban, M., Küçüker, H., & Küçüker, M. (2017). Kurumsal sürdürülebilirlik ile ilgili raporlama çerçeveleri ve sürdürülebilirlik raporlamasında muhasebenin rolü. *İşletme Bilimi Dergisi*, 5(1), 101-115.
- Schinasi, G. J. (2004, October). Defining Financial Stability. *IMF Working Paper*, s. No.04/187.
- Sen, D., Datta, S., & Mahapatra, S. (2018). Sustainable supplier selection in intuitionistic fuzzy environment: a decision-making perspective. *Benchmarking: An International Journal*, 545-574.

- Sharaf, I. (2022). A New Approach for Spherical Fuzzy TOPSIS and Spherical Fuzzy VIKOR Applied to the Evaluation of Hydrogen Storage Systems. *Research Square*.
- Sharaf, I. (2023). A New Approach for Spherical Fuzzy TOPSIS and Spherical Fuzzy VIKOR Applied to the Evaluation of Hydrogen Storage Systems. *Soft Computing*, 4403-4423.
- Shell Global. (2023). *Shell Energy Outlook 2023*. Shell Global Web Site: from <https://www.shell.com/energy-and-innovation/natural-gas/liquefied-natural-gas-ling/ling-outlook-2023.html#download-the-shell-ling-outlook-2023=&iframe=L3dIYmFwcHMvTE5HX291dGxvb2tfMjAyMy8>
- Simchi-Levi, D., Kaminsky, P., & Simchi-Levi, E. (2008). *Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies*. Boston: McGraw-Hill.
- Smarandache, F. (1998). *Neutrosophy : Neutrosophic Probability, Set, and Logic: Analytic Synthesis & Synthetic Analysis*. Rehoboth: American Research Press.
- Stevic, Ž., Pamučar, D., Puška, A., & Chatterjee, P. (2020). Sustainable Supplier Selection in Healthcare Industries Using a New MCDM Method: Measurement of Alternative and Ranking According to Compromise Solution (MARCOS). *Computer & Industrial Engineering*, 140.
- Suopajärvi, L., Poelzer, G. A., Ejdemo, T., Klyuchnikova, E., Korchak, E., & Nygaard, V. (2016). Social sustainability in northern mining communities: A study of the European North and Northwest Russia. *Resources Policy*, 47, 61-68.
- Sutherland, J., Richter, J., & Hutchins, M. (2016). The role of manufacturing in affecting the social dimension of sustainability, in: *CIRP Annals* 65(2). 689-712.
- Torra, V. (2010). Hesitant Fuzzy Sets. *International Journal of Intelligent Systems*, 25(6), 529-539.
- Van Thanh, N., & Thi Kim Lan, N. (2022). A New Hybrid Triple Bottom Line Metrics and Fuzzy MCDM Model: Sustainable Supplier Selection in the Food-Processing Industry. *Mathematical Fuzzy Logic in the Emerging Fields of Engineering, Finance, and Computer Sciences*.

- Vasiljevic, M., Fazlollahtabar, H., Stevic, Z., & Veskovic, S. (2018). A rough multicriteria approach for evaluation of the supplier criteria in automotive industry. *Decision Making: Applications in Management and Engineering*, 82-96.
- Wang Chen, H., Chou, S.-Y., Luu, Q., & Yu, T.-K. (2016). A Fuzzy MCDM Approach for Green Supplier Selection from the Economic and Environmental Aspects. *Mathematical Models for Supply Chain Management*.
- Wilson, M. (2003). Corporate sustainability: What is it and where does it come from. *Ivey Business Journal*, 67(6), 1-5.
- Wisner, J. D., Tan, K.-C., & Keong Leong, G. (2022). *Principles of Supply Chain Management: A Balanced Approach*. Cengage Learning.
- Yıldızbaşı, A., Öztürk, C., Efendioğlu, D., & Bulkan, S. (2021). Assessing the Social Sustainable Supply Chain Indicators Using an Integrated Fuzzy Multi-Criteria Decision-Making Methods: A Case Study of Turkey. *Environment, Development and Sustainability: A Multidisciplinary Approach to the Theory and Practice of Sustainable Development*, 4285-4320.
- Yoon, K. (1987). A reconciliation among discrete compromise situations. *J. of the Op. Res. Soc.* 38(3), 277-286.
- Zadeh, L. (1965). Fuzzy sets. *Information and Control*, 8(3), 338-353.
- Zadeh, L. (1975). The Concept of a Linguistic Variable and Its Application to Approximate Reasoning—I. *Information Sciences*, 8(3), 199-249.
- Zaman, A. U. (2015). A comprehensive review of the development of zero waste management: Lessons learned and guidelines. *Journal of Cleaner Production*, Volume 91, 12-25.
- Zeng, S., Hussain, A., Mahmood, T., Irfan Ali, M., Ashraf, S., & Munir, M. (2019). Covering-Based Spherical Fuzzy Rough Set Model Hybrid with TOPSIS for Multi-Attribute Decision-Making. *Symmetry*, 11(4).
- Zhang, X., & Xu, Z. (2014). Extension of TOPSIS to multiple criteria decision making with Pythagorean fuzzy sets. *International Journal of Intelligent Systems* 29 (12), 1061-1078.

APPENDIX

In order to make a comparison with SF-TOPSIS, standard TOPSIS method is conducted with the same data set. Steps and results are given in the order. Weighted Spherical Fuzzy evaluations are defuzzified and used in standard TOPSIS method.

Table A. 1. Weights of Criteria

Fiscal Criteria	Weights	Environmental Criteria	Weights	Social Criteria	Weights
FC01	0,107	EC01	0,082	SC01	0,034
FC02	0,092	EC02	0,061	SC02	0,077
FC03	0,114	EC03	0,077	SC03	0,049
FC04	0,073	EC04	0,046	SC04	0,023
FC05	0,040	EC05	0,056	SC05	0,069

Table A. 2. Decision Matrix

Alternatives	FC01	FC02	FC03	FC04	FC05
S1	22,488	20,462	24,043	16,318	6,446
S2	20,271	19,060	20,482	14,926	7,347
S3	18,493	17,516	21,216	14,514	8,050
	EC01	EC02	EC03	EC04	EC05
S1	16,073	13,863	17,603	10,219	9,959
S2	16,478	15,687	16,828	9,346	8,724
S3	17,053	17,324	16,900	8,695	10,017
	SC01	SC02	SC03	SC04	SC05
S1	15,028	20,982	11,708	7,566	17,927
S2	13,442	21,466	10,612	7,371	21,072
S3	13,738	21,067	11,045	7,030	20,645

Table A. 3. Normalized Decision Matrix

Alternatives	FC01	FC02	FC03	FC04	FC05
S1	0,634	0,620	0,632	0,617	0,509
S2	0,571	0,578	0,538	0,564	0,580
S3	0,521	0,531	0,558	0,549	0,636
	EC01	EC02	EC03	EC04	EC05
S1	0,561	0,510	0,594	0,625	0,600
S2	0,575	0,577	0,568	0,572	0,525
S3	0,595	0,638	0,570	0,532	0,603
	SC01	SC02	SC03	SC04	SC05
S1	0,616	0,572	0,607	0,596	0,519
S2	0,551	0,585	0,550	0,581	0,610
S3	0,563	0,574	0,573	0,554	0,598

Table A. 4. Weighted Normalized Decision Matrix

Alternatives	FC01	FC02	FC03	FC04	FC05
S1	0,068	0,057	0,072	0,045	0,020
S2	0,061	0,053	0,061	0,041	0,023
S3	0,056	0,049	0,064	0,040	0,025
	EC01	EC02	EC03	EC04	EC05
S1	0,046	0,031	0,046	0,028	0,034
S2	0,047	0,035	0,044	0,026	0,029
S3	0,049	0,039	0,044	0,024	0,034
	SC01	SC02	SC03	SC04	SC05
S1	0,021	0,044	0,030	0,014	0,036
S2	0,019	0,045	0,027	0,013	0,042
S3	0,019	0,044	0,028	0,013	0,041

Table A. 5. Positive Ideal and Negative Ideal Solution

Alternatives	S+	S-	Sum of (S+&S-)
S1	0,012	0,020	0,032
S2	0,016	0,011	0,027
S3	0,018	0,012	0,031

Table A. 6. Performance Values

Alternatives	Performance
S1	0,635
S2	0,407
S3	0,397

Table A. 7. Final Ranking

Final Ranking	
S1	1
S2	2
S3	3



BIBLIOGRAPHICAL SKETCH

Ilgaz Cerit completed his secondary education at Ekrem Elginkan Anatolian High School, affiliated with Istanbul Technical University Development Foundation Schools, graduating in 2016. Subsequently, in the same year, he commenced his undergraduate studies at Istanbul Technical University, specializing in Mining Engineering, and successfully completed his degree in 2020, ranking as the Salutatorian. In that same year, he embarked on his postgraduate education at Galatasaray University, pursuing a Master's degree in Industrial Engineering. Currently, he is in the final stages of completing his Master of Science Degree in Industrial Engineering at the Galatasaray University Institute of Science. Ilgaz Cerit is currently employed as an Energy Procurement Assistant Supervisor at one of the world's largest glass manufacturing companies. He aspires to advance his professional career and enhance his expertise in procurement and negotiation, with the aim of achieving success in his chosen field.