SUPPLIER SELECTION WITH SUSTAINABILITY PERSPECTIVE USING AN INTEGRATED FUZZY APPROACH

(ENTEGRE BULANIK YAKLAŞIM KULLANARAK SÜRDÜRÜLEBİLİRLİK BAKIŞAÇISIYLA TEDARİKÇİ SEÇİMİ)

by

Çiğdem BERKOL, B. S.,

Thesis

Submitted in Partial Fulfillment

of the Requirements

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ÇİĞDEM BERKOL
15 May 2011

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LIST OF SYMBOLS

AHP:	Analytic Hierarchy Process
ANP:	Analytic Network Process
CFCS:	Converting Fuzzy data into Crisp Scores
CI:	Consistency Index
CILP:	Crisp Integer Linear Programming
COA:	Center of Area
CR:	Consistency Ratio
DEA:	Data Envelopment Analysis
DEMATEL:	Decision Making Trial and Evaluation Laboratory
DMT:	Decision Making Team
ELECTRE:	ELimination and Choice Expressing the REality
EMAS:	Eco-Management and Audit Scheme
FILP:	Fuzzy Integer Linear Programming
GA:	Genetic Algorithm
GP:	Goal Programming
GSCM:	Green Supply Chain Management
ISM:	Interpretive Structural Modeling
LP:	Linear Programming
MCDM:	Multi Criteria Decision Making
PLP:	Possibilistic Linear Programming
PROMETHEE:	Preference Ranking Organization Method for Enrichment Evaluations
RI:	Random Consistency Index
SCM:	Supply Chain Management
SMART:	Simple Multi-Attribute Rating Technique
SRI:	Socially Responsible Investment
SSCM:	Sustainable Supply Chain Management
TOPSIS:	Technique for Order Preference by Similarity to Ideal Solution

UN: United Nations

VIKOR: VlseKriterijumska Optimizacija I Kompromisno Resenje

ZOGP: Zero-One Goal Programming

$\tilde{w}_i$: Fuzzy priority of i

α: Confidence level

ω: Optimism index

δ: Degree of fuzziness

$\hat{a}_{ij}^{\alpha}$: Defuzzified value at a given level of α

$p_j(d)$: Preference function of criterion j

$f_k(a_t)$: Evaluation value of the alternative a_t according to the criterion k

$\Phi^+(a_t)$: Leaving flow of alternative a_t

$\Phi^-(a_t)$: Entering flow of alternative a_t

S: Unweighted supermatrix

S^{norm}: Normalized supermatrix

$S^{\lim}$: Limiting supermatrix

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ABSTRACT

The increasing awareness of non governmental organizations, academia and business on the environmental and social issues leads companies to pay attention on the novel concept of sustainability. Sustainability involves the multiple objectives of social, economic and environmental sustainability. Thus, in recent years the interest in sustainable supply chain has increased and supplier selection becomes critically important. In this study, the sustainability concept is integrated into the supplier evaluation and selection problem and evaluation criteria are determined based on the related literature. Due to the multi-criteria nature of the problem and the vagueness in the human judgments, this study proposes a hybrid model combined with fuzzy logic. This model applies Fuzzy Decision Making Trial and Evaluation Laboratory (Fuzzy DEMATEL) technique to deal with the interdependencies within an evaluation cluster, Fuzzy Analytic Network Process (Fuzzy ANP) to calculate the dependencies between clusters and then to determine the criteria weights and Fuzzy Preference Ranking Organization METHod for Enrichment Evaluations (Fuzzy PROMETHEE) technique to achieve a final ranking of the alternatives. Finally, a case study is presented to illustrate the application of the proposed method. The results showed that even though the final importance weights of the criteria under the Performance Evaluation cluster are approximate, *Sustainability Competence*, *Cost* and *Time* appeared to be the most important criteria among the others.

Keywords: Fuzzy ANP, Fuzzy DEMATEL, Fuzzy PROMETHEE, Fuzzy Sets, Sustainable supplier selection.

RESUME

De nos jours, en raison de la population humaine croissante et l'industrialisation, l'intérêt sur les ressources renouvelables a augmenté et l'utilisation des ressources naturelles est devenue d'une importance cruciale. Tant que la conscience des organisations non gouvernementales, les universités et les entreprises sur des sujets environnementaux et sociaux est augmentée, le nouveau concept de "durabilité" est émergé. La durabilité implique des dimensions sociales, économiques et environnementales. Ainsi, ces dernières années l'intérêt dans la chaîne d'approvisionnement durable a augmenté et le processus de sélection de fournisseur durable est devenu d'une importance critique. Dans ce travail, le concept de durabilité est intégré dans le problème d'évaluation et de sélection des fournisseurs et les critères d'évaluation sont déterminés selon la littérature. En raison de nature multicritère du problème de sélection des fournisseurs et l'imprécision dans les jugements humains, ce travail propose un hybride modèle basé sur la logique floue. Ce modèle s'applique Floue DEMATEL (Decision Making Trial and Evaluation Laboratory) technique pour calculer les interdépendances dans un cluster d'évaluation, Flou ANP (Analytic Network Process) technique pour calculer les dépendances entre les clusters et ensuite pour déterminer les poids d'importance des critères et puis Flou PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) technique pour obtenir le classement final des alternatives. Enfin, une étude de cas est présentée pour illustrer l'application de la méthode proposée. Les résultats ont montré que même si les poids d'importance finaux des critères sous le cluster d'Evaluation de Performance sont approximatifs, *Compétence de Durabilité*, *Coûts* et *Temps* ont semblé être les critères les plus importants parmi les autres.

Mots Clés: Flou ANP, Flou DEMATEL, Flou PROMETHEE, Ensembles Flous, Sélection de fournisseur durable.

ÖZET

Günümüzde, artan nüfus ve sanayileşme ile yenilenebilir kaynakların önemi artmış, doğal kaynakların kullanımına dikkat edilmeye başlanmıştır. Sivil toplum örgütleri, akademisyenler ve iş dünyasının çevreye duyarlı uygulamalar ve sosyal konulara ilgilerinin artmasıyla, "sürdürülebilirlik" kavramı ortaya çıkmıştır. Sürdürülebilirlik, çevresel, sosyal ve ekonomik sürdürülebilirlik olmak üzere üç boyutu içermektedir. Böylece son zamanlarda, sürdürülebilir tedarik zinciri yönetimine olan ilgi ve dolayısıyla sürdürülebilir tedarikçi seçimi sürecinin önemi artmıştır. Bu çalışmada sürdürülebilirlik kavramı tedarikçilerin değerlendirilmesi ve seçilmesi sürecine dahil edilmiş ve değerlendirme ölçütleri, ilgili literatüre dayanarak belirlenmiştir. Tedarikçi seçimi probleminin çok ölçütlü yapısı ve bireysel yargılarda mevcut olan belirsizlikler nedeniyle, bu çalışma bulanık melez bir model önermektedir. Bu model, Bulanık DEMATEL (Decision Making Trial and Evaluation Laboratory) tekniğini, ölçüt kümeleri içerisindeki karşılıklı iletişimlerinin hesaplanmasında, Bulanık ANP (Analytic Network Process) tekniğini ölçüt kümeleri arasındaki etkileşimlerin ve sonrasında ölçütlerin önem derecelerinin hesaplanmasında, bulanık PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) tekniğini ise alternatiflerin final sıralamasının elde edilmesinde kullanmaktadır. Son aşamada, önerilen modelin uygulanışının gösterilmesi amacıyla bir firmada uygulanması verilmiştir. Sonuçlar göstermiştir ki, Performans Değerlendirme ölçüt kümesi altındaki ölçütlerin önem dereceleri yakın olmasına rağmen, Sürdürülebilirlik Yetkinliği, Maliyet ve Zaman diğer ölçütler arasında en önemliler olarak ortaya çıkmıştır.

Anahtar Sözcükler: Bulanık kümeler, Bulanık ANP, Bulanık DEMATEL, Bulanık PROMETHEE, Sürdürülebilir tedarikçi seçimi.

1. INTRODUCTION

Earth as a resource system has a limited capacity for supporting a growing human population with an intensive exchange of materials and energy with its environment [1]. Therefore the awareness of non governmental organizations, academia and business on environmental subjects increased and the novel concept of “çyuısustainability” has emerged. Sustainability is generally defined as ‘‘using resources to meet the needs of the present without compromising the ability of future generations to meet their own’’. Sustainability involves the multiple objectives of social, economic and environmental sustainability. These multiple objectives generate the three dimensions of sustainability.

Nowadays consumer behaviour is widely changed and began to create high pressure on companies. These pressures drive enterprises to actively invest in environmental and sustainable issues. For example, some of the top global companies (Exxon Mobil, General Electric, Royal Dutch/Shell, Daimler Chrysler, Toyota Motor, Hitachi, Sony, etc.) began using terms like “Sustainability and Environment,” “Environmental Initiatives,” “Environmental Activities,” or “Environmental Leadership” [2].

Recently, the first objective of Supply Chain Management (SCM) defined as “the integration of key business processes from end-user through original suppliers that provides products, services, and information that add value for customers and other stakeholders” by Lambert et al. [3] was to provide better quality at lower cost while meeting the other requirements of stakeholders. Nowadays increasing pressures from shareholders and governments lead organizations to reorganize their SCM practices with a sustainability perspective [4], [5]. Such a SCM approach is then called as Sustainable Supply Chain Management (SSCM) and defined by New Zealand Business Council for Sustainable Development as “Management of raw materials and services from suppliers to manufacturer/service provider to customer and back with improvement of the social and environmental impacts explicitly considered”. As a result, quality and cost are no longer considered as competitive differences in SCM. On the other hand, the sustainable supply chain provides competitive advantages to the companies. It offers them the opportunity to differentiate from other companies by being equitable in the fair utilization of natural resources, prudent enough not to harm the environment, being socially responsible in terms of equal human development, ensuring health and safety of employees and contributing to humanity and the environment. As a result, supplier selection being one of the most important stages in the course of any supply chain becomes critically important for companies. How to choose the suppliers to balance profitability and environmental performance is considered among the crucial decisions that a company has to make. Supplier selection on the other hand consists of an important process for achieving supply chain effectiveness. This subject has been discussed for more than 30 years in the literature [6].

The supplier selection problem is considered as a multi-criteria decision making (MCDM) problem by many authors as it consists of qualitative and quantitative factors affecting the decision making process. These factors are mostly evaluated by decision makers and their assessments often involve gray areas, techniques employing only the exact numerical values can not quantified these assessments precisely. So, in order to cope with the gray areas within the human perception and judgment, Zadeh [7] introduced Fuzzy Set Theory (FST). In this study the FST is employed in combination with different methods in order to support decision making procedures for such problem. Criteria and clusters used in supplier selection problems are often interdependent in reality. Therefore, the hierarchical structures are not suitable enough for such problems. Replacing hierarchies with networks, Saaty [8] developed the Analytic Network Process (ANP) which allows for complex interrelationships among decision levels and criteria. An other method used in combination with ANP is the Decision Making Trial and Evaluation Laboratory (DEMATEL) method. DEMATEL is a comprehensive method for making and analyzing a structured model involving causal relationships between complex factors. Therefore, it can be used in combination with ANP to deal with the interdependencies in the model. On the other hand, criteria priorities can be derived from ANP application and then replaced in other decision making tools. One of these tools is the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) which is an outranking method for a finite set of alternative actions. In order to eliminate the ambiguities and uncertainties existing in the criteria evaluation and decision making phase FST mentioned above is integrated in ANP, DEMATEL and PROMETHEE applications in many cases.

Considering the importance of sustainability in SCM and particularly in supplier selection, this study focused on supplier selection with sustainability perspective. The plan of the study is summarized roughly in Figure 1.1.

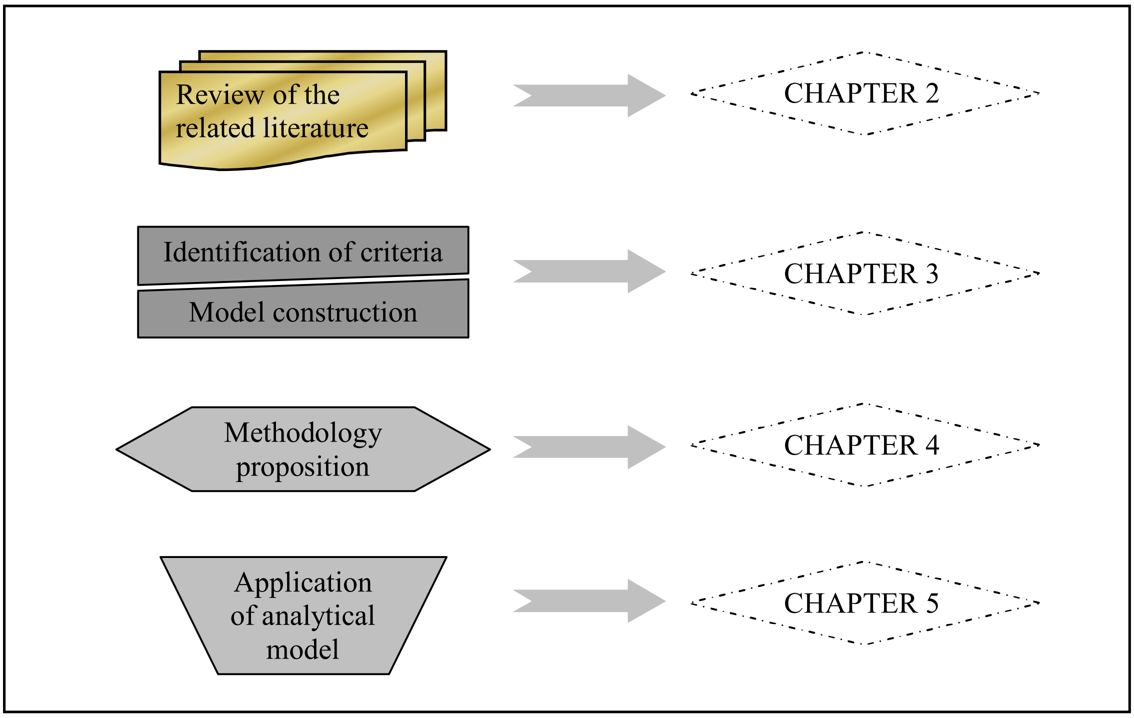

Figure 1.1 Plan of the study.

First in the following section, a detailed literature review of sustainable supply chain, green supplier selection, sustainable supplier selection and a brief survey about supplier selection are introduced. Then in the third section, a network model is proposed. The model considers the criteria selected through literature survey and expert opinions from HAVI Logistics. Moreover, in this section, criteria explanations and recent papers that used those criteria are listed. In the fourth section an integrated Fuzzy ANP, Fuzzy

DEMATEL and fuzzy- PROMETHEE methodology is proposed. Each of these techniques is then described in detail. The literature survey is conducted respecting the way that these techniques are implemented in the proposed model. Hence, studies using FST, PROMETHEE, Fuzzy ANP and DEMATEL integrated into ANP in order to select/evaluate suppliers are particularly presented. The studies applying those methods alone or combined with each other in the supplier selection field including green and sustainable approaches are reviewed. However, some of these techniques were applied scarcely for the sustainable or green supplier selection purposes in the earlier literature. In that case their implementations in the supplier selection or more generically in the MCDM problems are reviewed. Finally, the decision framework is illustrated via a case study.

2. LITERATURE SURVEY

2.1 SUSTAINABLE SUPPLY CHAIN

In the literature of SCM, there are several studies focused on SSCM where all the three dimensions of sustainability are taken into account as well as the studies that focus only on its environmental dimension. Although there are many studies about SSCM the existing literature is not very comprehensive and in most of these studies only the environmental dimension is considered [4]. Environmentally conscious SCM can be categorized as a special case of the SSCM called Green Supply Chain Management (GSCM) in many studies. Recent studies about SCM with environmental consideration, i.e. GSCM, their scope and findings are summarized below.

Sarkis [9] presented a strategic decision framework helping managerial decision making by evaluating alternatives that will affect external relationships among organizations. This decision framework was based on literature and practice in the area of environmentally conscious business practices. The focus of this paper was on the components and elements of GSCM and their role on the decision framework foundation.

Zhu and Sarkis [10] studied the relationships between GSCM practice and environmental and economic performance which is a commonly investigated subject in GSCM literature. They used empirical results from 186 respondents on GSCM practice in Chinese manufacturing enterprises, and focused on the influence of two primary types of management operations philosophies, quality management and just-in-time (or lean) manufacturing principles on this relationship.

Beamon [11] described environmentally conscious SCM as a component of engineering ethics and highlighted the major issues associated with ethical decision-making in SCM. According to the author engineering ethics primarily applies to decisions involving strategic-level facility location and material flow. The study also suggested that the potential environmental effects resulting from these decisions can be reduced or eliminated by taking appropriate actions.

Rao and Holt [12] examined the effect of GSCM practices on environmental and competitive performance of a firm. They conducted a survey with ISO 14001 certified companies in South East Asia and concluded that GSCM leads to competitiveness and economic performance.

Kainuma and Tawara [13] developed a new definition of supply chain by including the re-use and recycling operations into the life cycle of products or services. In order to evaluate the performance of a supply chain from an environmental point of view as well as a managerial point of view, the multiple attribute utility theory method was proposed and applied in the study.

Tsoulfas and Papis [1] identified environmental principles for SCM, described principles applicable to particular objects of logistics networks planning in order to improve the environmental performance of supply chain operations. Then, based on selective case studies from the literature they concluded with some remarks regarding the benefits for companies and societies that occur as a result of the application of the formulated principles.

Zhu and Sarkis [14] compared drivers and practices of GSCM in China focusing on three typical sectors; the automobile industry, the thermal power plants and the electronic/electrical industry. They indicated that companies in different industries have differing drivers and practices. In addition, China's entry into the world trade organization and globalization were stated as an aid to promote GSCM practices in manufacturing enterprises.

Ferretti et al. [15] is a study originated from an industrial case study in the field of the aluminium supply chain which integrated the concerns about transport pollution, addressing the topics of GSCM and incorporating the environmental aspects in its analytical description. Then, the authors proposed a transport model respecting the requirements of GSCM and balancing the economic benefit as well.

Zhu et al. [16] explored GSCM implementation of various manufacturing industrial sectors in China and examined the links between GSCM initiatives and performance outcomes. Conducted a survey with 171 organizations from four typical manufacturing industrial sectors in China which are power generating, chemical, electronic and automobile. Authors concluded that the different sectors display different levels of GSCM implementation and outcomes. They specifically found that the electronic industry has relatively higher levels of GSCM implementation and achieves better performance outcomes than the other three manufacturer types.

Zhu et al. [17] examined the GSCM drivers, initiatives and performance of the automotive supply chain using an empirical analysis of 89 automotive enterprises within China. The results showed that the enterprises experienced regulatory and market pressures and the improvements achieved by GSCM implementation are in environmental and operational performance but not in economic performance.

Carbone and Moatti [18] is an explorative paper investigating the current practices of companies in the context of a green supply chain, highlighting specific patterns per country and/or industry. The study also discussed the drivers, barriers and main results related to the GSCM based on a global survey on supply chain initiatives.

Walker et al. [19] explored the factors that drive or hinder organizations to implement GSCM initiatives and identified the main categories of internal and external drivers of GSCM practices based on interviews from seven different private and public sector organizations. The paper concluded that the external drivers have more influence on organizations then the internal drivers.

Zhu et al. [20] investigated the correlation of two major factors, organizational learning and management support, with the extent of adoption of GSCM practices in Chinese manufacturing firms. The paper then concluded that there exist a positive relation ship between these two factors and GSCM practices.

Zhu et al. [21] investigated the construct of and the scale for evaluating GSCM practices implementation with data collected from 341 Chinese manufacturers. Two measurement models of GSCM practices implementation were tested and compared by confirmatory factor analysis. The paper concluded that the models suggested are both reliable.

Zhu et al. [22] compared the implementation levels of five GSCM practices among small-, medium- and large-sized organizations in China based on data collected from 200 organizations. The analysis showed that medium- and large-sized organizations were more advanced than their smaller-sized counterparts on most aspects of these GSCM practices.

Zhou [23] studied the implementation of GSCM in textile firms operating in China. The author explained the core contents of GSCM implementation and then underlined the fact that the enterprises have to establish organization, cooperation mode and performance management system in the process of implementation.

Holt and Ghobadian [24] examined the extent of GSCM in the United Kingdom (UK) manufacturing sector through survey results obtained from 60 manufacturing companies. The environmental legislation in UK is cited as the most influential driving factor for manufacturing companies in this study.

Hu and Hsu [25] used the results of a survey with 84 participants to explore critical factors for GSCM practice implementation in the Taiwanese electrical and electronics industries relative to European Union directives. Finally, 20 critical factors were extracted into four dimensions which are supplier management, product recycling, organization involvement and life cycle management.

Kim [26]conducted a survey with 223 small and medium sized electronic companies in Korea in order to evaluate dimensions of GSCM implementation. The study provided evidence that GSCM practice implementation has a positive relationship with employees' job satisfaction, firms' operational efficiency, and relational efficiency between the suppliers but did not find a direct link between GSCM practice implementation and business performance.

Ninlawan et al. [27] utilized from case studies of 11 computer parts' manufacturers in Thailand in order to survey current green activities and to evaluate their GSCM activities. According to the obtained results, the authors then presented several suggestions to develop GSCM in electronics industry.

Thun and Müller [28] investigated the status of GSCM in the German automotive industry by analyzing the several aspects of GSCM such as driver forces, barriers and goals according to the opinions of managers and its effects on the competitiveness of the companies. A direct link between GSCM and higher performance is asserted by the authors.

As mentioned before, beside from GSCM studies that focus solely on the environmental dimension of sustainability, recently studies where economic and social dimensions of sustainability are considered as well as the environmental dimension are published. Studies about SSCM are listed and summarized below.

Koplin et al. [29] presented a SSCM approach to integrate social and environmental standards into supply policy and supply management at the Volkswagen AG. Therefore, required changes of the sourcing and supply structures were identified during an action research project, and possible options adaptable for company internal integration were shown.

Nagurney et al. [30] proved that the supply chain model with environmental concerns can be reformulated and solved as an elastic demand transportation network equilibrium problem. This paper, hence, tried to construct of a bridge between sustainable supply chains and transportation networks.

Svensson [31] described and illustrated aspects of SSCM based on an empirical study limited to the clothing industry. In this study, the terms of first-, second- and n-order supply chains are introduced. The author concluded that n-order supply chains should be considered in business practices from the point of origin in the first-order supply chains in order to enhance corporate efforts of SSCM.

Carter and Rogers [32] examined the concept of sustainability and its applications in SCM with a comprehensive literature review. They used conceptual theory building to introduce the concept of sustainability to the field of SCM and demonstrate the relationships among environmental, social, and economic performance within a SCM context.

Hutchins and Sutherland [33] reviewed in their study metrics, indicators, and frameworks of social impacts and initiatives relative to their ability to evaluate the social sustainability of supply chains. Then, the relationship between business decision-making and social sustainability was explored and a general strategy for considering measures of social sustainability was proposed, and a variety of indicators of Corporate Social Responsibility (CSR) are described.

Keating et al. [34] identified the actions to make for developing a SSCM. A case study of the Westpac Banking Corporation – one of the world's most socially responsible banks –was undertaken to examine how they approached the challenge of managing CSR in their supply chain.

Seuring and Müller [4] presented a literature review on SSCM taking 191 papers published from 1994 to 2007 into account and offered a conceptual framework to summarize the research. The authors proposed two distinct strategies; supplier management for risks and performance, and SCM for sustainable products. Finally they underscored the fact that research was still dominated by green/environmental issues and the integration of the three dimensions of sustainability was still rare.

Seuring and Müller [5] aggregated expert opinions and extracted four major topics using the findings from a Delphi study. These topics were pressures and incentives for SSCM, identifying and measuring impacts on SSCM, supplier management and SCM.

Pagell and Wu [35] created a sustainable supply chain model based on 10 case studies. The model is used for examining the social and environmental outcomes of supply chain activities. The analysis suggested that the practices that lead to a more sustainable supply chain help to achieve best practices in traditional SCM.

Studies that consider only the environmental issues and studies that consider sustainability in SCM are mentioned in this section. The scope of these papers and the tools they utilized from are denoted in Table 2.1.

Table 2.1 Sustainable and Green SCM studies.

Authors	*Ref.*	*Method(s)*	*Scope*
Sarkis (2003)	[9]	-	Green Supply Chain Management
Zhu and Sarkis (2004)	[10]	Survey	Sustainable Supply Chain Management
Beamon (2005)	[11]	-	Green Supply Chain Management
Rao and Holt (2005)	[12]	-	Green Supply Chain Management
Kainuma and Tawara (2006)	[13]	-	Green Supply Chain Management
Tsoulfas and Papis (2006)	[1]	-	Green Supply Chain Management
Zhu and Sarkis (2006)	[14]	-	Green Supply Chain Management
Ferretti et al. (2007)	[15]	-	Green Supply Chain Management
Koplin et al. (2007)	[29]	Case Study	Sustainable Supply Chain Management
Nagurney et al. (2007)	[30]	-	Sustainable Supply Chain Management
Svensson (2007)	[31]	Empirical Study	Sustainable Supply Chain Management
Zhu et al. (2007a)	[16]	Survey	Green Supply Chain Management
Zhu et al. (2007b)	[17]	Survey	Green Supply Chain Management
Carbone and Moatti (2008)	[18]	-	Green Supply Chain Management
Carter and Rogers (2008)	[32]	Literature Review	Sustainable Supply Chain Management
Hutchins and Sutherland (2008)	[33]	-	Sustainable Supply Chain Management
Keating et al. (2008)	[34]	Case Study	Sustainable Supply Chain Management
Seuring and Müller (2008a)	[4]	Literature Review	Sustainable Supply Chain Management
Seuring and Müller (2008b)	[5]	Delphi Study	Sustainable Supply Chain Management
Walker et al. (2008)	[19]	-	Green Supply Chain Management
Zhu et al. (2008a)	[20]	-	Green Supply Chain Management
Zhu et al. (2008b)	[21]	Survey	Green Supply Chain Management
Zhu et al. (2008c)	[22]	Survey	Green Supply Chain Management
Pagell and Wu (2009)	[35]	Case Study	Sustainable Supply Chain Management
Zhou (2009)	[23]	-	Green Supply Chain Management
Holt and Ghobadian (2010)	[24]	Survey	Green Supply Chain Management
Hu and Hsu (2010)	[25]	Survey	Green Supply Chain Management
Kim (2010)	[26]	Survey	Green Supply Chain Management
Ninlawan et al. (2010)	[27]	Case Study	Green Supply Chain Management
Thun and Müller (2010)	[28]	Case Study	Green Supply Chain Management

2.2 SUSTAINABLE SUPPLIER SELECTION

2.2.1 Supplier Selection

As the selection of the right supplier(s) helps companies to raise their competitive abilities, this subject attracted the attention of many scholars and administrators. Supplier selection has been discussed for more than 30 years and is also a popular topic within the field of SCM [6]. Kar [36] stated that the supplier selection studies have dated back to as early as 1960s. As the supplier selection literature is extremely rich, a detailed survey is not given here in this study and the readers are referred to several studies such as; Weber et al. [37] which classifies 74 articles appeared between 1966 and 1991, Sonmez [38] which analyzed 145 papers appeared between 1985 and 2005 and Ho et al. [39] which gathered 78 articles appeared between 2000 and 2008. Additionally an extensive survey of the state-of-the-art is provided by Bruno et al. [40]. They gathered and analyzed 201 articles on vendor selection/evaluation and supplier selection/evaluation problems published between 2003 and 2008. The authors also classified the articles according to the country where the institution of the first author is based. In their study, Turkey and Taiwan are stated as the most productive countries in this field following the major contributor United States of America. In order to keep the literature survey section of this study clear and subject oriented, the literature review of supplier selection with environmental considerations and supplier selection with sustainability considerations are presented in detail in the sections below respectively. Moreover, a wide literature review of the supplier selection studies utilizing from the MCDM techniques mentioned in the proposed methodology of this study is presented in Section 4. Beside these studies focused on environmental or sustainability issues and utilized from the techniques used in this study, recently numerous studies on the subject of supplier selection are published. Ng [41] proposed a weighted linear program for the multi-criteria supplier selection problem and presented a transformation technique which enables the weighted linear program to be solved without optimization. Golmohammadi et al. [42] developed a decision making problem using neural networks for selection of vendor suppliers. In order to find the initial weights and architecture of the network the Genetic Algorithm (GA) is used and the proposed approach is applied in a case study of a company in the automotive industry. Tsai et al. [6] developed the decision making procedure based on the attribute-based ant colony system platform examining the critical factors in order to select the appropriate suppliers. Aksoy and Öztürk [43] presented a novel approach based on a neural network used for supplier selection and performance evaluation in just in time production environments. Özkök and Tiryaki [44] proposed a compensatory method to solve multi-objective linear supplier selection problem with multiple-item where the problem is to select suppliers for each product and determine how much should be purchased from each selected supplier. The proposed approach is applied in a case study of a textile firm in Turkey.

2.2.2 Green Supplier Selection

In recent years, an increasing environmental awareness has favoured the emergence of the new green supply chain paradigm; thus, also in the supplier selection problem, green criteria have been incorporated [45]. Over the last decade, the green supplier selection and evaluation is studied by numerous authors. Papers covering the period from 2003-2010 are presented in detail in this section. This survey shows that the attention to this topic is at an early stage. However it is obvious that the interest on the environmental issues have grown increasingly between 2007 and 2010. Below, papers on the subject of green supplier selection/evaluation are listed and summarized in order to present the current situation of the related literature.

Handfield et al. [46] utilized from AHP as a decision support model in supplier selection. Environmental criteria are integrated into the model and three case studies were carried out to demonstrate the benefits and weaknesses of using AHP in this manner.

Humphreys et al. [47] constructed a knowledge based system for the supplier selection process which incorporates environmental performance. Additionally, in order to illustrate the implementation of the proposed model, an example is also used. The criteria identified in this study were put into two main groups; quantitative environmental criteria and qualitative environmental criteria.

Humphreys et al. [48] proposed a user-centred hierarchical system employing scalable fuzzy membership functions for the supplier selection process. The presented framework introduced environmental criteria into the existing supplier selection process.

Lu et al. [49] presented a multi-objective decision making process for GSCM in order to measure and evaluate suppliers' performance. In the methodology, to cope with the subjectivity in weighting process, the author utilized from fuzzy logic process.

Chiou et al. [50] identified criteria of green supplier selection and proposed a multi-criteria decision model based on fuzzy AHP. They applied the proposed model for selecting green suppliers among the American, Japanese and Taiwanese Electronics Industry in China.

Kannan et al. [51] analyzed the interaction of green supplier selection criteria. The authors utilized from Interpretive Structural Modelling (ISM) and AHP techniques in order to evaluate the environmental performance of the supplier alternatives. The effectiveness of the ISM and AHP model is then illustrated using an automobile company in the southern part of India.

Özgen et al. [52] integrated the AHP and the multi-objective possibilistic linear programming (PLP) techniques. The model is applied to determine the criteria used to evaluate and select suppliers considering environmental factors. Additionally the optimum order quantities assigned to each supplier are defined.

Yang and Wu [53] considered green supplier selection as a strategic phase in green SCM. For this purpose, the authors constructed the multi-level extensible synthetic evaluation model based on entropy weight. The order preference of green suppliers is attained applying the proposed evaluation model in the green supplier selection phase of an electrical appliance manufacturing enterprise

Yu and Tsai [54] proposed a framework which integrates the AHP and Integer Programming to evaluate supplier performance. A detailed case study is presented in which five wafer suppliers are evaluated in order to achieve an objective and flexible method. Beside the traditional factors such as cost, delivery and service, environment is also considered as a selection factor. The authors enounced that the proposed methodology can lead to substantial improvements in supplier management.

Hsu and Hu [55] presented an ANP approach to incorporate the issue of Hazardous Substance Management into supplier selection and evaluation in GSCM practice. An illustrative example in an electronics company where the supplier selection process is in accordance with the requirements of hazardous substance for environmental regulations is also presented in this study.

Jabbour, A. and Jabbour, C. [56] investigated if Brazilian companies are adopting environmental requirements in the supplier selection process. Based on five Brazilian case studies with industrial companies the authors analyzed the relation between the level of environmental management maturity and the inclusion of environmental criteria in the companies' selection of suppliers. The paper concluded that a company with more advanced environmental management adopts more formal procedures for selecting environmentally appropriate suppliers than others.

Lee et al. [57] proposed a model to select the factors for evaluating green suppliers, and to evaluate the performance of suppliers. In this paper the Delphi method is applied to differentiate the criteria for evaluating traditional suppliers and green suppliers. The Fuzzy AHP technique is then used to evaluate the importance of the selected criteria and the performance of green suppliers. The proposed model is then illustrated by a case study of a TFT–LCD manufacturer in Taiwan,

Li and Zhao [58] used Threshold Method and the Gray Correlation Analysis for building a green supplier selection framework for the vehicle manufacturer enterprises. In this paper an assessment index system for suppliers of vehicle components is built based on GSCM requirements. The authors enounced that an effective assessment system can make supplier selection be more objective, scientific and supply chain be more green.

Önüt et al. [59] developed an approach based on ANP and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods for supplier evaluation of a telecommunication company in the GSM sector in Turkey under the fuzzy environment. This approach is demonstrated with a real world case study and followed by sensitivity analysis.

Qingkui and Juhnu [60] proposed a new construction method of the judgment matrix in AHP based on rough sets theory and built a supplier evaluation index system in green supply chain. According to this study, an ideal strategic partner in green supply chain not only ensures that the enterprise complies with environmental regulations, but also possesses the awareness to prevent environmental pollution at the source.

Tuzkaya et al. [61] presented a methodology where a hybrid Fuzzy ANP and Fuzzy PROMETHEE approach is utilized for the supplier evaluation considering the environmental performances of these suppliers. Additionally, a real life case study from Turkish White Goods Industry is given to foster the better understanding of the methodology and the obtained results are analyzed with sensitivity analyses.

Yan [62] proposed a methodology based on AHP combined GA for the green supplier evaluation. In the study, a program which makes real-time feedback of information for green industry is designed based on the proposed methodology.

Awasthi et al. [63] presented a fuzzy multi-criteria approach for evaluating environmental performance of suppliers. After identifying the environmental criteria, using linguistic assessments experts rated supplier alternatives and criteria. Then using Fuzzy TOPSIS, the overall ratings were generated. The proposed methodology is also illustrated by a numerical application.

Bai and Sarkis [64] mentioned that there exist a gap between the management of supplier development programs and green supplier development programs. Authors then introduced a model using rough set theory in order to investigate the relationships between organizational attributes, supplier development programs and performance outcomes which focus on environmental and business dimensions. The paper finally concluded that for higher performance in either business or environmental performance, the investment and resource transfer within the SC is not needed and the organizational size is not an indicator.

Kuo et al. [65] combined Analytic Neural Network and ANP into Data Envelopment Analysis (DEA) to build a green supplier selection system. In order to determine the green supplier selection indicators, this study carried out Delphi method which helps collecting data form a series of expert panels. The model contains as supplier selection indicators six dimensions including environment and CSR beside the traditional indicators such as quality, cost, delivery and service. Hereby, this study goes beyond the scope of green supplier selection and can be considered as well as a sustainable supplier selection study.

Sang and Qi [66] presented an ANP with benefits, opportunities, costs and risks model including environmental considerations to evaluate the performance of buyer-supplier and to select the most suitable supplier for cooperation. The model is then illustrated by an example of a pharmaceutical enterprise.

Thongchattu and Siripokapirom [67] proposed a model using AHP and Neural Network in order to establish a framework for green supplier selection. They concluded that acquisition of ISO 14000 is a strong marketing tool worth investing than other green projects which would normally be eliminated during economic recessions.

Zhu et al. [68] utilized from a methodology using portfolio analysis based on the ANP which integrates and applies the portfolio supplier management approach to an environmentally oriented decision environment. The paper also discerned various characteristics of the suppliers and produced recommendations on supplier management for an exemplary case scenario.

The above mentioned studies on the subject of green supplier selection/evaluation are summarized and listed in Table 2.2.

Table 2.2 Green supplier selection studies and the methods used.

Authors	***Date***	***Ref.***	***Method(s)***
Handfield et al.	2002	[46]	AHP
Humphreys et al.	2003	[47]	Knowledge Based System
Humphreys et al.	2006	[48]	Fuzzy Set Theory
Lu et al.	2007	[49]	Fuzzy Set Theory
Chiou et al.	2008	[50]	AHP
Kannan et al.	2008	[51]	ISM & AHP
Özgen et al.	2008	[52]	AHP & PLP
Yang and Wu	2008	[53]	Entropy
Yu and Tsai	2008	[54]	AHP & IP
Hsu and Hu	2009	[55]	ANP
Jabbour, A. and Jabbour, C.	2009	[56]	Empirical Study
Lee et al.	2009	[57]	Fuzzy AHP & Delphi
Li and Zhao	2009	[58]	Threshold Method & Gray Correlation Analysis
Önüt et al.	2009	[59]	ANP & TOPSIS
Qingkui and Juhnu	2009	[60]	AHP & Rough Set Theory
Tuzkaya et al.	2009	[61]	Fuzzy ANP & Fuzzy PROMETHEE
Yan	2009	[62]	AHP & GA
Awasthi et al.	2010	[63]	Fuzzy TOPSIS
Bai and Sarkis	2010a	[64]	Rough Set Theory
Kuo et al.	2010	[65]	ANN & ANP & DEA
Sang and Qi	2010	[66]	ANP
Thongchattu and Siripokapirom	2010	[67]	AHP & Neural Network
Zhu et al.	2010	[68]	Portfolio Analysis & ANP

2.2.3 Sustainable Supplier Selection

As the interest in green and sustainable supply chain management increases, supplier selection which is an important process in the SCM becomes more important. Consequently, in the literature many authors studied these supplier selection approaches. Green supplier selection has been a popular subject which is focused on the environmental considerations as well as the traditional economic considerations since the last decade. On the other hand sustainable supplier selection which adds social dimension into the supplier selection process with economic and environmental considerations is a novel topic. Thus, there are several studies about the green supplier selection explained in detail in the previous section and remarkably few studies about the sustainable supplier selection. While the works on the supplier selection with environmental and economic considerations are abundant, those that concern sustainability issues with its three dimensions are rather limited.

Beske et al. [69] asserted that to achieve a sustainable supply chain, suppliers should be evaluated according to their sustainability competence. For such evaluation, the implementation of environmental and social standards is considered as critically important. However the authors mentioned the lack of data on their importance for supplier selection. This study investigated the implementation degree of these standards in the German car industry utilizing from a survey. They concluded that the environmental standards are widely used and it is not the case for social standards.

Bai and Sarkis [70] expanded the novel approach introduced by Li et al. [71] in order to integrate sustainability discussion into the supplier selection modelling area. The model utilized grey system and rough set theory and included the explicit consideration of sustainability attributes. The study focused on the integration of generic sustainability metrics and attributes based on the literature and provided examples of various triple-bottom-line attributes that could be included in the methodology.

Ladd and Badurdeen [72] presented a review and selection of metrics that can be used to evaluate suppliers from economic, environmental and social perspectives of sustainability. For this purpose, the typical relationship between an Original Equipment Manufacturer and a contract manufacturer is considered with particular emphasis on consumer electronics. The metrics reviewed in this study are grouped under three categories such as environmental, economic and social. The definitions of these metrics are also stated according to the related literature.

Büyüközkan and Çifçi [73] proposed an effective model for supplier selection with sustainability principles. The proposed novel approach is based on Fuzzy ANP within multi-person decision-making schema under incomplete preference relations. In order to prove the efficiency of the model, the proposed evaluation framework was applied at a main producer of Turkish white goods industry. In their model, the authors cited social responsibility and environmental competencies among the evaluation criteria for sustainable supplier selection.

According to the literature review, there are very few studies that take into account the sustainability issue with its three dimensions in supplier selection procedure. Even though there are several studies that consider the environmental factors beside the economic ones in order to evaluate the supplier alternatives, the lack of sustainable supplier selection studies still exists. Therefore, in this a supplier evaluation and selection model that considers economic, social and environmental dimensions of the sustainability concept is proposed.

3. EVALUATION MODEL PROPOSITION

As reported by De Boer et al. [74] and De Boer and Wegen [75], a supplier selection problem typically consists of four phases, namely (1) problem definition, (2) formulation of criteria, (3) qualification of suitable suppliers and (4) final selection of the ultimate supplier(s). After determining the criteria and the dependency relations between them, the network structure of the proposed framework is constructed through expert opinions. In this study the expert opinions are provided by HAVI Logistics which is detailed in the illustrative example section. The problem of sustainable supplier selection is already defined in the earlier sections. Hence, at this section based on the literature of supplier evaluation or selection criteria an evaluation model containing these criteria and criteria clusters is proposed.

In this study, the novel concept of sustainability is integrated into the supplier selection and evaluation phase. According to this aim, selection criteria and sub criteria are chosen based on the related literature with a broad sustainability perspective. Table 3.1 gives a detailed review of the literature covering 56 papers published between 2000 and 2011. This review particularly summarizes the studies where the criteria of the proposed model are cited. Those criteria and sub-criteria are explained in detail in this section.

3.1 SUSTAINABILITY DIMENSION

Many studies in academia and business show that there is an increasing interest on the concept of sustainability and it offers undeniable benefits to companies. Sustainable development and sustainability is frequently interpreted as a synthesis of economic, environmental and social development, which is also called as the triple-bottom-line approach [4], [70]. In fact achieving sustainability is achieving a balance between economic activities and associated environmental and social impacts. When dealing with SSCM all these three types of sustainability objectives should be considered [76]. According to the triple bottom line approach, the three criteria below are selected.

Environmental:

This criterion includes supplier's environmental performance and practices. In general, environmental practices refer to policies and procedures and environmental performance refers to resource consumption and pollution production [70]. Zhou et al. [76] denote that the environmental sustainability consists of efficient use of resources and minimized waste generation.

Economic:

Economic dimension of the sustainability is one of the most common factors used in the literature of supplier selection as it is the main objective of businesses. Economic sustainability is defined by the Global Reporting Initiative as concerning ''an organization's impacts on the economic circumstances of its stakeholders and on economic systems at the local, national and global levels.'' This definition involves both external and internal effects while the definition of the United Nations (UN) considers only the internal effects. UN defines the economic dimension as the business' short and long term financial stability and survival capabilities [77]. External factors mentioned in the first definition may be included in the social dimension of the sustainability. Thus, in this study the second approach is adopted.

Social:

Social factors were not commonly used in the earlier literature of supplier evaluation or selection. On the other hand recent studies where the sustainability concept is adopted showed that the social criteria are used as a supplier selection or evaluation criteria. The social dimension of the sustainability is concerned with the supplier's impacts on the social systems in which it operates and the supplier's relationship with its various stakeholders [77].

Table 3.1 Literature review for supplier selection criteria (Part1).

		New et al. (2000) [78]	Zhou et al. (2000) [76]	Min and Galle (2001) [79]	Carter and Dresner (2001) [80]	Hall (2001) [81]	Handfield et al. (2002) [46]	Petroni and Panciroli (2002) [82]	Barla (2003) [83]	Bovea and Wang (2003) [84]	Humpreys et al. (2003) [47]	Labuschagnea et al. (2005) [77]	Rao and Holt (2005) [12]	Tsoulfas and Pappis (2006) [1]	Zhu and Sarkis (2006) [14]	Araz et al. (2007) [85]	Chan and Kumar (2007) [86]	Gencer and Gürpınar (2007) [87]	Huang and Keskar (2007) [88]	Koplin et al. (2007) [29]	Lu et al. (2007) [49]	Yuzhong and Liyun (2007) [89]	Chan et al. (2008) [90]	Chiou et al. (2008) [50]	Ho et al. (2008) [39]	Hutchins and Sutherland [33]	Seuring and Müller (2008b) [5]	Tello and Yoon (2008) [92]
Sustainability Dimension	Environmental		*																								*	
	Economical											*															*	
	Social											*								*						*	*	
Sustainability Motivation	Government & Legal Regulations			*	*	*	*				*													*				
	Customer pressure	*			*	*				*					*													*
	Economic Advantage												*		*												*	
	Brand Image						*				*													*				
Supplier Profile	Reputation of Industry																								*			
	Cooperative History																											
	Geographical Position																	*					*					
	Financial Status								*							*	*	*				*	*	*				
Operational & Managerial Competencies	Technological Capability																	*										
	System Adaptability																										*	
	Human Resources										*					*		*										
	Production Facilities & Capacity																	*										
Environmental & Social Competencies	Environmental Management						*				*													*				
	Design for Environment						*				*													*				
	Pollution Control										*								*		*							
	Laws & Regulations						*				*													*			*	
	Health & Safety Practices																		*								*	
	Community Development																											
Performance Targets	Time															*						*		*	*			
	Cost															*						*		*	*			
	Quality															*						*		*	*			
	Flexibility													*		*												
	Innovativeness							*																			*	
	Sustainability Competence											*															*	

Table 3.2 Literature review for supplier selection criteria (Part2).

Group	Criterion	Walker et al. (2008) [19]	Yang and Wu (2008) [53]	Cui et al. (2009) [93]	Hsu and Hu (2009) [55]	Jabbour,A. & Jabbour,C. [56]	Lee et al. (2009a) [57]	Li and Zhao (2009) [58]	Önüt et al. (2009) [59]	Pagell and Wu (2009) [35]	Pang (2009) [94]	Qingkui and Juhnu (2009) [60]	Shen and Yu (2009) [95]	Tuzkaya et al. (2009) [61]	Tsai et al. (2009) [144]	Wu et al. (2009) [97]	Yan (2009) [62]	Awasthi et al. (2010) [63]	Bai and Sarkis (2010a) [64]	Bai and Sarkis (2010b) [70]	Chakraborty et al. (2010) [98]	Fan et al. (2010) [99]	Grisi et al. (2010) [100]	Kuo et al. (2010) [65]	Razmi and Rafiei (2010) [101]	Tuzkaya et al. (2010) [102]	Zhu et al. (2010) [68]	Punniyamoorthy et al. (2011) [103]	Vinodh et al. (2011) [104]
Sustainability Dimension	Environmental																			*									
	Economical																												
	Social						*							*						*				*					
Sustainability Motivation	Government & Legal Regulations						*							*				*											
	Customer pressure																												
	Economic Advantage	*								*																			
	Brand Image					*	*							*				*					*						
Supplier Profile	Reputation of Industry							*	*							*							*					*	*
	Cooperative History						*					*				*				*									
	Geographical Position							*				*											*		*			*	
	Financial Status						*														*		*		*			*	*
Operational & Managerial Competencies	Technological Capability						*	*			*		*			*				*	*		*				*		
	System Adaptability													*							*					*			
	Human Resources							*							*						*		*						
	Production Facilities & Capacity			*																			*					*	
Environmental & Social Competencies	Environmental Management				*	*														*			*				*		
	Design for Environment					*																	*						
	Pollution Control					*	*					*		*	*		*	*		*		*					*		
	Laws & Regulations						*							*				*						*					
	Health & Safety Practices														*				*										
	Community Development																		*			*							
Performance Targets	Time		*					*	*			*				*	*			*	*		*	*			*	*	*
	Cost		*	*					*			*				*	*			*	*		*	*			*	*	
	Quality		*	*	*			*	*		*	*	*							*	*		*	*			*	*	*
	Flexibility			*												*				*	*						*		*
	Innovativeness			*									*		*					*							*		
	Sustainability Competence						*																*	*					

3.2 SUSTAINABILITY MOTIVATION

Sustainability with its economic, environmental and social aspects attracts attention of many different groups in contact with the companies such as customers, suppliers, shareholders, stakeholders, partners, outsourcers, legislative and judicial branches. Each of these groups acquires several objectives depending on their relationships with the company. Thus there exist various forces driving companies to be sustainable such as regulations, social activism, business opportunities from technological advance, customer demand for environmentally friendly products, transition of business mission and orientation toward CSR [92]. In many studies legal demands/regulation, response to stakeholders, competitive advantage, customer demands, reputation loss, and environmental and social pressure groups are considered as sustainability drivers [4]. Additionally, sustainability-oriented supplier selection obligates the company to act according to its own sustainability motivation. The motivations of the company distinguish the evaluation criteria and their weights in the decision making process.

Government & Legal Regulations:

Due to increasing governmental and local regulation and pressure on the environmental problem all over the world, companies must acknowledge and respond to regulatory authorities' requirements to comply with the environmental standard [50].

Customer pressure:

Recently as the awareness of people about the environmental and social issues grows, consumers act more responsible and selective. This shift in customer perspectives and attitudes is affecting their relationships with the producer or service provider companies. Customer attitude and demand toward sustainable products and services is certainly helping to change the way that corporations produce goods and services [92]. As much as the business profitability and economic growth are affected by the customer demand, the company's strategy of supplier selection becomes more sensitive to the customer pressure [105].

Economic Advantage:

The advantages of the sustainability are discussed in the early literature. By reducing the waste created and the energy consumption sustainability provides cost savings. Pagell and Wu [25] denoted that by reducing the fuel usage and cutting the costs of packaging, it is possible to reduce the shipping costs which are considered as a traditional goal in logistics. On the other hand as the demand for sustainable products and services grows, by getting more sustainable companies increase their market shares and their revenues. That is why gaining economic advantage can be stated as a motivation for sustainable supplier selection.

Brand Image:

The increasing awareness about the environmental issues leads companies to rearrange their positions on the market by strengthening their images. Earlier studies discuss environmental dimension of the sustainability and introduce the importance of the green image. Handfield et al. [46], Humphreys et al. [47], Lee et al. [57], Tuzkaya et al. [61], mentioned that besides the well known direct environmental costs, loss on environmental image can be considered as a cost. Environmental and economic image of a company form also its brand image. From this point of view by implementing sustainability into their actions, companies strengthen their images. Thus, a strong brand image is one of the motivations for selecting a supplier with sustainable considerations.

3.3 SUPPLIER PROFILE

Supplier profile consists of general information about the supplier. It is one of the main supplier selection criteria used in many studies in the literature. Sustainable supplier selection as it is mainly about selecting a supplier; it includes the basic supplier selection criteria. These criteria are commonly used in supplier selection or evaluation studies. Based on the relevant literature sub criteria below are selected.

Reputation of Industry

Supplier's reputation consists of the level of satisfaction of the existing customers and is related to the supplier's success in business. As the reputation of industry is an indicator for the existing and potential customers it is commonly used as a selection criterion in the literature.

Cooperative History

Similar to the reputation of industry criterion, cooperative history can be considered as an indicator for the potential customers. But in that case, the main purpose is the evaluation of the supplier based on its earlier cooperation practices. Additionally, suppliers which realized some cooperation projects successfully and provided satisfaction for all the co-operators, are more likely to achieve success in the forthcoming cooperative activities. Hence, the cooperative history is utilized as a sub-criterion of supplier profile criterion.

Geographical Position

Geographical position of a company directly affects the access to several sources such as raw materials, human resources, transportation networks. Thus this criterion has important impacts on the supplier's performance. This sub criterion is cited in supplier selection by many authors.

Financial Status

Financial status of a supplier affects the supplier's performance in many fields. It is considered as an important criterion in many studies since Dickson [106]. As cited in Chan and Kumar [86] this criterion should be analyzed carefully in supplier selection.

3.4 OPERATIONAL & MANAGERIAL EVALUATION CRITERIA

In this study operational and managerial evaluation of the suppliers is considered as a supplier selection criteria as in recent studies such as Araz et al. [85] and Grisi et al. [100]. Operational and managerial evaluation of the suppliers is the evaluation of their capacities and capabilities which affects the performance of the relationship between the company and its supplier. Therefore, through a detailed literature survey on the subject, four sub criteria below are selected.

Technological Capability

Technological capability consists of a firm's capability to adopt new technologies used in production or in management and to produce new product. Moreover, suppliers providing technological support for manufacturers and being involved in product development of manufacturers have become essential tendencies in SCM according to Wu and Weng [107].

System Adaptability

When selecting a supplier any kind of accordance between the company and the supplier plays an important role. A supplier that has high system adaptability can be a good business partner as it will adapt to the management or operation systems already present. Additionally, in such case, the supplier will adapt easily the newly developed systems. System adaptability therefore is selected as a sub criterion of operational and managerial evaluation criteria in this study as in Tuzkaya et al. [61], Tuzkaya et al. [102].

Human Resources

Human resources of a supplier can be evaluated by different indicators. Besides the education level and the capacity of the employees enounced in Araz et al. [85], Li and Zhao [58], Chakraborty et al. [98] and Grisi et al. [100], the training possibilities offered to the employees consists of the human resources quality according to Humphreys et al. [47], Gencer and Gürpınar [87], Tsai et al. [96]. As the human resource quality affects the performance of a firm it is used as a supplier selection criterion.

Production Facilities Capacity

Facility capacity is an essential criterion because of its impacts on the order fulfilment. On the other hand the importance of the capacity of the supplier varies according to the duration of the planned cooperation. In case of long term cooperation, the current capacity may not be sufficient even if it is enough for that time.

3.5 ENVIRONMENTAL & SOCIAL COMPETENCIES

As mentioned in the earlier sections, with the increasing interest on the environmentally conscious supply chains that are also called green supply chains, the environmental competencies gained importance in supplier selection. Noci [108] defines environmental competency as "the sum of qualitative factors which reflect the ability of the suppliers to implement a process of gradual reduction of the environmental impact due to their production processes, to design components that optimize the use of natural resources and which are in agreement with the environmental management dictated by the laws and the company". Furthermore, sustainability including environmental and social issues beside economic ones obliges to consider social competencies in order to realize a sustainable supplier selection. There exist numerous studies in the literature that considered environmental and social competencies as an evaluation criterion for suppliers.

Environmental Management Systems

According to Humphreys et al. [47] diffusing environmental management techniques along the supply chain is an appropriate method of enhancing the environmental performance of an industry. It provides periodically repeated verification of environmental compliance which overall aim to the continuous improvement of the environmental performance [100]. Environmental management systems consist of ISO certifications, implementations, operations [46], environmental policies and planning.

Design for Environment

Design for environment criterion includes the supplier's capability of designing a product according to the environmental requirements according to Humphreys et al. [47]. In other words, design for environment refers to a design which reduces the environmental impact of products throughout the whole product life cycle including the choice of raw materials, development, production, marketing, use and disposal of products [50].

Pollution Control

According to Tsai et al. [96], pollution control consists of the optimization of resource consumption and prevention of waste. The consumption of water, fossil fuels or other natural resources results in waste creation such as solid wastes, hazardous wastes and all kind of emissions. Therefore, pollution control including pollution production and resource consumption which are separately used in studies such as Bai and Sarkis [70] and Zhu et al. [68], is cited as a sub-criterion in this study. Additionally, in the literature of supplier selection where environmental concerns are integrated in the selection process the pollution control is used as a criterion in many studies.

Laws & Regulations

Governments and international organizations take precautions in order to protect the environment and the rights of the society by making laws and regulations. These laws and regulations consist of necessary steps to take for the protection of the environment and social rights. A supplier which respects these laws and regulations means that it provided the basic requirements of environmental and social dimensions of sustainability even though these requirements can be considered insufficient for some cases. There are several studies in the literature that highlights the importance of this criterion in supplier selection.

Health & Safety Practices

Health and safety practices are related to the social dimension of sustainability and they indicate the supplier's sustainability level. Therefore it is used as a criterion for supplier selection in several studies. Tsai et al. [96] used health and safety as a criterion which helps to measure a firm's social responsibility level. While Huang and Keskar [88] used only safety as a society related supplier selection factor, Bai and Sarkis [64] cited health and safety practices as a social metric in sustainable supplier selection.

Community Development

As the social awareness growing, companies are more expected to spend on community and make charitable contributions [99]. On the other hand, it is possible to strengthen the relationship with stakeholders, customers and non-governmental organizations by supporting educational institutions, community projects and giving grants and donations [64]. Hence, supplier's support for community development is cited as a sustainability oriented selection criterion in this study.

3.6 PERFORMANCE TARGETS

Supplier's performance measurement is a commonly studied subject in the literature. Since the pioneering work of Dickson in 1966 many authors studied on this issue. According to Chiou et al. [50] a suitable supplier can offer the company the right quality products and right quantity at reasonable prices and at the right time. As time, cost and quality are the most commonly used factors for supplier selection in the relevant literature these factors are used as performance targets in this study. In addition to this, as the global competition grows, performance evaluation needed new indicators. Thus, flexibility and innovativeness are cited as supplier selection criteria.

Finally with the increasing awareness of first environmental then sustainability issues during the last decades, sustainability competence (including green competence) of a supplier is denoted as a selection criterion. This cluster consists of the basic and simple sub-criteria and it is influenced by many other clusters mentioned earlier.

Time

This sub-criterion consists of supplier's commitment for on-time delivery and the length of the supply chain. There are numerous studies where time used as a supplier selection or evaluation criterion.

Cost

Cost criterion consists of price of goods, shipping costs and costs of pollution effects. In order to increase revenues and achieve competitive advantage, reducing costs is the main goal for companies. That is why when selecting a supplier overall cost is a critical factor. Cost is used in numerous studies like time.

Quality

Like cost and time, quality is also one of the most important criteria for companies. Quality as a sub criterion includes mainly quality systems, process quality, service quality and total quality management.

Flexibility

Flexibility criterion is a qualitative measure [85]. Flexibility is the capability to respond to a changing environment. Flexibility helps companies to cope with the uncertainties. Since sustainable development requires a long-term perspective for planning and policy development, flexibility is a crucial criterion for sustainable supplier selection.

Innovativeness

There is general agreement among scholars and practitioners that the innovative capacity of suppliers is a critical factor of their ability to respond to the increasing demands and challenges set by customers. According to Petroni and Panciroli [82] innovation capabilities are not only associated with traditionally measured innovation efforts in research and development and product/process innovation but also in supportive organizational capabilities in the form of innovation-oriented culture, skills and know-how of individuals and managerial practices. Thus innovative capabilities of a supplier are directly related to the attitude to knowledge exchange, culture of information sharing, technological awareness and managerial competence.

Sustainability Competence

Noci [108] cited green competence criterion for supplier selection and defined it as the assessment of the consistency of the suppliers' environmental performance with respect to the identified standards. Lee et al. [57] and Grisi et al. [100] defined environmental competence as the use of materials and process that have lower impact on natural resources. In this study as the main goal is achieving a sustainable supplier selection, sustainability competence is cited as a criterion. This criterion includes as well as the previously mentioned environmental competencies social and economic competencies. Thus sustainability competence is about environmental performance, potential financial benefits, economic performance, financial health, labour conditions, quality of human resources and income level and distribution as denoted in Labuschagnea et al. [77] and Kuo et al. [65].

4. PROPOSED INTEGRATED EVALUATION METHODOLOGY

The supplier selection problem is considered as a MCDM problem in numerous studies as it depends on many quantitative and qualitative factors. There are different MCDM methods used in supplier selection studies such as the AHP, ANP, Case-Based Reasoning, DEA , FST, GA, mathematical programming, Simple Multi-Attribute Rating Technique (SMART), and their hybrids. In the literature, these methods are applied for the supplier selection problem of different industries such as consumer product manufacturing [109] pharmaceutical [110], electronic [87] and agriculture [41], and industries. Ho et al. [39] gathered and analyzed 78 papers appeared in the international journals from 2000 to 2008 which use multi-criteria decision making approaches for supplier evaluation and selection. Readers are referred to this study for detailed information.

An integrated MCDM framework is proposed in this study, similar to the hybrid approaches in the literature, such as ANP and Goal Programming (GP) used in Demirtaş and Üstün [111], Fuzzy SMART used in Chou and Chang [112] and SMART integrated DEA approach used in Seydel [113]. Additionally, a detailed literature review of these methods and their application in supplier selection studies is presented in the sections below. The aim of the proposed methodology is to cope with the vagueness of the human judgments by the integration of FST into the analytic techniques which are DEMATEL used for determining the interdependencies between criteria, ANP used for determining the criteria weights and PROMETHEE to obtain the final ranking of the alternatives. The proposed evaluation procedure is illustrated in Figure 4.1.

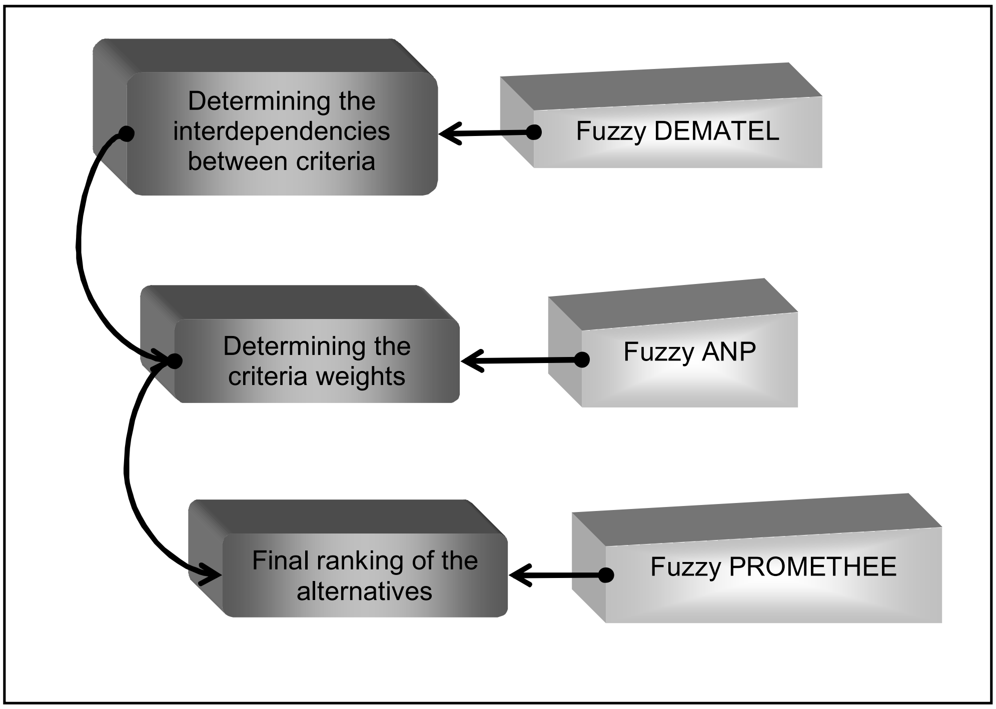

Figure 4.1 Evaluation procedure.

4.1 FUZZY SET THEORY

The supplier selection problem consists of a variety of qualitative and quantitative factors affecting the decision making process. This is a complicated process due to the fact that the relative importance values of these factors are determined through the expert opinions given in the form of linguistic assessment. Those assessments often involve gray areas indicated by the statements like maybe, more, little, etc. Approaches employing only exact numerical (crisp) values cannot support decision-making procedures for such evaluation problems. In order to deal with the vagueness and uncertainties of human opinions Zadeh [7] first introduced the FST. FST is incorporated into many concepts and procedures in order to enhance their capabilities to treat MCDM problems in vague environment. Thus, many studies in the field of supplier selection are utilized from FST and its combinations with different techniques. Boran et al. [114], Kara [115] and Sevkli et al. [116] used TOPSIS combined with fuzzy logic, Azadeh and Alem [117] used fuzzy DEA and Sevkli [118] proposed a fuzzy approach based on ELECTRE (ELimination and Choice Expressing the REality) for the supplier selection problem.

As mentioned before, to deal with the uncertainty due to imprecision and vagueness Zadeh [7] proposed the FST and introduced the concept of membership function. A major contribution of this theory is its capability of representing vague data [119]. As the FST is very helpful to deal with the vagueness of human expression, it is a commonly used theory in decision making problems. Hence in this study the fuzzy approach is used in combination with other techniques. In the following, some essential definitions of fuzzy logic are briefly reviewed.

Definition 1:

A fuzzy set $\widetilde{A}$ is a subset of a universe of discourse X, which is characterized by a membership function $\mu_{\widetilde{A}}(x)$ representing a mapping $\mu_{\widetilde{A}} : X \rightarrow [0, \ 1]$. The function value of $\mu_{\widetilde{A}}(x)\widetilde{A}$ is called the membership value, which represents the degree of truth that x is an element of fuzzy set $\widetilde{A}$. It is assumed that $\mu_{\widetilde{A}}(x) \in [0, \ 1]$, where $\mu_{\widetilde{A}}(x) = 1$ reveals that x belongs completely to $\widetilde{A}$, while $\mu_{\widetilde{A}}(x) = 0$ indicates that x does not belong to the fuzzy set $\widetilde{A}$.

Definition 2. A triangular fuzzy number can be defined as a triplet (a^l, a^m, a^u);.the membership function of the fuzzy triangular number $\widetilde{A}$ is defined as below [120]:

$$f_{\widetilde{A}}(x) = \begin{Bmatrix} 0, & x < a^l, \\ (x - a^l)/(a^m - a^l), & a^l \le x \le a^m, \\ (a^u - x)/a^u - a^m), & a^m \le x \le a^u, \\ 0, & x > a^u. \end{Bmatrix} \qquad (4.1)$$

Let $\widetilde{A}$ and $\widetilde{B}$ be two triangular fuzzy numbers parameterized by the triplets (a^l, a^m, a^u) and (b^l, b^m, b^u) respectively; then the operational laws of these two triangular fuzzy numbers are as follows [120]:

$$\widetilde{A}(+)\widetilde{B} = (a^l, a^m, a^u) \oplus (b^l, b^m, b^u) = (a^l + b^l, a^m + b^m, a^u + b^u) \qquad (4.2)$$

$$\widetilde{A}(-)\widetilde{B} = (a^l, a^m, a^u) - (b^l, b^m, b^u) = (a^l - b^u, a^m - b^m, a^u - b^l) \quad (4.3)$$

$$\widetilde{A}(\times)\widetilde{B} = (a^l, a^m, a^u) \otimes (b^l, b^m, b^u) = (a^l b^l, a^m b^m, a^u b^u) \quad (4.4)$$

$$\widetilde{A}(\div)\widetilde{B} \cong (a^l, a^m, a^u) \div (b^l, b^m, b^u) = (\frac{a^l}{b^l}, \frac{a^m}{b^m}, \frac{a^u}{b^u}) \quad (4.5)$$

$$k\widetilde{A} = (ka^l, ka^m, ka^u) \text{ for } k > 0. \quad (4.6)$$

$$(\widetilde{A})^{-1} \equiv (\frac{1}{a^u}, \frac{1}{a^m}, \frac{1}{a^l}) \quad (4.7)$$

Definition 3. A linguistic variable is a variable whose values are linguistic terms. These linguistic variables can also be represented by fuzzy numbers.

4.2 FUZZY ANP

The very commonly used AHP method assumes that the criteria are independent and there exist a hierarchical structure without interactive relationships. However in the reality, criteria are seldom independent and always have a degree of interactive relationships, sometimes with dependence and feedback effects [121]. To overcome the problem of interdependence and feedback between criteria or alternatives of AHP, the ANP method is developed by replacing hierarchies with networks. Whether alone or combined with other methods the AHP and the ANP are used in several studies in the field of supplier selection. Sarkis and Talluri [122], Bayazit [123], Gencer and

Gürpınar [87], Chakraborty et al. [98] are the studies that apply just the ANP method without combining it with any other. On the other hand, while Wu et al. [97] and Razmi and Rafiei [101] propose a methodology where they use ANP and Mixed Integer Programming to solve the supplier selection problem, Cui et al. [93] combines ANP with the entropy method and Zhu et al. [68] with portfolio based analysis. In order to achieve better solutions by coping with the uncertainty of the expert opinions, fuzzy logic mentioned earlier is integrated into these techniques in the most of the recent studies on supplier selection. Those studies and the methods combined are listed in Table 4.1. Apart from the general supplier selection approach, there are several studies focused on the green supplier selection among these studies. Önüt et al. [59] and Tuzkaya et al. [61] applied Fuzzy ANP method combined with Fuzzy TOPSIS and Fuzzy PROMETHEE respectively while Lu et al. [49], Chiou et al. [50] and Lee et al. [57] used Fuzzy AHP method in order to select suitable green suppliers. In this study, the Fuzzy ANP method is employed in order to solve the problem of supplier selection due to the fact that this approach is considered as very useful in situations where there is a high degree of interdependence between various attributes of criteria [59]. The essentials of the Fuzzy ANP, including some basic explanations about AHP, are stated in the section below.

Table 4.1 AHP and ANP applications in supplier selection.

Authors	*Date*	*Ref.*	*Method(s)*
Lu et al.	2007	[49]	Fuzzy AHP
Chiou et al.	2008	[50]	Fuzzy AHP
Kokangul and Susuz	2009	[124]	Fuzzy AHP & Mathematical Programming
Lee et al.	2009a	[57]	Fuzzy AHP
Lee et al.	2009b	[125]	Fuzzy AHP & Mathematical Programming
Lin	2009	[126]	Fuzzy ANP & Mathematical Programming
Önüt et al.	2009	[59]	Fuzzy ANP & Fuzzy TOPSIS
Pang	2009	[94]	Fuzzy ANP & Fuzzy Preference Programming
Razmi et al.	2009	[127]	Fuzzy ANP
Tuzkaya et al.	2009	[61]	Fuzzy ANP & Fuzzy PROMETHEE
Chen and Hu	2010	[128]	Fuzzy ANP
Kang et al.	2010	[129]	Fuzzy ANP
Kubat and Yüce	2010	[130]	Fuzzy AHP & Genetic Algorithm
Kuo et al.	2010	[65]	Fuzzy AHP & Fuzzy DEA
Punniyamoorthy et al.	2011	[103]	Fuzzy AHP
Vinodh et al.	2011	[104]	Fuzzy ANP

Analytic Hierarchy Process (AHP) is proposed by Saaty [131] as a method of solving decision making problems and has been used to solve a wide range of problems. AHP is based on the assumption that there are no interdependences between clusters. However, the elements within the hierarchy of various rules are often interdependent in reality. Thus Saaty [8] developed ANP that allows for complex interrelationships among decision levels and criteria. The ANP feedback approach replaces hierarchies with networks in which the relationships between levels are not easily represented as higher or lower, dominant or subordinate. Graphically, a two-way arrow among different levels of criteria represents the dependencies in an ANP model, a ‘‘looped arc” is used to represent such interdependence if dependencies are present within the same level of analysis. The hierarchy structure of AHP and the network structure of ANP are shown in Figure 4.2.

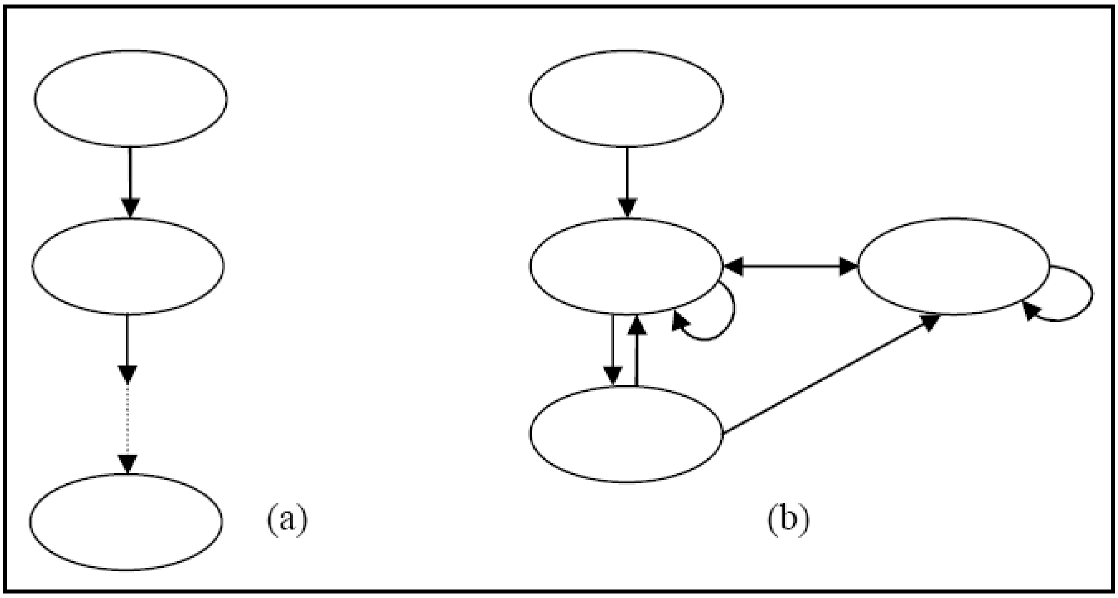

Figure 4.2 Hierarchy structure of AHP (a), network structure of ANP (b).

The classical ANP consists of three phases where the criteria are evaluated, unweighted and weighted supermatrices are generated and finally the solution is generated. Those phases are detailed in the section below.

Phase 1: Pairwise comparison evaluations. The pairwise comparisons of the elements within each cluster are conducted to form pairwise comparison matrices. The valuation scales, recommended by Saaty, are ranked 1 as equal importance, 3 as moderate importance, 5 as strong importance, 7 as very strong or demonstrated importance, and 9 is extreme importance. Even numbered values are placed between the above importance levels. Reciprocal values (e.g. 1/3, 1/5, etc.) mean less importance, strongly less importance, etc. After finishing pairwise comparisons, the relative importance weight ω for each component is calculated. A Consistency Index (CI) and Consistency Ratio (CR) also need to be calculated, the consistency index determined by the expression, CI = $(\lambda_{\max} - n)/(n-1)$, where $\lambda_{\max}$ is the largest eigenvalue calculated from the expression $A\omega = (\lambda max)\omega$ and $\lambda max \geq n$, n is the number of components that are evaluated in the pairwise comparison matrix A. The next step is to calculate the CR by dividing the CI to the Random Consistency Index (RI) given in the Table 4.2 derived from Saaty [131]. According to Saaty if the CR exceeds 0.1 the set of judgments may be too inconsistent to be reliable.

Table 4.2 Random consistency index according to the order of the matrix.

n:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI:	0,00	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49	1,51	1,48	1,56	1,57	1,59

Phase 2: The formation and normalization of the supermatrix. The supermatrix is formed by using the priority vectors of each pairwise comparison matrices. The supermatrix needs to be stochastic to derive meaningful limiting priorities. Thus, the sums of the columns should be normalized to equal 1. Eq. (4.8) is a generalized form of a supermatrix introduced by Saaty in 1996 to deal with the interdependence characteristics among elements and components. A supermatrix is actually a partitioned matrix, where each matrix segment represents a relationship between two components or clusters in a system [132].

$$
W = \begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & & C_n \\ e_{11}e_{12}\cdots e_{1m_1} & e_{21}e_{22}\cdots e_{2m_2} & \cdots\cdots\cdots\cdots\cdots & e_{n1}e_{n2}\cdots e_{nm_n} \end{array} \\ \begin{array}{cc} C_1 & \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1m_1} \end{array} \\ C_2 & \begin{array}{c} e_{21} \\ e_{22} \\ \vdots \\ e_{2m_2} \end{array} \\ \vdots & \vdots \\ C_n & \begin{array}{c} e_{n1} \\ e_{n2} \\ \vdots \\ e_{nm_n} \end{array} \end{array} & \begin{bmatrix} W_{11} & W_{12} & \cdots\cdots\cdots\cdots\cdots & W_{1n} \\ W_{21} & W_{22} & \cdots\cdots\cdots\cdots\cdots & W_{2n} \\ \vdots & \vdots & \cdots\cdots\cdots\cdots\cdots & \vdots \\ W_{n1} & W_{n2} & \cdots\cdots\cdots\cdots\cdots & W_{nn} \end{bmatrix} \end{array} \tag{4.8}
$$

Here C_k denotes the kth cluster, e_{kl} denotes the lth element in the kth cluster, m_k denotes the number of criteria within the cluster k and W_{ij} is the principal matrix which contains in its columns the eigenvectors of the influence of the elements compared in the jth cluster to the ith cluster. In addition, if there is no influence between jth and ith clusters, then $W_{ij} = 0$.

Phase3: The convergence to a solution. The last part is to calculate global weights by raising the weighted supermatrix to a large power until convergence occurs and thus generate a limiting super matrix by using Eq. (4.9).

$$\lim_{k \to \infty} \mathrm{W}^k \qquad (4.9)$$

In Fuzzy ANP approach, pairwise comparison matrices are formed with the help of triangular fuzzy numbers that take into account the ambiguities and uncertainties in the human judgments. These pairwise comparison matrices are structured by using triangular fuzzy numbers (a^l, a^m, a^u). The $m \times n$ triangular fuzzy matrix can be given as in Eq. (4.10). The element a_{mn} represents the comparison of the component m (row element) with component n (column element).

$$\widetilde{A} = \begin{bmatrix} (a^l{}_{11}, a^m{}_{11}, a^u{}_{11}) & (a^l{}_{12}, a^m{}_{12}, a^u{}_{12}) & \cdots & (a^l{}_{1n}, a^m{}_{1n}, a^u{}_{1n}) \\ (a^l{}_{21}, a^m{}_{21}, a^u{}_{21}) & (a^l{}_{21}, a^m{}_{21}, a^u{}_{21}) & \cdots & (a^l{}_{2n}, a^m{}_{2n}, a^u{}_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ (a^l{}_{m1}, a^m{}_{m1}, a^u{}_{m1}) & (a^l{}_{m2}, a^m{}_{m2}, a^u{}_{m2}) & \cdots & (a^l{}_{mn}, a^m{}_{mn}, a^u{}_{mn}) \end{bmatrix} \qquad (4.10)$$

$$\widetilde{A} = \begin{bmatrix} (1,1,1) & (a^{l}{}_{12}, a^{m}{}_{12}, a^{u}{}_{12}) & \cdots & (a^{l}{}_{1n}, a^{m}{}_{1n}, a^{u}{}_{1n}) \\ (\frac{1}{a_{12}^{u}}, \frac{1}{a_{12}^{m}}, \frac{1}{a_{12}^{l}}) & (1,1,1) & \cdots & (a^{l}{}_{2n}, a^{m}{}_{2n}, a^{u}{}_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ (\frac{1}{a_{1n}^{u}}, \frac{1}{a_{1n}^{m}}, \frac{1}{a_{1n}^{l}}) & (\frac{1}{a_{2n}^{u}}, \frac{1}{a_{2n}^{m}}, \frac{1}{a_{2n}^{l}}) & \cdots & (1,1,1) \end{bmatrix} \tag{4.11}$$

If Ã is a pairwise comparison matrix, it is assumed that it is reciprocal, and the reciprocal value $1/\widetilde{a}_{mn}$, is assigned to the element $\widetilde{a}_{nm}$.

As in the phase 2 of the ANP explained earlier, the fuzzy supermatrix is also formed by using the fuzzy priority vectors of each pairwise comparison matrices. There are several methods for calculating the fuzzy priorities $\widetilde{w}_i = (w_i^l, w_i^m, w_i^u)$, i=1, 2, …, n, from the judgment matrix $\widetilde{A}$. One of these methods, logarithmic least squares method [133] is used in this study as it is a reasonable and effective method [59]. The logarithmic least squares method for calculating triangular fuzzy weights can be given as follows [134]:

$$\widetilde{w}_k = (w_k^l, w_k^m, w_k^u), \ k=1, 2, \ldots, n \tag{4.12}$$

Where $$w_k^s = \frac{\left(\prod_{j=1}^{n} a_{kj}^s\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}^m\right)^{1/n}}, s \in \{l, m, u\}.$$

After evaluating the criteria as previously expressed, for converting the fuzzy weights of the criteria to crisp numbers different approaches are utilized. Such as Chang’s extent analysis (1996) method, Center of Area (COA) method [135], Yager Index [136] and alpha cut method are utilized. Like Promentilla et al. [137] and Ayağ and Özdemir [138], Vinodh et al. [104], in their recent study they utilized alpha cut method as a defuzzification tool. This method is also used in this study in order to transform fuzzy values in the Fuzzy ANP matrices into crisp values.

Deffuzification in Fuzzy ANP

To convert fuzzy numbers to crisp numbers in Fuzzy ANP the Alpha cut (α - cut) method is preferred in this study. This method employs interval arithmetic and optimism index to transform the fuzzy comparative judgment matrix into set of crisp matrices. By defining the interval of confidence level denoted as α (also known as the alpha-cut), the triangular fuzzy number $\widetilde{M} = (l, m, u)$ can be characterized as:

$$\forall \alpha \in [0,1] \widetilde{M}_{\alpha} = [l^{\alpha}, u^{\alpha}] = [l + (m - l)\alpha, u - (u - m)\alpha]. \qquad (4.13)$$

The optimism index ω integrates the decision maker's attitude into the algorithm. Such that a higher value of ω means more optimistic decision maker as it tends to higher values of the crisp interval at a given level of confidence α .

The scale used in this study is represented as a triangular fuzzy number, $\widetilde{a}_{ij} = (l_{ij,} m_{ij}, u_{ij})$. This will be characterized by the degree of fuzziness (δ). According to AHP's reciprocal axiom, the smaller element would have the reciprocal or inverse value when compared with the larger element. Consequently, the proposed membership function will be based on a premise that the support of any fuzzy scale should be mapped in either the value of 0–1, or $1-\infty$ subdomains. Thus, the lower and upper bound of the dominance scale (i.e., $\widetilde{a}_{ij} \geq 1$) are set equal to 1 and ∞, respectively. As the subdomain of the support ($1-\infty$) becomes meaningless for the reciprocal of the judgment in case of $u_{ij} = \infty$, it is more appropriate to use the following triangular fuzzy number to describe the fuzzy judgment with scale value of $m_{ij} > 1$ [137].

$$\widetilde{M} = (\max(1, m_{ij} - \delta), m_{ij}, m_{ij} + \delta) \tag{4.16}$$

The reciprocal of the fuzzy number $\widetilde{M}$ is denoted as:

$$\widetilde{M}^{-1} = \left(\frac{1}{m_{ij} + \delta}, \frac{1}{m_{ij}}, \frac{1}{\max(1, m_{ij} - \delta)} \right). \tag{4.17}$$

Finally, the interval value $\widetilde{a}_{ij}^{\alpha} = \left[a_{ijl}^{\alpha}, a_{iju}^{\alpha} \right]$ of the fuzzy numbers at a given δ and α are computed by Eq. (4.13). For example if $\delta = 1$, the interval value of the triangular fuzzy number and its reciprocal at a given alpha-cut are as follows:

$$\widetilde{a}_{ij}^{\alpha} = \left[l_{ij} + \alpha, u_{ij} - \alpha \right],\ \widetilde{a}_{ji}^{\alpha} = \frac{1}{\widetilde{a}_{ij}^{\alpha}} = \left[\frac{1}{u_{ij} - \alpha}, \frac{1}{l_{ij} + \alpha} \right]. \tag{4.18}$$

4.3 FUZZY DEMATEL

The difficulty of ANP is to determine the dependence and feedback among dimensions/criteria. In order to overcome this problem the DEMATEL technique can be used to build the network relationship and to calculate the inner dependence between criteria for objectively constructing supermatrix in ANP. Like in many studies in the literature, in this study, Fuzzy DEMATEL technique is applied in combination with Fuzzy ANP in the proposed model. As the application of the Fuzzy DEMATEL in this study consists of its integration with the Fuzzy ANP, the related literature is reviewed in particular.

Wu [139] proposed a combined ANP and DEMATEL approach to help companies that need to evaluate and select knowledge management strategies. In this study, the DEMATEL is used to deal with the inner dependences within evaluation clusters. Then the results obtained through DEMATEL are integrated into the ANP in order to calculate the weights of elements of evaluation clusters and to achieve a final solution according to the overall priorities of the alternatives.

Tsai and Chou [132] proposed a novel hybrid model for systematic evaluation and selection of the optimal management systems under resource constraints and illustrated the practical application of it through an example. In the proposed model, the authors first applied the DEMATEL approach to construct interrelations among criteria, the ANP method to obtain the criterion weights and a Zero-One Goal Programming (ZOGP) model to obtain optimal alternatives with desired organizational benefits by fully utilizing limited resources.

Tsai et al. [96] proposed an integrated model for selecting Socially Responsible Investment (SRI) stocks and illustrated the practical application of such a model through a case study. This model first applied the DEMATEL approach to deal with the interdependencies existing among the criteria, and then integrated the DEMATEL, the ANP, and the ZOGP method to select an optimal portfolio of SRI. Additionally, the sustainability balanced scorecard is used in this study as a multi-criteria framework for SRI evaluation.

Büyüközkan and Öztürkcan [140] developed an approach based on a combined ANP and DEMATEL technique to help companies determine critical Six Sigma projects and identify the priority of these projects especially in logistics companies. The DEMATEL technique is used to determine the interdependencies between criteria while the ANP technique is used to obtain criteria weights. The proposed approach is then illustrated with a case study realized in a leading logistics company in Turkey.

Chen, J-K. and Chen, I-S. [141] constructed a novel MCDM approach that combines DEMATEL, Fuzzy ANP and TOPSIS for Taiwanese higher education institutes to comprehensively evaluate their innovation performance. The proposed model considers the interdependence and relative weights of each measurement criterion and different types of universities.

Hung, S.-J. and Hung, Y.-A [142] proposed an integrated approach to plan the production allocation for an enterprise with Divergent Supply Chain, in the risky global market and then presented a case study of a consumer-oriented cell phone DSC. In the integrated approach, DEMATEL analysis is used to determine the interdependence relationship between the risk criteria, ANP to evaluate the risk weights of the alternatives and finally the Fuzzy GP to achieve the optimal product mix.

Liou and Chuang [121] proposed a new hybrid MCDM model for selection of outsourcing providers. The model addresses the dependent relationships among criteria with the aid of the DEMATEL method to build a relation structure among criteria. The ANP is used to determine the relative weights of each criterion with dependence and feedback. The VIKOR method (VlseKriterijumska Optimizacija I Kompromisno Resenje in Serbian, meaning Multi-criteria Optimization and Compromise Solution) is then used to prioritize the alternatives. The proposed model is then illustrated through a case study of a Taiwanese airline company.

Shen et al. [143] proposed a novel hybrid MCDM method that integrates fuzzy Delphi method, the DEMATEL technique, and the ANP to construct a technology selection model regarding the economic and industrial prospects. Fuzzy Delphi method is employed in order to gather information, conduct the vagueness and imprecision within the experts' judgments and identify the critical technology selection criteria. The DEMATEL is used for determining the interdependent relationship among criteria and constructs the network for ANP by group judgments. The combination of DEMATEL and ANP is employed to determine criteria weights and hence to construct the technology selection model regarding economic and industrial criteria. The applicability of the proposed model is then verified through a case study.

Tsai et al. [144] proposed a MCDM approach using the DEMATEL, ANP and ZOGP methods to determine the weights of criteria for final ranking of the alternative information systems projects. The inner dependencies between criteria are calculated by the use of the DEMATEL, the overall priorities through the ANP method and these overall priorities are finally deployed as a constrained condition in the ZOGP model. An illustrative example is presented in this study in order to help can help practitioners to evaluate how well each sourcing decision is aligned with the company's strategic direction, and reap the greatest possible benefits from their sourcing decision.

Tseng [145] presented a hybrid model for developing a quantitative evaluation of environmental practice in knowledge management capability measures. The model incorporated hierarchical aspects and criteria structure, FST, ANP and DEMATEL, comprising an effective weighting of a firm from subjective information. FST is used to interpret the linguistic information in accordance with the subjective evaluation; ANP is used to analyze the dependence aspects, while DEMATEL is used to determine the inner dependencies among the criteria. The application of the proposed model is illustrated through a case study of a healthcare service provider and original product manufacturer company.

The results of this review shows that this hybrid approach is not implemented in any study for neither sustainable nor green supplier selection/evaluation purposes. Therefore in Table 4.3 several studies utilizing from DEMATEL for the construction of the network structure and/or for the calculations of the inner dependences in ANP and their application areas are presented. Then the method is described in general in the remainder of this section.

Table 4.3 DEMATEL and ANP combined studies.

Authors	Date	Ref.	Methods	Scope
Wu	2008	[139]	DEMATEL & ANP	Strategy selection
Tsai and Chou	2009	[132]	DEMATEL & ANP & ZOGP	Management system selection
Tsai et al.	2009	[96]	DEMATEL & ANP & ZOGP	Investment selection
Chen, J-K. and Chen, I-S.	2010	[141]	DEMATEL & Fuzzy ANP & TOPSIS	Performance evaluation
Hung, S.-J. and Hung, Y.-A	2010	[142]	DEMATEL & ANP & Fuzzy GP	Supply chain planning
Liou and Chuang	2010	[121]	DEMATEL & ANP & VICOR	Outsourcing provider selection
Shen et al.	2010	[143]	DEMATEL & ANP & Fuzzy Set Theory	Technology selection
Tsai et al.	2010a	[144]	DEMATEL & ANP & ZOGP	Technology project selection
Tseng	2011	[145]	DEMATEL & ANP	Knowledge management evaluation

The DEMATEL method converts the relationship between cause and effect factors into an intelligent structural model of the system [152]. Using this method illustrates the interrelations among criteria and applied matrices and digraphs for visualizing the structure of complicated causal relationships [146]. The essentials of the DEMATEL method suppose that a system contains a set of criteria $C = \{C_i | i = 1,2,\ldots,n\}$ and the particular pairwise relations are determined for modelling with respect to a mathematical relation. The following steps are used to obtain the solution [147], [148], [149], [145]:

Step 1: *Generating the direct relation matrix.*

The initial data can be obtained as the direct-relation matrix that is a $n \times n$ matrix A obtained by pair-wise comparisons in terms of influences and directions between criteria, in which a_{ij} is denoted as the degree to which criterion *i* affects criterion *j*, i.e., $A = [a_{ij}]_{n \times n}$.

Step 2: *Normalizing the direct relation matrix.*

On the base of the direct relation matrix A, the normalized direct relation matrix $X = [x_{ij}]_{n \times n}$ and $0 \le x_{ij} \le 1$ in which all principal diagonal elements are equal to zero can be obtained through the following formulas:

$$X = k \cdot A \tag{4.19}$$

$$k = \frac{1}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}}, \qquad i, j = 1,2....,n \tag{4.20}$$

Step 3: *Attaining the total relation matrix.*

Once the normalized direct relation matrix X is obtained, the total relation matrix T can be acquired by using formula below, in which I is denoted as the identity matrix:

$$T = X(I - X)^{-1} \tag{4.21}$$

Step 4: *Producing a causal diagram.*

The sum of rows and the sum of columns are separately denoted as vector D and vector R respectively within the total relation matrix T through the Eq. (4.22) – Eq. (4.24):

$$T = [t_{ij}]_{n \times n}, \qquad i, j = 1,2....,n, \tag{4.22}$$

$$D = \sum_{j=1}^{n} t_{ij}, \tag{4.23}$$

$$R = \sum_{i=1}^{n} t_{ij}, \tag{4.24}$$

Step 5: *Obtaining the inner dependence matrix.*

In this step, the sum of each column in total relation matrix is equal to 1 by the normalization method, and then the inner dependence matrix can be acquired [139].

Step 6: *Obtaining the casual diagram.*

The casual diagram is acquired by mapping the dataset of ($D+R$, $D-R$), where the horizontal axis ($D+R$) is made by adding D to R, and the vertical axis ($D-R$) is made by subtracting D from R.

On the other hand, Fuzzy DEMATEL is a practical method that helps to take into account the dynamic and uncertain nature of the human judgments. The analytical procedure of the proposed Fuzzy DEMATEL method according to Wu and Lee [150] and Fekri et al. [146] is explained as follows:

Step 1: *Identifying the decision goal and selecting an expert or a committee of experts.*

Step 2: *Developing evaluation factors and designing the fuzzy linguistic scale.*

For dealing with the ambiguities of human assessments, the linguistic variable ''influence'' is used with linguistic terms [151] such as very high, high, low, very low, equal, strong, absolute, no, etc. that are expressed in positive triangular fuzzy numbers $(l_{ij,} m_{ij}, u_{ij})$.

Step 3: *Acquiring and aggregating the assessments of decision makers.*

To measure the relationship between evaluation factors $C = \{C_i | i = 1,2,\ldots,n\}$, it is usually necessary to ask an expert or a group of experts named Decision Making Team (DMT) to make assessments in terms of influences and directions between factors. Then, using a defuzzification method, those fuzzy assessments are defuzzified and aggregated (in case of a group of expert) as a crisp value which is the a_{ij}. Hence, the initial direct-relation matrix $A = [a_{ij}]_{n\times n}$ can be obtained.

Step 4: *Establishing and analyzing the structural model.*

On the base of the initial direct-relation matrix A, the normalized direct-relation matrix X can be obtained through Eq. (4.19) and Eq. (4.20). Then, the total relation matrix T can be acquired by using Eq. (4.21). Additionally a causal diagram can be acquired through step 4 and step 6 of the DEMATEL explained in detail in the previous section.

As the Fuzzy DEMATEL is used in this study to obtain the interrelation matrices that are then replaced in the supermatrix, the casual diagram is not requisite. Hence, the Fuzzy DEMATEL approach used in this study terminates by calculating the total relation matrix *T*.

Deffuzification in Fuzzy DEMATEL

There exist several defuzzification methods used for converting the triangular fuzzy numbers to crisp numbers. Particularly in Fuzzy DEMATEL studies like Wu and Lee [150], Chen et al. [147], Fekri et al. [146], Tseng and Lin [148], Chang et al. [152], Tseng [149], Tseng [145]. the Converting Fuzzy data into Crisp Scores (CFCS) method is used as a defuzzification tool. Therefore, the CFCS defuzzification method is adopted for the proposed procedure.

The CFCS method is proposed by Opricovic and Tzeng [153]. The method is based on the procedure of determining the left and right scores by fuzzy min and fuzzy max, and the total score is determined as a weighted average according to the membership functions [150]. Let $\widetilde{Z}_{ij}^{k} = (l_{ij}^{k}, m_{ij}^{k}, r_{ij}^{k})$ indicate the fuzzy assessments of evaluator *k* ($k = 1,2,...,p$) about the degree to which the criterion *i* affects the criterion *j*. The CFCS method includes five-step algorithms described as follows:

Step 1. *Normalization.*

$$xl_{ij}^{k} = (l_{ij}^{k} - \min l_{ij}^{k}) / \Delta_{\min}^{\max} , \tag{4.25}$$

$$xm_{ij}^{k} = (m_{ij}^{k} - \min l_{ij}^{k}) / \Delta_{\min}^{\max} , \tag{4.26}$$

$$xr_{ij}^{k} = (r_{ij}^{k} - \min l_{ij}^{k}) / \Delta_{\min}^{\max} , \tag{4.27}$$

Where $\Delta_{\min}^{\max} = \max r_{ij}^{k} - \min l_{ij}^{k}$

Step 2. *Compute left (ls) and right (rs) normalized value.*

$$xls_{ij}^{k} = xm_{ij}^{k} \big/ (1 + xm_{ij}^{k} - xl_{ij}^{k}), \tag{4.28}$$

$$xrs_{ij}^{k} = xr_{ij}^{k} \big/ (1 + xr_{ij}^{k} - xm_{ij}^{k}), \tag{4.29}$$

Step 3. *Compute total normalized crisp value.*

$$x_{ij}^{k} = [xls_{ij}^{k}(1 - xls_{ij}^{k}) + xrs_{ij}^{k} xrs_{ij}^{k}] \big/ [1 - xls_{ij}^{k} + xrs_{ij}^{k}], \tag{4.30}$$

Step 4. *Compute crisp values.*

$$w_{ij}^{k} = \min l_{ij}^{k} + x_{ij}^{k} \Delta_{\min}^{\max}, \tag{4.31}$$

Step 5. *Integrate crisp values.*

$$w_{ij} = \frac{1}{p}(w_{ij}^{1} + w_{ij}^{2} + \cdots + w_{ij}^{p}). \tag{4.32}$$

4.4 FUZZY PROMETHEE

One of the most recent MCDM method is the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) method developed by Brans [154]. PROMETHEE is an outranking method for a finite set of alternative actions to be ranked and selected considering several criteria, which are sometimes conflicting [155].

PROMETHEE is used in several studies on the topics of environment management, hydrology and water management, business and financial management, chemistry, logistics and transportation, manufacturing and assembly, energy management, social, etc. Some of these studies are listed below.

Goumas and Lygerou [156] extended the PROMETHEE technique to deal with fuzzy input data and proposed a Fuzzy PROMETHEE approach. The method is applied for the evaluation and ranking of alternative energy exploitation schemes of a low temperature geothermal field. Then the authors concluded that this approach produced a reliable ranking for problems, such as the evaluation of alternative energy exploitation scenarios, where the input data are not well defined.
Fernandez Castro and Jimenez [157] developed a new approach to select the most suitable subset of alternatives, within a finite set of possible alternatives through an hybrid methodology where a combination of PROMETHEE , Crisp Integer Linear Programming (CILP) and Fuzzy Integer Linear Programming (FILP) is used. The method is applied in distribution centre selection for a firm in Belgium.

Bilsel [158] presented a fuzzy multi-criteria model for building a stock investment portfolio under uncertainty and apply it to select and rank stocks exchanged on the Istanbul Stock Exchange – 30 index. The Fuzzy PROMETHEE method is used to obtain the set of stocks possible to invest and Linear Programming (LP) to determine the investment percentage within the set of stocks.

Aloini et al. [159] presented a MCDM method based on Fuzzy PROMETHEE for the selection of the carrier among a number of preselected logistic service providers. The proposed method is applied to the case of a multinational company running in the electronic power systems and alternative energy systems market.

Moreira et al. [160] proposed a Fuzzy PROMETHEE methodology for the identification and prioritization of failure modes of equipment in operation on electric power substations. With a case study, the authors illustrated the application of the proposed Fuzzy PROMETHEE approach and compared the results obtained through Fuzzy PROMETHEE and PROMETHEE approaches.

Zhang et al. [161] developed a ranking system for contaminated sites based on comparative risk methodology using both Fuzzy PROMETHEE and PROMETHEE techniques to deal with the fuzzy and crisp input data respectively. The authors illustrated the proposed methodology through a case study.

Ignatius et al. [162] proposed and compared two hybrid models in modelling decision making under uncertainty which are AHP combined Fuzzy PROMETHEE and AHP combined Fuzzy TOPSIS. These techniques are applied in a strategic outsourcing decision of a company in Malaysia that seeks to evaluate their training providers. The final results indicate that both AHP-Fuzzy TOPSIS and AHP-Fuzzy PROMETHEE achieved consistent results and arrived at the same ranking order.

Saidi Mehrabad and Anvari [163] presented a methodology based on Fuzzy C-Means and Fuzzy PROMETHEE methods for the flexible manufacturing system selection problem. The methodology was illustrated through its application on an example containing a set of five flexible manufacturing system proposals.

Tuzkaya et al. [102] proposed an integrated fuzzy multi-criteria decision making methodology for material handling equipment selection problem. Evaluation criteria determined in the study are weighted by Fuzzy ANP approach and the alternative material handling equipments are evaluated by Fuzzy PROMETHEE approach. The methodology is then applied for a manufacturing company located in Istanbul, Turkey to prove its effectiveness.

Chen et al. [164] worked on the process of information systems outsourcing which is one of the most important decision issues for organizations. The authors introduced the Fuzzy PROMETHEE method and then used it to evaluate four potential suppliers based on seven criteria and four decision makers by using a realistic case study conducted in a bank in Taiwan.

Yılmaz and Dağdeviren [165] proposed a combined approach where Fuzzy PROMETHEE and ZOGP methods are used in order to select the best alternative of equipment. The proposed model is then applied in a real world case for the equipment selection decision process where the main aim of the company is to select the most suitable welding machine.

Table 4.4 summarizes the above mentioned studies where the Fuzzy PROMETHEE technique is used.

Table 4.4 Fuzzy PROMETHEE studies and their scopes.

Authors	*Date*	*Ref.*	*Method(s)*	*Scope*
Goumas and Lygerou	2000	[156]	Fuzzy PROMETHEE	Evaluation of energy exploitation schemes
F.Castro and Jimenez	2005	[157]	PROMETHEE & CILP & FILP	Selection of distribution center
Bilsel	2007	[158]	Fuzzy PROMETHEE & LP	Selection and ranking of stocks
Aloini et al.	2009	[159]	Fuzzy PROMETHEE	Selection of logistic service provider
Moreira et al.	2009	[160]	Fuzzy PROMETHEE	Ranking of failure modes on electric power substations
Zhang et al.	2009	[161]	PROMETHEE & FUZZY PROMETHEE	Ranking of contaminated sites
Ignatius et al.	2010	[162]	AHP & Fuzzy PROMETHEE & Fuzzy TOPSIS	Selection of training providers
Saidi Mehrabad and Anvari	2010	[163]	Fuzzy C-Means & Fuzzy PROMETHEE	Selection of flexible manufacturing systems
Tuzkaya et al.	2010	[102]	Fuzzy ANP & Fuzzy PROMETHEE	Selection of material handling equipments
Chen et al.	2011	[164]	Fuzzy PROMETHEE	Selection of information systems outsourcers
Yılmaz and Dağdeviren	2011	[165]	Fuzzy PROMETHEE and ZOGP	Selection of equipments

However, in the field of supplier selection, there are a few number of studies where the PROMETHEE method is used such as Dulmin and Mininno [166] and Araz and Ozkarahan [167]. Additionally, a methodology which integrates Fuzzy ANP and Fuzzy PROMETHEE approaches is proposed by Tuzkaya et al. [61] for the supplier's environmental performance evaluation problem. For detailed information, readers are referred to Behzadian et al. [168] that has presented an extensive review of the literature on PROMETHEE methodologies and applications consisting of 217 papers from 100 scholarly journals.

Unlike other ranking methods in the literature, PROMETHEE method enables to define different preference functions for criteria [169]. PROMETHEE is a ranking method quite simple in conception and application compared to other methods for MCDM [61]. Thus, in this study, for coping with the ambiguities of the assessments, fuzzy extension of the PROMETHEE namely the Fuzzy PROMETHEE is applied for the supplier selection process. In the section below, the method and some definitions are explained briefly

<u>PROMETHEE</u>

The implementation of PROMETHEE requires two types of information:

- Information on the relative importance (i.e. the weights) of the criteria considered,
- Information on the decision-makers' preference function, which he/she uses when comparing the contribution of the alternatives in terms of each separate criterion.

The basic steps of the PROMETHEE algorithm can be outlined as follows [61], [102]:

Step 1: Specify a generalized preference function $p_j(d)$ for each criterion j. as shown in Figure 4.3.

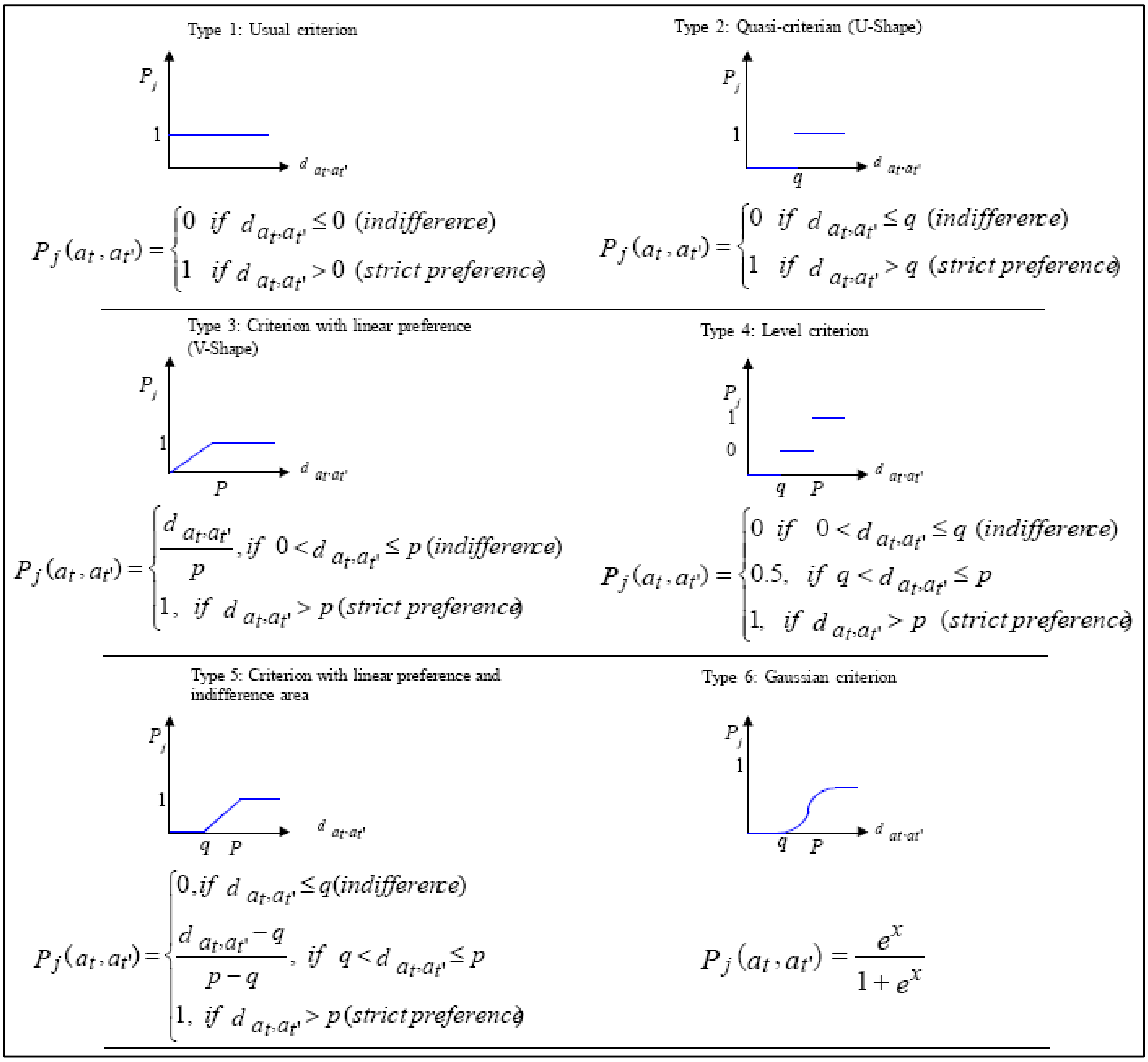

Figure 4.3 PROMETHEE generalized preference functions.

Step 2: Define a vector containing the weights, which are a measure for the relative importance of each criterion, $w^T = [w_1, ..., w_k]$. If all the criteria are of the same importance in the opinion of the decision maker, all weights can be taken as being equal. The normalization of the weights, $\sum_{k=1}^{K} w_k = 1$, is not necessarily required.

Step 3: Define for all the alternatives $a_t, a_{t'} \in A$ the outranking relation π :

$$\pi : \begin{cases} A \times A \rightarrow [0,1] \\ \pi(a_t, a_{t'}) = \dfrac{\sum_{k=1}^{K} w_k (p_k (f_k(a_t) - f_k(a_{t'}))}{\sum_{k=1}^{K} w_k} \end{cases} \tag{4.33}$$

The preference index $\pi(a_t, a_{t'})$ is a measure for the intensity of preference of the decision maker for an alternative a_t in comparison with an alternative $a_{t'}$ for the simultaneous consideration of all criteria. It is basically a weighted average of the preference functions $p_k(d)$ and can be represented as a valued outranking graph. Here $f_k(a_t)$ represents the evaluation value of the alternative a_t according to the criterion *k*.

Step 4 : Calculate the leaving flow of each alternative which indicates a preference of the alternative over all other actions. It shows how "good" the alternative is [170]. The leaving flow is calculated as follows:

$$\Phi^{+}(a_t) = \sum_{\substack{t'=1 \\ t' \neq t}}^{n} \pi(a_t, a_{t'}) \tag{4.34}$$

Step 5: Calculate the entering flow that indicates a preference of all other alternatives, compared to an alternative. It shows how "weak" the alternative is [170]. The entering flow is calculated as follows:

$$\Phi^{-}(a_t) = \cdot \sum_{\substack{t'=1 \\ t' \neq t}}^{n} \pi(a_{t'}, a_t) \tag{4.35}$$

Step 6: A graphical evaluation of the outranking relation is derived: Basically, the alternative with a higher leaving flow and a lower entering flow is considered better than the others. This result is graphically represented by a partial preorder (PROMETHEE I) or a complete preorder (PROMETHEE II).

According to the PROMETHEE I, the alternative a_t is superior to the alternative $a_{t'}$ if the leaving flow of a_t is greater than that of $a_{t'}$ and the entering flow of a_t is smaller than that of $a_{t'}$. In other words, in PROMETHEE I, alternative a_t is preferred to alternative $a_{t'}$ ($a_t P a_{t'}$) at least one of the elements of Eq. (4.36) is satisfied.

$$a_t P a_{t'} \text{ if } \quad \Phi^+(a_t) > \Phi^+(a_{t'}) \text{ and } \Phi^-(a_t) < \Phi^-(a_{t'}) \tag{4.36a}$$

$$\text{Or } \Phi^+(a_t) > \Phi^+(a_{t'}) \text{ and } \Phi^-(a_t) = \Phi^-(a_{t'}) \tag{4.36b}$$

$$\text{Or } \Phi^+(a_t) = \Phi^+(a_{t'}) \text{ and } \Phi^-(a_t) < \Phi^-(a_{t'}). \tag{4.36c}$$

The indifference situation occurs in case of two alternatives having the same leaving and entering flows.

$$a_t I a_{t'} \text{ if } \quad \Phi^+(a_t) = \Phi^+(a_{t'}) \text{ and } \Phi^-(a_t) = \Phi^-(a_{t'}) \tag{4.37}$$

Two alternatives are incomparable, $a_t R a_{t'}$, if the leaving flow of the alternative a_t is better than the leaving flow of alternative $a_{t'}$, while the corresponding entering flows indicate the reverse.

$$a_t R a_{t'} \text{ if } \quad \Phi^+(a_t) > \Phi^+(a_{t'}) \text{ and } \Phi^-(a_t) > \Phi^-(a_{t'}) \tag{4.38a}$$

$$\text{Or } \Phi^+(a_t) < \Phi^+(a_{t'}) \text{ and } \Phi^-(a_t) < \Phi^-(a_{t'}) \tag{4.38b}$$

To overcome the issue of incomparability and to obtain a complete ranking, the PROMETHEE II method can be applied [170]. For the complete ranking calculations, net flow values of alternatives are calculated as Eq. (4.39). Here, the alternative with a higher net flow is better than the ones with lower net flows.

$$\Phi^{net}(a_t) = \Phi^{+}(a_t) - \Phi^{-}(a_t) \quad (4.39).$$

Fuzzy PROMETHEE

In order to interpret the linguistic variables and to cope with the fuzzy nature of the problem which contains the vagueness of the expert opinion, in this study the PROMETHEE method is combined with the FST. This combination is called Fuzzy PROMETHEE and recently used in the literature as mentioned in the previous sections.

In the following Fuzzy PROMETHEE formulas, a fuzzy number is represented in the form $\widetilde{F} = (n, a, b)$. This form is a different version of the representation used in the previous sections (ANP, Fuzzy ANP and Fuzzy Sets). It is equivalent to the previous representation by $\widetilde{F} = (n - a, n, n + b)$. In the generalized preference function, values corresponding to indifference and preference threshold, q and p respectively. are needed to be determined. In Fuzzy PROMETHEE approach, the evaluation function explained in Figure 4, can be converted to Eq. (4.40).

$$P_j(a_t, a_{t'}) = \begin{cases} 0, if \quad n - a \leq q(indifference) \\ \dfrac{(n,a,b) - q}{p - q}, if \quad q \leq (n - a) \quad and \quad (n + b) \leq p \\ 1, if \quad n + b > p(strict \quad preference) \end{cases} \quad (4.40)$$

Where $P_j(a_t, a_{t'}) = P_j(f_j(a_t) - f_j(a_{t'}))$.

For the proper application of PROMETHEE, preference indices for single and multiple criteria must be placed in the interval $[0,1]$. Therefore, in Eq. (4.40) the membership function of the fuzzy number $C(a_t, a_{t'}) = (n, a, b)$ is adjusted accordingly so that $n - a \geq 0$ and $n + b \leq 1$.

In the proposed Fuzzy PROMETHEE approach the results obtained are fuzzy numbers. To derive a solution, these numbers must be ranked, which means that fuzzy numbers have to be compared [170]. For this purpose the Yager index method can be used. This method corresponds to calculating the weighted average of a given fuzzy number as Eq. (4.41).

$$\widetilde{F} = (n - a, n, n + b) = (3n - a + b)/3 \qquad \text{Eq. (4.41).}$$

Similarly to the PROMETHEE approach, the leaving flow, the entering flow and the net flow notions are valid in the case of Fuzzy PROMETHEE [170]. Apart from the differences mentioned above, Fuzzy PROMETHEE application consists of the same steps as the PROMETHEE method. Additionally, in Fuzzy PROMETHEE, for the operations with fuzzy numbers, the basic operators of the FST are used.

4.5 PROCEDURE OF THE PROPOSED HYBRID MODEL

The supplier selection problem is formulated as a mu1tiple criteria decision-making (MCDM) problem in numerous studies. There are many MCDM methods used in similar problems. These methods differ from each other by their application areas, computational work they require and efficiencies. Therefore in this study a novel hybrid model is presented. This hybrid model is a combination of Fuzzy ANP, Fuzzy DEMATEL and Fuzzy PROMETHEE techniques. An overview of the proposed evaluation process is given in Figure 4.4.

The framework presented in this study roughly consists of four phases typically used in supplier selection problems as mentioned earlier in the evaluation model proposition section.

Phase 1: A Decision Maker Team (DMT) is created in order to achieve expert opinions, the main goal is determined and the decision objectives are identified based on the literature review and the expert opinions. Then, the evaluation clusters and criteria are defined.

Phase 2: The structure of the network model is generated. The interdependencies within the criteria clusters and the dependencies between these clusters are determined.

Phase 3: The suitable suppliers are determined in this phase. The supplier alternatives are selected by the DMT with respect to actual profiles of the company's existing supplier alternatives.

Phase 4: This phase covers a combination of the Fuzzy PROMETHEE technique with the Fuzzy DEMATEL integrated Fuzzy ANP method. Here, the Fuzzy ANP method is used to calculate the weights of elements of evaluation clusters with the assumption of there is no interdependence between them while the Fuzzy DEMATEL is applied to deal with the situation when inner dependences occur within an evaluation cluster. In the Fuzzy ANP, the DMT is asked to compare the criteria considering their effects on achieving main goal and asked to compare them considering their effects on the other criteria. In this process, linguistic scale used in Fuzzy ANP and Fuzzy DEMATEL for relative importance is given in Table 4.5 and Table 4.6 respectively. Then, these matrices are located in the unweighted supermatrix which is normalized to form the normalized supermatrix. The last part is to calculate global weights by raising the normalized supermatrix to a large power until convergence occurs and thus generate a limiting super matrix.

Table 4.5 Linguistic scale for importance used in Fuzzy ANP.

Linguistic scale	*Triangular fuzzy scale*	*Triangular fuzzy reciprocal scale*
Just equal	(1, 1, 1)	(1.00, 1.00, 1.00)
Equally important	(1, 1, 2)	(0.50, 1.00, 1.00)
Very weakly more important	(1, 2, 3)	(0.33, 0.50, 1.00)
Weakly more important	(2, 3, 4)	(0.25, 0.33, 0.50)
Strongly more important	(3, 4, 5)	(0.20, 0.25, 0.33)
Very strongly more important	(4, 5, 6)	(0.17, 0.20, 0.25)
Absolutely more important	(5, 6, 7)	(0.14, 0.17, 0.20)

Table 4.6 Linguistic scale for importance used in Fuzzy DEMATEL.

Linguistic scale	*Triangular fuzzy scale*
No influence (No)	(0.00, 0.00, 0.25)
Very low influence (VL)	(0.00, 0.25, 0.50)
Low influence (L)	(0.25, 0.50, 0.75)
High influence (H)	(0.50, 0.75, 1.00)
Very high influence (VH)	(0.75, 1.00, 1.00)

The criteria weights are utilized for the calculations of the Fuzzy PROMETHEE. Then, the DMT is asked to evaluate alternatives considering each criterion linguistically. In this process, the used linguistic scale is given in Table 4.7. At the end of the Fuzzy PROMETHEE application the final ranking of the supplier alternatives is achieved.

Table 4.7 Linguistic scale for Fuzzy PROMETHEE evaluation.

Linguistic scale	*Triangular fuzzy scale*
Strongly disagree (SDA)	(0.00, 0.00, 0.15)
Disagree (DA)	(0.00, 0.15, 0.30)
Little disagree (LDA)	(0.15, 0.30, 0.50)
No comment (NC)	(0.30, 0.50, 0.65)
Little agree (LA)	(0.50, 0.65, 0.80)
Agree (A)	(0.65, 0.80, 1.00)
Strongly agree (SA)	(0.80, 1.00, 1.00)

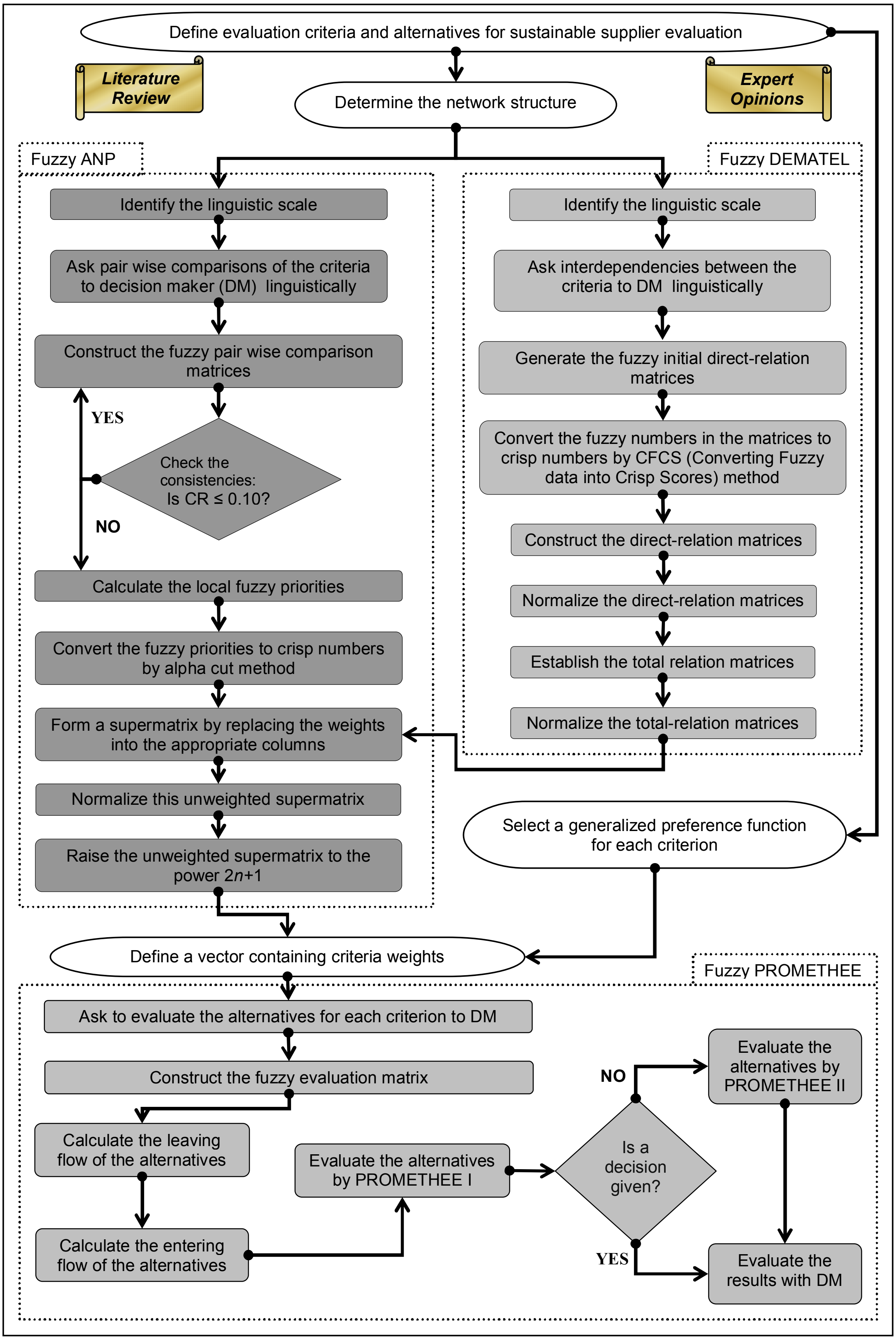

Figure 4.4 Proposed evaluation framework.

5. CASE STUDY

In this section a case study is presented in order to illustrate the application and to foster the better understanding of the proposed methodology for evaluating and selecting suppliers with sustainability considerations. This case study was realized at HAVI Logistics which is an international logistics company's local branch in Istanbul, Turkey. HAVI Logistics is "The Global Lead Logistics Provider" for food and non-food logistics. Besides many brands, company commonly serves McDonald's. Over the past 30 years HAVI Logistics has grown to an international network of more than 40 distribution, logistics and service companies providing a total and exclusive service for more than 6,916 delivery points in 31 countries. In addition, HAVI Logistics is one of the first companies worldwide to achieve validation in accordance with the environmental requirements of the EMAS III Regulation (Eco-Management and Audit Scheme), which are currently the most stringent standards in use. Hence, the reason why this company is chosen for the application of the proposed methodology is that HAVI Logistics has been implementing several initiatives considering sustainability and following the goals associated with sustainable development.

In this study, at the stages that required expert opinions, the necessary data was provided by the DMT. The team is made up of the distribution centre manager Ata Akıcı and the warehouse manager Necip Cem Gülaç conducting sustainability projects of the company. The supplier evaluation process is performed according to the four phase-procedure mentioned in the above section and following the steps of each technique explained in the methodology section. For the purpose of brevity, the details of the pairwise comparison matrices are not discussed in this section. Only a sample of the numerical calculations is given to demonstrate the proposed method.

5.1 PHASE 1: PROBLEM DEFINITION

The main goal in this case study is achieving a supplier evaluation and selection with sustainability concerns. The evaluation clusters and criteria were already discussed and explained in details in Section 3.

5.2 PHASE 2: MODEL FORMULATION

The network model including the interdependencies between criteria and the dependencies between the clusters are generated through the expert opinion. The dependency and inner dependency relations between the evaluation criteria and clusters mentioned in the Section 3 are determined by the DMT. Figure 5.1 shows the schematic view of the network model. A two-way arrow among different levels of criteria represents graphically the dependencies in the ANP model. Additionally, a ‘‘looped arc” is used to represent interdependencies which are the dependencies present within the same level.

5.3 PHASE 3: SUPPLIER ALTERNATIVES DETERMINATION

According to the actual supplier alternatives, the DMT selected six suitable alternatives. Detailed information about these supplier alternatives are not mentioned in this study for ethical and privacy reasons.

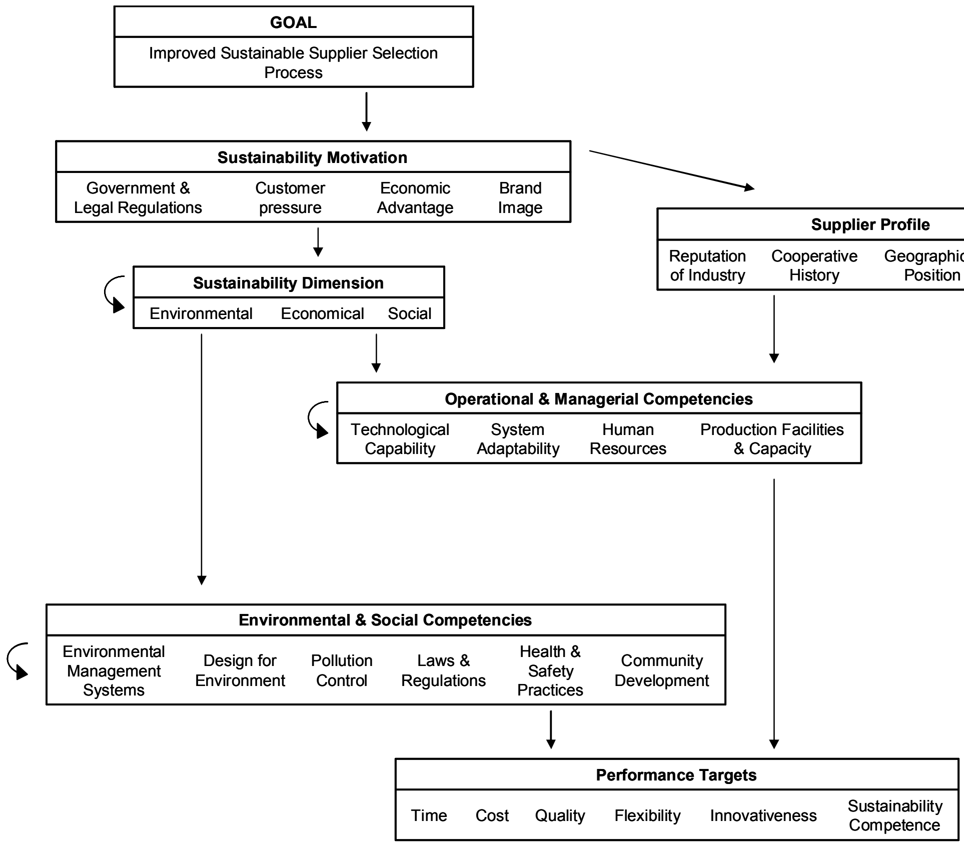

Figure 5.1 Network structure of the model.

5.4 PHASE 4: EVALUATION FRAMEWORK

In this phase the supermatrix S is constructed according to the network model as shown in Table 5.1. The submatrices of the supermatrix S are generated through a hybrid Fuzzy ANP and Fuzzy DEMATEL approach. According to the proposed hybrid approach, Fuzzy ANP is used for calculations of the dependencies between criteria clusters. Hence, the matrices H, A, B, C, D, E, F and G are formed by following the Fuzzy ANP steps. On the other hand the interdependencies within clusters are determined through Fuzzy DEMATEL technique, thus the matrices Tx, Ty and Tz are formed following the steps of this technique.

Phase 4 contains four separate parts. Part 1 covers the Fuzzy ANP steps utilized for the calculation of A, B, C, D, E, F and G. Part 2 covers the application of the Fuzzy DEMATEL technique used to generate Tx, Ty and Tz. In Part 3, all the matrices generated in Part 1 and Part 2 are placed in the unweighted supermatrix S. On the other hand in order to achieve the importance weights for the criteria in C6 the identity matrix I is placed as shown in Table 8 and then the limiting supermatrix $S^{\lim}$ is achieved. Finally, in Part 4 Fuzzy PROMETHEE calculations are realized using the criteria weights calculated through the Fuzzy DEMATEL integrated Fuzzy ANP approach. Hence the final ranking of the alternatives is determined.

Table 5.1 Submatrix notation for the unweighted supermatrix S.

		GOAL	C1	C2	C3	C4	C5	C6
	GOAL	0	0	0	0	0	0	0
	Sustainability Motivation (C1)	**H**	0	0	0	0	0	0
	Supplier Profile (C2)	0	**A**	0	0	0	0	0
S =	Sustainability Dimension (C3)	0	**B**	0	**Tx**	0	0	0
	Operational & Managerial Competencies (C4)	0	0	**C**	**D**	**Ty**	0	0
	Environmental & Social Competencies (C5)	0	0	0	**E**	0	**Tz**	0
	Performance Targets (C6)	0	0	0	0	**F**	**G**	**I**

5.4.1 Part 1: Dependency matrices generation through Fuzzy ANP.

This part begins with the determination of the fuzzy linguistic scale. The fuzzy linguistic scale is already stated in the Section 4.5. For the formation of the pairwise comparison matrices the DMT is asked to express its linguistic judgment about the relative importance of the criteria. For example, the matrix A located in the unweighted supermatrix is generated from the pairwise comparison matrices where the DMT compares all the criteria contained in the cluster C2 with each other with respect to each criterion of the cluster C1. The questionnaire is formulated like this: ‘‘Comparing Reputation of Industry (C21) and Cooperative History (C22), which one is more preferable with respect to Government & Legal Regulations (C11), and by how much is it preferred over the other?’’ The DMT considered that C22 “strongly more important” over C21 with respect to C11, this judgment corresponds to the fuzzy number (3, 4, 5). The linguistic preferences of the DMT are converted to triangular fuzzy numbers utilizing from Table 4.5 and thus matrix A1 is generated as shown in Table 5.2.

Table 5.2 Pairwise comparison matrix A1.

	(Government & Legal Regulations)	Reputation of Industry			Cooperative History			Geographical Position			Financial Status		
	Reputation of Industry	1,00	1,00	1,00	3,00	4,00	5,00	2,00	3,00	4,00	1,00	1,00	2,00
A1=	Cooperative History	0,20	0,25	0,33	1,00	1,00	1,00	1,00	1,00	2,00	0,17	0,20	0,25
	Geographical Position	0,25	0,33	0,50	0,50	1,00	1,00	1,00	1,00	1,00	0,20	0,25	0,33
	Financial Status	0,50	1,00	1,00	4,00	5,00	6,00	3,00	4,00	5,00	1,00	1,00	1,00

Then using the logarithmic least squares method (Eq. (4.12)), the fuzzy relative importance weight Fuzzy W(A1) is calculated and converted in crisp numbers by the alpha cut method (Eqs. (4.13)–(4.17)) forming the relative weight vector W(A1). This vector is called an eigenvector and that vector is used in the consistency check process with λmax. The next stage is to calculate λmax so as to lead to the CI and the CR. Estimates of λmax are obtained from the expression Aω= (λmax)(ω) and λmax ≥ n. Here in this study the λmax is equal to the mean of the estimates of λ calculated. For the matrix A1, the estimates of λ are (4.146, 4.139, 4.138, 4.114) as shown in Table 5.3. Consequently the λmax is 4.1344. CI is calculated utilizing from the expressions CI = $(\lambda_{max} - n)/(n-1)$ and CR=CI/RI where RI is the random index determined according to the Table 3. For the matrix A1 the CR is equal to 0.4978 and does not exceed the consistency limit of 0.10 determined by [131]Saaty (1981), thus it is consistent. In Table 5.3. the results obtained through the calculations of the W(A1) are shown in detail.

Table 5.3 Fuzzy and crisp values of the relative weights of A1 and CI calculations.

Fuzzy W(A1)			W(A1)	λ
0,314	0,373	0,504	0,389	4,146
0,086	0,095	0,128	0,100	4,139
0,080	0,108	0,128	0,105	4,138
0,314	0,424	0,469	0,406	4,114

λmax=	4,1344	Lmax>n
CI=	0,0448	
CR=	0,04978	CR<0,1

CONSISTENT !

Repeating the same steps used in the example of A1, three remaining pairwise comparison matrices are generated with respect to each criterion remaining in the Sustainability Motivation (C1) cluster. Those matrices are denoted as A2, A3 and A4 and the related eigenvectors/ relative weight vectors are W(A2), W(A3) and W(A4) as shown in Table 5.4.

Table 5.4 Pairwise comparison matrices A2, A3, A4 and the related eigenvectors.

	(Customer pressure)	Reputation of			Cooperative			Geographical			Financial Status			W(A2)
	Reputation of Industry	1,00	1,00	1,00	3,00	4,00	5,00	4,00	5,00	6,00	2,00	3,00	4,00	0,551
A2=	Cooperative History	0,20	0,25	0,33	1,00	1,00	1,00	2,00	3,00	4,00	1,00	1,00	2,00	0,195
	Geographical Position	0,17	0,20	0,25	0,25	0,33	0,50	1,00	1,00	1,00	0,50	1,00	1,00	0,099
	Financial Status	0,25	0,33	0,50	0,50	1,00	1,00	1,00	1,00	2,00	1,00	1,00	1,00	0,155

	(Economic Advantage)	Reputation of			Cooperative			Geographical			Financial Status			W(A3)
	Reputation of Industry	1,00	1,00	1,00	0,33	0,50	1,00	2,00	3,00	4,00	0,33	0,50	1,00	0,214
A3=	Cooperative History	1,00	2,00	3,00	1,00	1,00	1,00	2,00	3,00	4,00	0,33	0,50	1,00	0,291
	Geographical Position	0,25	0,33	0,50	0,25	0,33	0,50	1,00	1,00	1,00	0,25	0,33	0,50	0,098
	Financial Status	1,00	2,00	3,00	1,00	2,00	3,00	2,00	3,00	4,00	1,00	1,00	1,00	0,397

	(Brand Image)	Reputation of			Cooperative			Geographical			Financial Status			W(A4)
	Reputation of Industry	1,00	1,00	1,00	1,00	1,00	2,00	2,00	3,00	4,00	0,33	0,50	1,00	0,264
A4=	Cooperative History	0,50	1,00	1,00	1,00	1,00	1,00	3,00	4,00	5,00	1,00	1,00	2,00	0,314
	Geographical Position	0,25	0,33	0,50	0,20	0,25	0,33	1,00	1,00	1,00	0,25	0,33	0,50	0,093
	Financial Status	1,00	2,00	3,00	0,50	1,00	1,00	2,00	3,00	4,00	1,00	1,00	1,00	0,329

These eigenvectors are then placed in such a way that they constitute the columns of A which is a submatrix of the unweighted supermatrix S. Figure 5.2. shows the submatrix A which is generated through the eigenvectors and its location in S. Following the same procedure used in the generation of A, the remaining sub-matrices B, C, D, E, F, G and H are determined as shown in Table. 5.5.

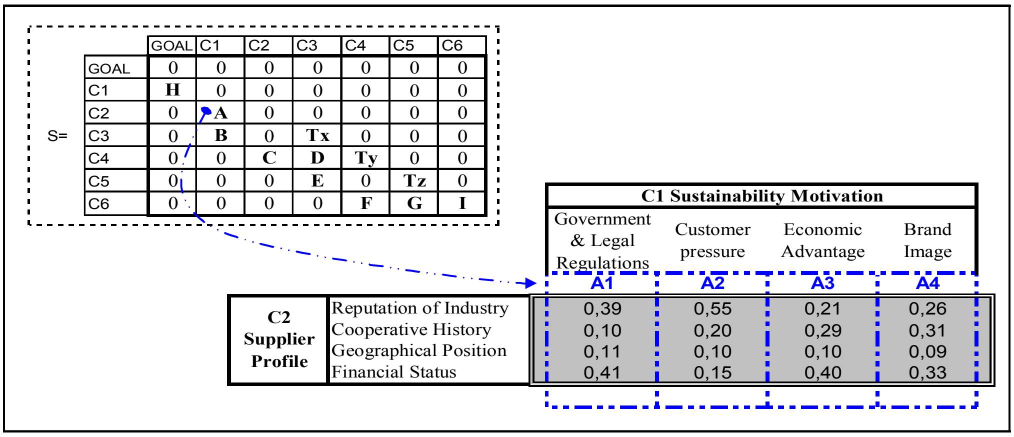

Figure 5.2 Submatrix A.

5.4.2 Part 2: Inner-dependency matrices generation through Fuzzy DEMATEL.

This part covers the formation of the matrices Tx, Ty and Tz utilizing from the Fuzzy DEMATEL technique. The fuzzy linguistic scale used in Fuzzy DEMATEL is already stated in Table 4.6 in Section 4.5. The DMT is asked to identify the different degrees of influence of a criterion on another criterion within the same cluster in linguistic terms. These linguistic assessments are then converted to triangular fuzzy numbers utilizing from Table 4.6.

For example, to form the matrix Tx located in the unweighted supermatrix S, first the DMT is asked to identify the influence of each criterion on the others within the same cluster Sustainability Dimensions (C3). This linguistic preferences matrix shown in Table 5.6 is then converted to triangular fuzzy numbers and hence the fuzzy initial direct relation matrix F-iD(x) is obtained as shown in Table 5.7. In the next step, F-iD(x) is defuzzified by CFCS method utilizing from Eqs. (4.25) - (4.31) and the initial direct relation matrix iD(x) is achieved as shown in Table 5.8.

Table 5.5 Pairwise comparison matrices generated through Fuzzy ANP.

[B]=

C3 Sustainability Dimension	C1 Sustainability Motivation: Government & Legal Regulations (B1)	Customer pressure (B2)	Economic Advantage (B3)	Brand Image (B4)
Environmental	0,41	0,45	0,49	0,51
Economical	0,49	0,15	0,10	0,11
Social	0,10	0,40	0,41	0,38

[C]=

C4 Operational & Managerial Competencies	C2 Supplier Profile: Reputation of Industry (C1)	Cooperative History (C2)	Geographical Position (C3)	Financial Status (C4)
Technological Capability	0,42	0,16	0,11	0,33
System Adaptability	0,10	0,34	0,12	0,16
Human Resources	0,19	0,33	0,33	0,16
Production Facilities & Capacity	0,29	0,16	0,45	0,34

[D]=

C4 Operational & Managerial Competencies	C3 Sustainability Dimension: Environmental (D1)	Economical (D2)	Social (D3)
Technological Capability	0,32	0,37	0,07
System Adaptability	0,30	0,12	0,13
Human Resources	0,11	0,11	0,60
Production Facilities & Capacity	0,27	0,40	0,20

[E]=

C5 Environmental &Social Competencies	C3 Sustainability Dimension: Environmental (E1)	Economical (E2)	Social (E3)
Environmental Management Systems	0,21	0,08	0,05
Design for Environment	0,07	0,07	0,06
Pollution Control	0,21	0,40	0,11
Laws & Regulations	0,22	0,20	0,21
Health & Safety Practices	0,20	0,18	0,28
Community Development	0,09	0,07	0,30

[F]=

C6 Performance Targets	C4 Operational & Managerial Competencies: Technological Capability (F1)	System Adaptability (F2)	Human Resources (F3)	Production Facilities & Capacity (F4)
Time	0,13	0,20	0,22	0,32
Cost	0,10	0,09	0,11	0,31
Quality	0,22	0,10	0,21	0,18
Flexibility	0,20	0,33	0,11	0,07
Innovativeness	0,20	0,19	0,18	0,06
Sustainability Competence	0,15	0,09	0,18	0,06

[G]=

C6 Performance Targets	C5 Environmental & Social Competencies: Environmental Management Systems (G1)	Design for Environment (G2)	Pollution Control (G3)	Laws & Regulations (G4)	Health & Safety Practices (G5)	Community Development (G6)
Time	0,07	0,05	0,05	0,10	0,05	0,09
Cost	0,07	0,06	0,30	0,10	0,26	0,09
Quality	0,08	0,08	0,11	0,21	0,15	0,09
Flexibility	0,18	0,15	0,05	0,06	0,08	0,09
Innovativeness	0,20	0,26	0,19	0,07	0,06	0,09
Sustainability Competence	0,40	0,39	0,30	0,46	0,39	0,54

[H]=

C1 Sustainability Motivation	GOAL (H1)
Government & Legal Regulations	0,39
Customer pressure	0,15
Economic Advantage	0,08
Brand Image	0,39

Table 5.6 Linguistic preference matrix for C3.

	Environmental	Economical	Social
Environmental	-	H	VH
Economical	H	-	VL
Social	VH	H	-

Table 5.7 Fuzzy initial direct relation matrix F-iD(x).

	Environmental			Economical			Social		
[F- iD(x)] = Environmental	0,00	0,00	0,00	0,50	0,75	1,00	0,75	1,00	1,00
Economical	0,50	0,75	1,00	0,00	0,00	0,00	0,00	0,25	0,50
Social	0,75	1,00	1,00	0,50	0,75	1,00	0,00	0,00	0,00

Table 5.8 Initial direct relation matrix iD(x) for C3.

[iD(x)]=	Environmental	Economical	Social
Environmental	0,000	0,733	0,967
Economical	0,733	0,000	0,267
Social	0,967	0,733	0,000

Based on the initial direct-relation matrix iD(x), the normalized direct-relation matrix nD(x) is obtained through Eq. (4.19) and Eq. (4.20) as shown in Table 5.9. Then, the total relation matrix Tr(x) is acquired by using Eq. (4.21) and then normalized by dividing each component in a column to the sum of the column, thus the normalized total relation matrix also called the inner-dependency matrix Tx is achieved and shown in Table 5.10.

Table 5.9 Normalized direct relation matrix nD(x).

[nD(x)]=	Environmental	Economical	Social
Environmental	0,000	0,431	0,569
Economical	0,431	0,000	0,157
Social	0,569	0,431	0,000

Table 5.10 Normalized total relation matrix Tx .

[Tx]=	Environmental	Economical	Social
Environmental	0,339	0,386	0,404
Economical	0,270	0,227	0,256
Social	0,391	0,386	0,340

As in this study the Fuzzy DEMATEL is used to determine the interdependencies between criteria in the same cluster, the application of the Fuzzy DEMATEL technique is terminated as the inner-dependency matrix Tx is achieved. Tx is a submatrix located in the unweighted supermatrix S as shown in Figure 5.3.

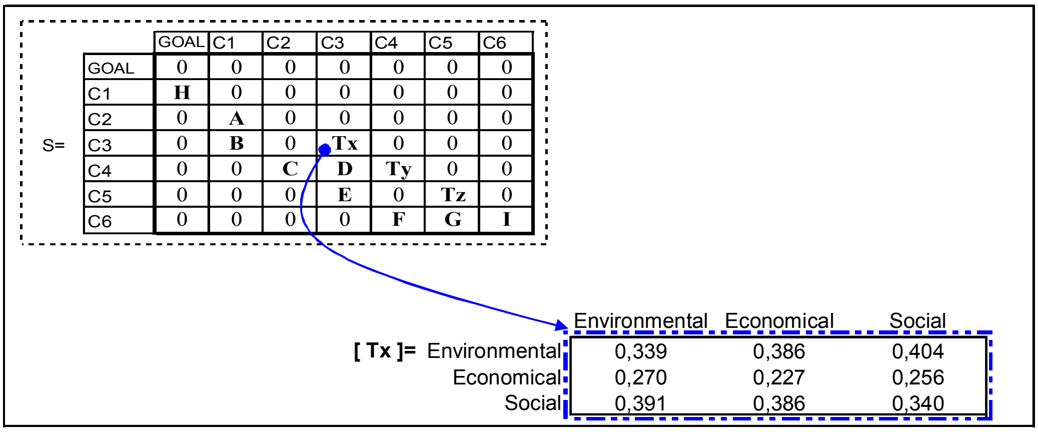

Figure 5.3 Submatrix Tx.

Following the same procedure used in the generation of Tx, the remaining sub-matrices Ty and Tz are determined as shown in Table. 5.11.

Table 5.11 Pairwise comparison matrices generated through Fuzzy DEMATEL.

[Ty]=		Technological Capability	System Adaptability	Human Resources	Production Facilities & Capacity
	Technological Capability	0,24	0,31	0,36	0,30
	System Adaptability	0,20	0,14	0,18	0,19
	Human Resources	0,27	0,31	0,22	0,30
	Production Facilities & Capacity	0,29	0,24	0,24	0,20

[Tz]=		Environmental Management Systems	Design for Environment	Pollution Control	Laws & Regulations	Health & Safety Practices	Community Development
	Environmental Management Systems	0,08	0,14	0,21	0,10	0,14	0,10
	Design for Environment	0,15	0,07	0,17	0,12	0,13	0,18
	Pollution Control	0,23	0,21	0,11	0,17	0,25	0,26
	Laws & Regulations	0,33	0,30	0,31	0,14	0,36	0,23
	Health & Safety Practices	0,17	0,21	0,14	0,14	0,08	0,20
	Community Development	0,05	0,07	0,06	0,33	0,05	0,04

5.4.3 Part 3: Supermatrix generation.

The matrices generated in Part 2 through the Fuzzy ANP and Fuzzy DEMATEL methods are located in the unweighted supermatrix S. Additionally the purpose of the hybrid Fuzzy ANP and Fuzzy DEMATEL approach is to achieve the importance weight of the six criteria under the cluster of Performance Targets (C6), thus the identity matrix I is placed as shown in Table 5.1.

The unweighted supermatrix S is normalized and the normalized supermatrix S^{norm} is achieved as shown in Table 5.12 and Table 5.13 respectively. Finally, in order to achieve the global weights for those criteria the normalized supermatrix S^{norm} is raised to a large power hence the limiting supermatrix $S^{\lim}$ is achieved as shown in Table 5.14. The importance weight achieved for Time, Cost, Quality, Flexibility, Innovativeness and Sustainability Competence criteria are 0.180, 0.158, 0.170, 0.147, 0.150, 0.195 respectively.

Hence, the procedure followed at this part is to calculate global weights by raising the weighted supermatrix to a large power until convergence to a solution occurs and thus obtain the limiting supermatrix by using Eq. (4.9).

Table 5.12 Unweighted supermatrix S.

		C1				C2				C3			C4				C5						C6					
		Sustainability Motivation				Supplier Profile				Sustainability Dimension			Operational & Managerial Competencies				Environmental & Social Competencies						Performance Targets					
	GOAL	Government & Legal Regulations	Customer pressure	Economic Advantage	Brand Image	Reputation of Industry	Cooperative History	Geographical Position	Financial Status	Environmental	Economical	Social	Technological Capability	System Adaptability	Human Resources	Production Facilities & Capacity	Environmental Management Systems	Design for Environment	Pollution Control	Laws & Regulations	Health & Safety Practices	Community Development	Time	Cost	Quality	Flexibility	Innovativeness	Sustainability Competence
GOAL	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Government & Legal Regulations	0,39	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Customer pressure	0,15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Economic Advantage	0,08	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Brand Image	0,39	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Reputation of Industry	0,00	0,39	0,55	0,21	0,26	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cooperative History	0,00	0,10	0,20	0,29	0,31	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Geographical Position	0,00	0,11	0,10	0,10	0,09	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Financial Status	0,00	0,41	0,15	0,40	0,33	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Environmental	0,00	0,41	0,45	0,49	0,51	0,00	0,00	0,00	0,00	0,34	0,39	0,40	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Economical	0,00	0,49	0,15	0,10	0,11	0,00	0,00	0,00	0,00	0,27	0,23	0,26	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Social	0,00	0,10	0,40	0,41	0,38	0,00	0,00	0,00	0,00	0,39	0,39	0,34	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Technological Capability	0,00	0,00	0,00	0,00	0,00	0,42	0,16	0,11	0,33	0,32	0,37	0,07	0,24	0,31	0,36	0,30	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
System Adaptability	0,00	0,00	0,00	0,00	0,00	0,10	0,34	0,12	0,16	0,30	0,12	0,13	0,20	0,14	0,18	0,19	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Human Resources	0,00	0,00	0,00	0,00	0,00	0,19	0,33	0,33	0,16	0,11	0,11	0,60	0,27	0,31	0,22	0,30	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Production Facilities & Capacity	0,00	0,00	0,00	0,00	0,00	0,29	0,16	0,45	0,34	0,27	0,40	0,20	0,29	0,24	0,24	0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Environmental Management Systems	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,21	0,08	0,05	0,00	0,00	0,00	0,00	0,08	0,14	0,21	0,10	0,14	0,10	0,00	0,00	0,00	0,00	0,00	0,00
Design for Environment	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,07	0,07	0,06	0,00	0,00	0,00	0,00	0,15	0,07	0,17	0,12	0,13	0,18	0,00	0,00	0,00	0,00	0,00	0,00
Pollution Control	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,21	0,40	0,11	0,00	0,00	0,00	0,00	0,23	0,21	0,11	0,17	0,25	0,26	0,00	0,00	0,00	0,00	0,00	0,00
Laws & Regulations	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,22	0,20	0,21	0,00	0,00	0,00	0,00	0,33	0,30	0,31	0,14	0,36	0,23	0,00	0,00	0,00	0,00	0,00	0,00
Health & Safety Practices	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,18	0,28	0,00	0,00	0,00	0,00	0,17	0,21	0,14	0,14	0,08	0,20	0,00	0,00	0,00	0,00	0,00	0,00
Community Development	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,09	0,07	0,30	0,00	0,00	0,00	0,00	0,05	0,07	0,06	0,33	0,05	0,04	0,00	0,00	0,00	0,00	0,00	0,00
Time	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,13	0,20	0,22	0,32	0,07	0,05	0,05	0,10	0,05	0,09	1,00	0,00	0,00	0,00	0,00	0,00
Cost	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,09	0,11	0,31	0,07	0,06	0,30	0,10	0,26	0,09	0,00	1,00	0,00	0,00	0,00	0,00
Quality	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,22	0,10	0,21	0,18	0,08	0,08	0,11	0,21	0,15	0,09	0,00	0,00	1,00	0,00	0,00	0,00
Flexibility	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,33	0,11	0,07	0,18	0,15	0,05	0,06	0,08	0,09	0,00	0,00	0,00	1,00	0,00	0,00
Innovativeness	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,19	0,18	0,06	0,20	0,26	0,19	0,07	0,06	0,09	0,00	0,00	0,00	0,00	1,00	0,00
Sustainability Competence	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,15	0,09	0,18	0,06	0,40	0,39	0,30	0,46	0,39	0,54	0,00	0,00	0,00	0,00	0,00	1,00

Table 5.13 Normalized super matrix S^{norm}.

		C1				C2				C3			C4				C5						C6					
		Sustainability Motivation				Supplier Profile				Sustainability Dimension			Operational & Managerial Competencies				Environmental & Social Competencies						Performance Targets					
	GOAL	Government & Legal Regulations	Customer pressure	Economic Advantage	Brand Image	Reputation of Industry	Cooperative History	Geographical Position	Financial Status	Environmental	Economical	Social	Technological Capability	System Adaptability	Human Resources	Production Facilities & Capacity	Environmental Management Systems	Design for Environment	Pollution Control	Laws & Regulations	Health & Safety Practices	Community Development	Time	Cost	Quality	Flexibility	Innovativeness	Sustainability Competence
GOAL	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Government & Legal Regulations	0,39	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Customer pressure	0,15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Economic Advantage	0,08	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Brand Image	0,39	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Reputation of Industry	0,00	0,19	0,28	0,11	0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cooperative History	0,00	0,05	0,10	0,15	0,16	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Geographical Position	0,00	0,05	0,05	0,05	0,05	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Financial Status	0,00	0,20	0,08	0,20	0,16	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Environmental	0,00	0,20	0,23	0,25	0,25	0,00	0,00	0,00	0,00	0,11	0,13	0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Economical	0,00	0,25	0,07	0,05	0,06	0,00	0,00	0,00	0,00	0,09	0,08	0,09	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Social	0,00	0,05	0,20	0,20	0,19	0,00	0,00	0,00	0,00	0,13	0,13	0,11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Technological Capability	0,00	0,00	0,00	0,00	0,00	0,42	0,16	0,11	0,33	0,11	0,12	0,02	0,12	0,15	0,18	0,15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
System Adaptability	0,00	0,00	0,00	0,00	0,00	0,10	0,34	0,12	0,16	0,10	0,04	0,04	0,10	0,07	0,09	0,10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Human Resources	0,00	0,00	0,00	0,00	0,00	0,19	0,33	0,33	0,16	0,04	0,04	0,20	0,14	0,15	0,11	0,15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Production Facilities & Capacity	0,00	0,00	0,00	0,00	0,00	0,29	0,16	0,45	0,34	0,09	0,13	0,07	0,14	0,12	0,12	0,10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Environmental Management Systems	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,07	0,03	0,02	0,00	0,00	0,00	0,00	0,04	0,07	0,11	0,05	0,07	0,05	0,00	0,00	0,00	0,00	0,00	0,00
Design for Environment	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,02	0,02	0,00	0,00	0,00	0,00	0,08	0,04	0,08	0,06	0,06	0,09	0,00	0,00	0,00	0,00	0,00	0,00
Pollution Control	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,07	0,13	0,04	0,00	0,00	0,00	0,00	0,11	0,10	0,06	0,08	0,12	0,13	0,00	0,00	0,00	0,00	0,00	0,00
Laws & Regulations	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,07	0,07	0,07	0,00	0,00	0,00	0,00	0,16	0,15	0,16	0,07	0,18	0,11	0,00	0,00	0,00	0,00	0,00	0,00
Health & Safety Practices	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,07	0,06	0,09	0,00	0,00	0,00	0,00	0,08	0,10	0,07	0,07	0,04	0,10	0,00	0,00	0,00	0,00	0,00	0,00
Community Development	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,03	0,02	0,10	0,00	0,00	0,00	0,00	0,02	0,04	0,03	0,16	0,02	0,02	0,00	0,00	0,00	0,00	0,00	0,00
Time	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,06	0,10	0,11	0,16	0,03	0,02	0,03	0,05	0,02	0,05	1,00	0,00	0,00	0,00	0,00	0,00
Cost	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,05	0,04	0,05	0,16	0,04	0,03	0,15	0,05	0,13	0,05	0,00	1,00	0,00	0,00	0,00	0,00
Quality	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,11	0,05	0,10	0,09	0,04	0,04	0,06	0,11	0,08	0,05	0,00	0,00	1,00	0,00	0,00	0,00
Flexibility	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,16	0,05	0,03	0,09	0,08	0,02	0,03	0,04	0,05	0,00	0,00	0,00	1,00	0,00	0,00
Innovativeness	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,10	0,09	0,03	0,10	0,13	0,09	0,03	0,03	0,05	0,00	0,00	0,00	0,00	1,00	0,00
Sustainability Competence	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,08	0,05	0,09	0,03	0,20	0,20	0,15	0,23	0,20	0,27	0,00	0,00	0,00	0,00	0,00	1,00

Table 5.14 Limiting supermatrix $S^{\lim}$.

		C1				C2				C3			C4				C5						C6					
		Sustainability Motivation				Supplier Profile				Sustainability Dimension			Operational & Managerial Competencies				Environmental & Social Competencies						Performance Targets					
	GOAL	Government & Legal Regulations	Customer pressure	Economic Advantage	Brand Image	Reputation of Industry	Cooperative History	Geographical Position	Financial Status	Environmental	Economical	Social	Technological Capability	System Adaptability	Human Resources	Production Facilities & Capacity	Environmental Management Systems	Design for Environment	Pollution Control	Laws & Regulations	Health & Safety Practices	Community Development	Time	Cost	Quality	Flexibility	Innovativeness	Sustainability Competence
GOAL	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Government & Legal Regulations	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Customer pressure	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Economic Advantage	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Brand Image	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Reputation of Industry	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cooperative History	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Geographical Position	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Financial Status	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Environmental	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Economical	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Social	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Technological Capability	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
System Adaptability	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Human Resources	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Production Facilities & Capacity	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Environmental Management Systems	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Design for Environment	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pollution Control	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Laws & Regulations	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Health & Safety Practices	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Community Development	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Time	**0,18**	0,18	0,18	0,18	0,18	0,21	0,21	0,23	0,22	0,14	0,14	0,15	0,17	0,21	0,22	0,26	0,07	0,06	0,06	0,09	0,06	0,08	1,00	0,00	0,00	0,00	0,00	0,00
Cost	**0,16**	0,16	0,16	0,16	0,16	0,16	0,14	0,17	0,16	0,16	0,17	0,15	0,13	0,12	0,13	0,23	0,11	0,11	0,22	0,12	0,20	0,13	0,00	1,00	0,00	0,00	0,00	0,00
Quality	**0,17**	0,17	0,17	0,17	0,17	0,19	0,18	0,18	0,18	0,16	0,16	0,16	0,20	0,14	0,20	0,18	0,11	0,11	0,12	0,17	0,14	0,11	0,00	0,00	1,00	0,00	0,00	0,00
Flexibility	**0,15**	0,15	0,15	0,15	0,15	0,16	0,18	0,15	0,16	0,13	0,13	0,12	0,18	0,24	0,14	0,12	0,14	0,12	0,07	0,08	0,09	0,09	0,00	0,00	0,00	1,00	0,00	0,00
Innovativeness	**0,15**	0,15	0,15	0,15	0,15	0,16	0,16	0,15	0,15	0,15	0,14	0,14	0,18	0,18	0,17	0,11	0,16	0,19	0,16	0,10	0,10	0,12	0,00	0,00	0,00	0,00	1,00	0,00
Sustainability Competence	**0,19**	0,19	0,20	0,20	0,20	0,12	0,12	0,12	0,12	0,27	0,26	0,28	0,14	0,11	0,15	0,09	0,41	0,40	0,36	0,44	0,40	0,47	0,00	0,00	0,00	0,00	0,00	1,00

Part 4: Fuzzy PROMETHEE application and ranking of alternatives

In this part Fuzzy PROMETHEE calculations are realized using the criteria weights calculated through the Fuzzy DEMATEL integrated Fuzzy ANP approach in Part 3. As a first step of Fuzzy PROMETHEE, the DMT is asked to determine the thresholds values q and p that are utilized in the generalized preference function stated in Eq. (4.40). Hence, the DMT determined the preference threshold p as 0.7 and the indifference threshold q as 0.

Following this step, the DMT is asked to evaluate the alternatives linguistically on the judgment criteria. Considering that the alternative set had six alternatives and judgment criteria set had six criteria Table 5.15 illustrates the linguistic evaluation of the DMT for alternatives A1, A2, A3, A4, A5 and A6.

In the following Fuzzy PROMETHEE calculations, a fuzzy number is represented in the form $\widetilde{F} = (n, a, b)$ which is a different version of the representation used in the previous sections including the linguistic evaluation matrix stated in Table 5.15 and the linguistic scale denoted in Table 4.7. It is equivalent to the previous representation by $\widetilde{F} = (n - a, n, n + b)$. Then, utilizing from Table 4.7 and the equivalency above, these linguistic evaluations are converted to triangular fuzzy numbers in form $\widetilde{F} = (n, a, b)$ as shown in Table 5.16.

Table 5.15 Linguistic evaluations of the alternatives by DMT.

	Time	Cost	Quality	Flexibility	Innovativeness	Sustainability Competence
A1	LDA	SA	A	DA	LDA	A
A2	A	SDA	SA	DA	LDA	NC
A3	LA	LDA	NC	SDA	NC	DA
A4	SA	LA	NC	LA	LDA	SA
A5	LDA	LDA	DA	SA	A	LA
A6	A	SDA	SDA	SDA	DA	SDA

Table 5.16 Fuzzy values of the linguistic evaluation in form (n,a,b).

	Time			Cost			Quality			Flexibility			Innovativeness			Sustainability Competence		
A1	0,30	0,15	0,20	1,00	0,20	0,00	0,80	0,15	0,20	0,15	0,15	0,20	0,30	0,15	0,20	0,80	0,15	0,20
A2	0,80	0,15	0,20	0,00	0,00	0,15	1,00	0,20	0,00	0,15	0,15	0,20	0,30	0,15	0,20	0,50	0,20	0,15
A3	0,65	0,15	0,15	0,30	0,15	0,20	0,50	0,20	0,15	0,00	0,00	0,15	0,50	0,20	0,15	0,15	0,15	0,20
A4	1,00	0,20	0,00	0,65	0,15	0,15	0,50	0,20	0,15	0,65	0,15	0,15	0,30	0,15	0,20	1,00	0,20	0,00
A5	0,30	0,15	0,20	0,30	0,15	0,20	0,15	0,15	0,20	1,00	0,20	0,00	0,80	0,15	0,20	0,65	0,15	0,15
A6	0,80	0,15	0,20	0,00	0,00	0,15	0,00	0,00	0,15	0,00	0,00	0,15	0,15	0,15	0,20	0,00	0,00	0,15

At the next step, the differences between each alternative pair for each criterion are calculated by $f_k(Ai) - f_k(Aj)$ which represents the difference between the evaluation value of the alternative Ai and Aj according to the criterion k. Table 5.17 shows the $f_k(Ai) - f_k(Aj)$ values obtained through the evaluation matrix denoted in Table 5.16.

Then using these differences, the preference values $P_k(Ai, Aj) = P_k(f_k(Ai) - f_k(Aj))$ are calculated by Eq. (4.40) for each criterion k as shown in Table 5.18 and then converted to crisp values utilizing from Yager Index method (Eq. (4.41)). Table 5.19 illustrates the crisp values of $P_k(Ai, Aj)$.

The next step is the calculation of preference index $\pi(Ai, Aj)$ which is the weighted average of the preference functions $P_k(Ai, Aj)$ using criteria weights achieved from Fuzzy ANP in Part 3 and utilizing from Eq. (4.33). The preference index values are stated in Table 5.20.

Based on the preference index values, the leaving and entering flows are calculated through Eq.(4.34) and Eq.(4.35) respectively. Table 5.21 shows the entering and leaving flows of alternatives. Then, the partial ranking of alternatives is found via PROMETHEE I calculation using Eqs. (4.36)-(4.38). The partial ranking is illustrated in Figure 5.4.

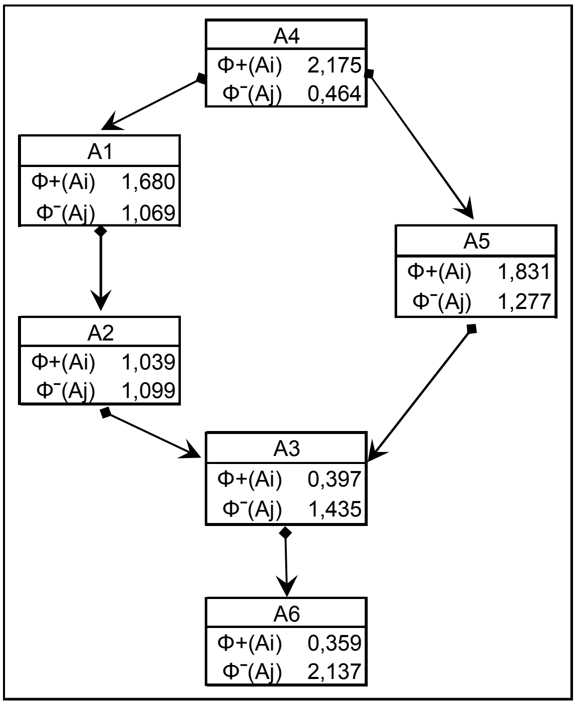

Figure 5.4 Partial ranking of alternatives via PROMETHEE I.

According to the partial ranking achieved, A4 outranks all the other alternatives. A1 outranks A2, A3 and A6. A2 and A5 outranks A3. A5, A2, A1 cannot be compared and A6 is the worst alternative. As the partial ranking does not provide a complete ranking to make a decision, the procedure continues with the calculations of PROMETHEE II. Hence, the net flows of alternatives are calculated by Eq. (4.39) and the complete ranking of alternatives is determined as shown in Figure 5.5.

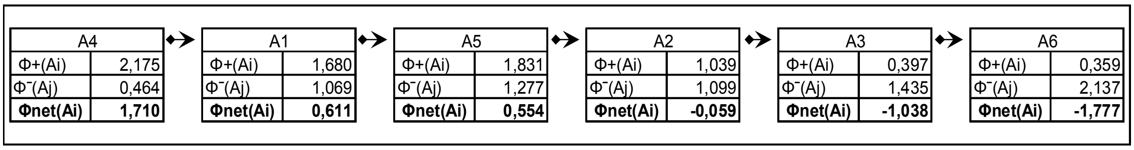

Figure 5.5 Complete ranking of alternatives achieved via PROMETHEE II.

Table 5.17 Evaluation differences calculated for each criterion k.

k= Time

	A1	A2	A3	A4	A5	A6
A1		-0,50 0,35 0,35	-0,35 0,30 0,35	-0,70 0,15 0,40	0,00 0,35 0,35	-0,50 0,35 0,35
A2	0,50 0,35 0,35		0,15 0,30 0,35	-0,20 0,15 0,40	0,50 0,35 0,35	0,00 0,35 0,35
A3	0,35 0,35 0,30	-0,15 0,35 0,30		-0,35 0,15 0,35	0,35 0,35 0,30	-0,15 0,35 0,30
A4	0,70 0,40 0,15	0,20 0,40 0,15	0,35 0,35 0,15		0,70 0,40 0,15	0,20 0,40 0,15
A5	0,00 0,35 0,35	-0,50 0,35 0,35	-0,35 0,30 0,35	-0,70 0,15 0,40		-0,50 0,35 0,35
A6	0,50 0,35 0,35	0,00 0,35 0,35	0,15 0,30 0,35	-0,20 0,15 0,40	0,50 0,35 0,35	

k= Cost

	A1	A2	A3	A4	A5	A6
A1		1,00 0,35 0,00	0,70 0,40 0,15	0,35 0,35 0,15	0,70 0,40 0,15	1,00 0,35 0,00
A2	-1,00 0,00 0,35		-0,30 0,20 0,30	-0,65 0,15 0,30	-0,30 0,20 0,30	0,00 0,15 0,15
A3	-0,70 0,15 0,40	0,30 0,30 0,20		-0,35 0,30 0,35	0,00 0,35 0,35	0,30 0,30 0,20
A4	-0,35 0,15 0,35	0,65 0,30 0,15	0,35 0,35 0,30		0,35 0,35 0,30	0,65 0,30 0,15
A5	-0,70 0,15 0,40	0,30 0,30 0,20	0,00 0,35 0,35	-0,35 0,30 0,35		0,30 0,30 0,20
A6	-1,00 0,00 0,35	0,00 0,15 0,15	-0,30 0,20 0,30	-0,65 0,15 0,30	-0,30 0,20 0,30	

k= Quality

	A1	A2	A3	A4	A5	A6
A1		-0,20 0,15 0,40	0,30 0,30 0,40	0,30 0,30 0,40	0,65 0,35 0,35	0,80 0,30 0,20
A2	0,20 0,40 0,15		0,50 0,35 0,20	0,50 0,35 0,20	0,85 0,40 0,15	1,00 0,35 0,00
A3	-0,30 0,40 0,30	-0,50 0,20 0,35		0,00 0,35 0,35	0,35 0,40 0,30	0,50 0,35 0,15
A4	-0,30 0,40 0,30	-0,50 0,20 0,35	0,00 0,35 0,35		0,35 0,40 0,30	0,50 0,35 0,15
A5	-0,65 0,35 0,35	-0,85 0,15 0,40	-0,35 0,30 0,40	-0,35 0,30 0,40		0,15 0,30 0,20
A6	-0,80 0,20 0,30	-1,00 0,00 0,35	-0,50 0,15 0,35	-0,50 0,15 0,35	-0,15 0,20 0,30	

k= Flexibility

	A1	A2	A3	A4	A5	A6
A1		0,00 0,35 0,35	0,15 0,30 0,20	-0,50 0,30 0,35	-0,85 0,15 0,40	0,15 0,30 0,20
A2	0,00 0,35 0,35		0,15 0,30 0,20	-0,50 0,30 0,35	-0,85 0,15 0,40	0,15 0,30 0,20
A3	-0,15 0,20 0,30	-0,15 0,20 0,30		-0,65 0,15 0,30	-1,00 0,00 0,35	0,00 0,15 0,15
A4	0,50 0,35 0,30	0,50 0,35 0,30	0,65 0,30 0,15		-0,35 0,15 0,35	0,65 0,30 0,15
A5	0,85 0,40 0,15	0,85 0,40 0,15	1,00 0,35 0,00	0,35 0,35 0,15		1,00 0,35 0,00
A6	-0,15 0,20 0,30	-0,15 0,20 0,30	0,00 0,15 0,15	-0,65 0,15 0,30	-1,00 0,00 0,35	

k= Innovativeness

	A1	A2	A3	A4	A5	A6
A1		0,00 0,35 0,35	-0,20 0,30 0,40	0,00 0,35 0,35	-0,50 0,35 0,35	0,15 0,35 0,35
A2	0,00 0,35 0,35		-0,20 0,30 0,40	0,00 0,35 0,35	-0,50 0,35 0,35	0,15 0,35 0,35
A3	0,20 0,40 0,30	0,20 0,40 0,30		0,20 0,40 0,30	-0,30 0,40 0,30	0,35 0,40 0,30
A4	0,00 0,35 0,35	0,00 0,35 0,35	-0,20 0,30 0,40		-0,50 0,35 0,35	0,15 0,35 0,35
A5	0,50 0,35 0,35	0,50 0,35 0,35	0,30 0,30 0,40	0,50 0,35 0,35		0,65 0,35 0,35
A6	-0,15 0,35 0,35	-0,15 0,35 0,35	-0,35 0,30 0,40	-0,15 0,35 0,35	-0,65 0,35 0,35	

k= Sustainability Competence

	A1	A2	A3	A4	A5	A6
A1		0,30 0,30 0,40	0,65 0,35 0,35	-0,20 0,15 0,40	0,15 0,30 0,35	0,80 0,30 0,20
A2	-0,30 0,40 0,30		0,35 0,40 0,30	-0,50 0,20 0,35	-0,15 0,35 0,30	0,50 0,35 0,15
A3	-0,65 0,35 0,35	-0,35 0,30 0,40		-0,85 0,15 0,40	-0,50 0,30 0,35	0,15 0,30 0,20
A4	0,20 0,40 0,15	0,50 0,35 0,20	0,85 0,40 0,15		0,35 0,35 0,15	1,00 0,35 0,00
A5	-0,15 0,35 0,30	0,15 0,30 0,35	0,50 0,35 0,30	-0,35 0,15 0,35		0,65 0,30 0,15
A6	-0,80 0,20 0,30	-0,50 0,15 0,35	-0,15 0,20 0,30	-1,00 0,00 0,35	-0,65 0,15 0,30	

Finally, according to the complete ranking, the alternative A4 is the best alternative according to the model presented in this study, and it outranks the second alternative A2 with a high margin. Thus A4 can be considered as the most "sustainable" alternative among others.

Table 5.18 Preference values calculated for each criterion k.

k= Time

	A1	A2	A3	A4	A5	A6
A1		0	0	0	0	0
A2	1		0	0	1	0
A3	0,50 0,50 0,43	0		0	0,50 0,50 0,43	0
A4	1	0	0,50 0,50 0,21		1	0
A5	0	0	0	0		0
A6	1	0	0	0	1	

k= Cost

	A1	A2	A3	A4	A5	A6
A1		1	1	0,50 0,50 0,21	1	1
A2	0		0	0	0	0
A3	0	0,43 0,43 0,29		0	0	0,43 0,43 0,29
A4	0	1	0,50 0,50 0,21		0,50 0,50 0,43	1
A5	0	0,43 0,43 0,29	0	0		0,43 0,43 0,29
A6	0	0	0	0	0	

k= Quality

	A1	A2	A3	A4	A5	A6
A1		0	0,43 0,43 0,57	0,43 0,43 0,57	1	1
A2	0		0,71 0,50 0,29	0,71 0,50 0,29	1	1
A3	0	0		0	0	0,71 0,50 0,21
A4	0	0	0		0	0,71 0,50 0,21
A5	0	0	0	0		0
A6	0	0	0	0	0	

k= Flexibility

	A1	A2	A3	A4	A5	A6
A1		0	0	0	0	0
A2	0		0	0	0	0
A3	0	0		0	0	0
A4	1	1	1		0	1
A5	1	1	1	0,50 0,50 0,21		1
A6	0	0	0	0	0	

k= Innovativeness

	A1	A2	A3	A4	A5	A6
A1		0	0	0	0	0
A2	0		0	0	0	0
A3	0	0		0	0	0
A4	0	0	0		0	0
A5	1	1	0,43 0,43 0,57	1		1
A6	0	0	0	0	0	

k= Sustainability Competence

	A1	A2	A3	A4	A5	A6
A1		0,43 0,43 0,57	1	0	0	1
A2	0		0	0	0	0,71 0,50 0,21
A3	0	0		0	0	0
A4	0	0,71 0,50 0,29	1		0,50 0,50 0,21	1
A5	0	0	1	0		1
A6	0	0	0	0	0	

Table 5.19 Crisp preference values calculated for each criterion k.

k= Time

	A1	A2	A3	A4	A5	A6
A1		0	0	0	0	0
A2	1		0	0	1	0
A3	0,48	0		0	0,48	0
A4	1	0	0,40		1	0
A5	0	0	0	0		0
A6	1	0	0	0	1	

k= Cost

	A1	A2	A3	A4	A5	A6
A1		1	1	0,40	1	1
A2	0		0	0	0	0
A3	0	0,38		0	0	0,38
A4	0	1	0,40		0,48	1
A5	0	0,38	0	0		0,38
A6	0	0	0	0	0	

k= Quality

	A1	A2	A3	A4	A5	A6
A1		0	0,48	0,48	1	1
A2	0		0,64	0,64	1	1
A3	0	0		0	0	0,62
A4	0	0	0		0	0,62
A5	0	0	0	0		0
A6	0	0	0	0	0	

k= Flexibility

	A1	A2	A3	A4	A5	A6
A1		0	0	0	0	0
A2	0		0	0	0	0
A3	0	0		0	0	0
A4	1	1	1		0	1
A5	1	1	1	0,40		1
A6	0	0	0	0	0	

k= Innovativeness

	A1	A2	A3	A4	A5	A6
A1		0	0	0	0	0
A2	0		0	0	0	0
A3	0	0		0	0	0
A4	0	0	0		0	0
A5	1	1	0,48	1		1
A6	0	0	0	0	0	

k= Sustainability Competence

	A1	A2	A3	A4	A5	A6
A1		0,48	1	0	0	1
A2	0		0	0	0	0,62
A3	0	0		0	0	0
A4	0	0,64	1		0,40	1
A5	0	0	1	0		1
A6	0	0	0	0	0	

Table 5.20 Preference index values of alternatives.

π(Ai,Aj)	A1	A2	A3	A4	A5	A6
A1		0,251	0,434	0,145	0,328	0,523
A2	0,180		0,109	0,109	0,350	0,291
A3	0,086	0,060		0	0,086	0,166
A4	0,327	0,430	0,479		0,334	0,605
A5	0,297	0,358	0,413	0,210		0,552
A6	0,180	0	0	0	0,180	

Table 5.21 Leaving and entering flows of alternatives.

	A1	A2	A3	A4	A5	A6
Φ+(Ai)	1,680	1,039	0,397	2,175	1,831	0,359
Φ^{-}(Aj)	1,069	1,099	1,435	0,464	1,277	2,137
Φnet(Ai)	0,611	-0,059	-1,038	1,710	0,554	-1,777

6. DISCUSSION AND LIMITATIONS

This study presented a novel hybrid model that integrates sustainability into supplier selection process. The fuzzy approach used in the hybrid model accommodates the subjectivity of human judgment as being expressed in natural language which entails fuzziness in real-life decision-making problems.

Due to the integration of the Fuzzy DEMATEL into Fuzzy ANP, the inner-dependencies between criteria clusters are achieved without the time consuming and complicated calculations of the ANP. In addition, utilizing from the Fuzzy PROMETHEE approach, the final ranking of the supplier alternatives is simply and efficiently achieved. Hence, this paper proposed an effective solution that can resolve the problem of sustainable supplier selection to be more reasonable.

The case study realized in HAVI Logistics firm revealed that the importance weights of the criteria in the Performance Target cluster are not extremely different from each other. But however, Sustainability Competence, Cost and Time appeared to be slightly more important criteria then the others. Furthermore, according to the Fuzzy PROMETHEE application, among the six supplier alternatives, alternative A1 is appeared to be the most suitable supplier from a sustainability perspective. The study has also some limitations as it only looks at one company from one sector and one country. Replicating a similar model in other sectors and countries might provide valuable insights.

7. CONCLUSION

As the environmentally consciousness and the globalization increased recently, companies began to develop novel business strategies in order to keep their competitive position. Additionally the consumer behaviour is widely changed and began to create high pressure on companies. These pressures drive enterprises to invest in environmental and social issues beside from the economic investments. Moreover, many countries have started to enforce environmental legislations and regulations. At this point sustainability which combines economic, social and environmental development became an important requirement for manufacturing or service providing companies and thus for supply chains. On the other hand, SCM is a popular topic studied by numerous studies in the literature. Supplier selection process became critically important for achieving a successful SCM, hence in business. In this study a wide literature survey is also presented. The survey revealed the fact that there are many studies about the green supplier selection and remarkably few studies about the sustainable supplier selection. While the works on the supplier selection with environmental and economic considerations are abundant, those that concern sustainability issues with its three dimensions are rather limited.

The purpose of this study is to propose a supplier selection model that considers sustainability concerns and deals with the vagueness in the decision maker's evaluation. The supplier selection problem is a MCDM problem and it consists of qualitative and quantitative factors affecting the decision making process. The determination of the criteria and the criteria clusters is of great importance for MCDM problems. Thus, all the criteria and clusters used in this study are selected and determined through an extensive literature survey. As a result 27 criteria to be grouped under 6 clusters are determined and described in detail.

The decision makers, who evaluate these criteria, commonly make linguistic assessments that can not be expressed precisely by exact numbers. So, in order to cope with the vagueness of these assessments fuzzy approach combined methods are preferred in many studies. There are several criteria used in supplier selection problems. These criteria are mostly stated as interdependent. Therefore, the hierarchical structures are not suitable for supplier selection problems. The ANP technique that replaces the hierarchies with networks allows for complex interrelationships among criteria. Hence in this study, the Fuzzy ANP technique is preferred. However, due to the complexity of the ANP, this study proposes a new methodology to simplify the process by integrating Fuzzy ANP and Fuzzy DEMATEL. In this hybrid method the Fuzzy DEMATEL is used to calculate the interdependencies within criteria cluster in case they exist. These interdependency values are then integrated in Fuzzy ANP in order to obtain the importance weight of criteria. These weights are then used in Fuzzy PROMETHEE in order to achieve a final ranking of alternatives according to the selected criteria. According to the literature, no previous work has investigated this subject using this kind of integrated method.

The proposed fuzzy hybrid model combines numerous advantages of the integrated methods. Due to the fuzzy logic used in the model the DMT had the chance to evaluate the dependencies between criteria clusters, interdependencies among criteria within the same cluster and alternatives through linguistic assessments. The Fuzzy ANP and Fuzzy DEMATEL techniques incorporated the multi-criteria nature and the network structure of the sustainable supplier selection problem. The proposed hybrid model utilizing from Fuzzy DEMATEL to calculate the interdependencies and Fuzzy ANP to calculate the dependencies requires less computation than the application of the Fuzzy ANP alone to determine the criteria weights. Additionally the he Fuzzy PROMETHEE method is commonly considered as a simple and easy to apply outranking method. So the effectiveness and efficiency of the proposed model makes it preferable and suitable for MCDM problems of different industries.

Consequently, in order to illustrate the application and to foster the better understanding of the proposed methodology a case study is presented. This case study was realized at HAVI Logistics which is an international logistics company. The application of the proposed approach in this company proves the above mentioned advantages of the methodology. Moreover, according to the achieved results even though the final importance weights of the criteria under the Performance Evaluation cluster are approximate, Sustainability Competence, Cost and Time are appeared to be the most important criteria among the others according to the expert opinions provided from HAVI Logistics. Due to these importance weight results, alternative A1 is determined as the most appropriate alternative among the six others.

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