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Research Article

Evaluating Green Performance of Suppliers via Analytic Network Process and TOPSIS

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Developments in environmental issues in the last few years have been forcing manufacturing companies to improve their environmental performances. Many firms developed integrated relationships with their suppliers to increase their environmental performance and to decrease their hazardous effects on the environment. Then, selecting suitable and green suppliers in the supply chain has become a key strategic consideration. A performance evaluation system for green suppliers is necessary to determine the suitability of suppliers to cooperate with the firm. Therefore, in this study, a model for evaluating green performance of suppliers is proposed, and a hybrid multicriteria decision making model is developed in order to evaluate green performance of the suppliers. The analytical network process technique is applied to handle the relationships and dependence of selection criteria and subcriteria and determine weights of the criteria. The technique for order preference by similarity to ideal solution is used to sequence the suppliers for ideal solution of the suppliers' green performance evaluation problem. After a comprehensive literature survey, evaluation criteria of green performance for suppliers are determined. Finally, green performance of 18 suppliers of an automobile company was evaluated by this model. These 18 suppliers manufacture chassis and its components.

1. Introduction

In recent years, because of growing worldwide awareness of environmental protection, increasing government regulations, and stronger public awareness in environmental protection, firms today cannot disregard environmental issues, and they have to pay attention to environmental issues in order to survive in the global market [1]. Therefore, in the world, there is a growing interest in the green supply chain management (GSCM), and the green issue has become more and more critical in supply chain management (SCM) [2]. Over the last decade linking supply chain activities and environmental issues such as green purchasing, reverse logistics, product stewardship, and design for the environment have been a topic of interest among many manufacturing organizations [3]. In order to decrease hazardous environmental effects, firms have been forced to improve their environmental issues like decreasing hazardous impacts of their products, their manufacturing processes, logistics processes, and so forth [4].

Environmental performance of a company can be determined by its own environmental efforts and environmental performance of its suppliers. For manufacturing industries, green manufacturing (i.e., manufacturing is environmentally responsible) and concerned processes need green supply chain (GSC) and studying suppliers with green abilities [5]. Therefore companies have to establish close and integrated relationships with their supplier to develop their environmental performance. They have to evaluate green performance of their suppliers. Thus there is an increasing need of a performance evaluation system for green suppliers to determine the suitability of suppliers to cooperate with the firm [6].

In the literature, while there are too many studies about supplier selection and evaluation, the number of studies about green supplier selection and evaluation is very limited.

Therefore this study was performed in the area of green supplier performance. Our contributions from this study include (1) modeling the decision problem within the context of a GSCM decision, and (2) evaluation of supplier performance by the view point of environmental issues.

In the green supply chain literature, various techniques are used to evaluate and select green suppliers, such as rating system [4], analytic hierarchy process (AHP) [7], fuzzy AHP [8, 9], a hybrid fuzzy analytic network process (ANP) and fuzzy Preference Ranking Organization method for enrichment evaluations (PROTMETHEE) [10], fuzzy extended AHP [1], fuzzy goal programming [11], artificial neural network, data envelopment analysis and analytic netwok process (ANP) [2], Rough set theory [12], fuzzy Technique for Order Preference by similarity to ideal solution (TOPSIS) [13], an integrated model of fuzzy decision making trial and evaluation laboratory (DEMATEL), ANP, TOPSIS [5], a grey-based DEMATEL approach [14], Grey approach [15], fuzzy AHP and fuzzy multiobjective linear programming [16].

Because there are both qualitative and quantitative factors that influence the evaluation and selection of green suppliers, evaluation and selection problem of green supplier is a multi-criteria decision making (MCDM) problem. Thus there is a need to employ MCDM techniques to tackle green supplier selection problem appropriately. Firstly, ANP technique [17] is applied to handle the relationships and dependence of selection criteria and subcriteria and to determine weights of criteria. Then, TOPSIS technique is used to sequence the suppliers for ideal solution of the supplier evaluation problem.

The paper is organized as follows. The paper begins with the literature research about GSCM. Then, after a brief literature review of methodologies used evaluation of supplier's environmental performance and selection of green supplier are examined to develop a structure for evaluating green supplier performance and selecting green suppliers. The next section illustrates the proposed green supplier evaluation and selection methodology through the case of an automobile company in Turkey. The paper finishes by a discussion section.

2. Literature Review

2.1. Green Supply Chain. Green et al. [18] defined green supply as "the way in which innovations in SCM and industrial purchasing may be considered in the context of the environment." Srivastava [19] defined GSCM as "integrating environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers and end-of-life management of the product after its useful life." Also, many researchers have defined a GSCM in various manners using different terms [20]. GSCM can be defined as integrating environmental issues into supply chain management. Originally, GSCM was bounded to purchasing issues. Hervani et al. [21] defined GSCM as integrating suppliers into environmental management processes. Rettab and Ben Brik [22] defined the GSC as a managerial approach that seeks to minimize a product or service's environmental effect. The bottom line of these definitions is the same, that is, "environment". GSCM contains the activities such as waste reduction, recycling, reuse, and the substitution of materials [23], and it includes green purchasing, green manufacturing and material management, green distribution and marketing, and reverse logistics [24].

According to Narasimhan and Carter [23], GSCM includes "the purchasing function's involvement in activities that include reduction, recycling, reuse and the substitution of materials." The most common GSCM practices are to evaluate the environmental performance of suppliers, to require suppliers to accept measures providing environmental quality of their supplied products and to evaluate the cost of waste in their manufacturing processes [7]. However, GSCM practices also extend to the entire value chain (from supplier to consumer) when organizations inform buyers of ways to reduce their impacts on the natural environment [25].

Hall [26] investigated the circumstances under which "environmental supply chain dynamics" emerge. He argued that environmental supply chain dynamics emerge when environmental pressures are synthesized with supply chain pressures which have had considerable influence on the supply base on the strength of case studies in the British and Japanese food retail sector and the British aerospace industry. Zhu et al. [27] expressed that "range of GSCM changes from green purchasing (GP) to integrated life-cycle management supply chains flowing from supplier, through to manufacturer, customer, and closing the loop with reverse logistics."

According to Vachon and Klassen [3], suppliers, manufacturers, and customers should collaborate to reduce hazardous environmental effects from manufacturing processes and products.

2.2. Evaluation of Green Supplier Performance. Supplier evaluation process is an important element in supplier-based manufacturing and SCM has been gaining attention in both the academic literature and industrial practice. The supplier selection decision is one of the critical and important issues in SCM for many organizations to help maintain a strategically competitive position [28]. It becomes one of the most important components of production and operations management for many organizations. Supplier selection and evaluation process is the process by which the company identifies, evaluates, and contracts suppliers.

Measuring and understanding supplier performance is crucial to provide a well-functioning supply chain and to develop competitive position of a company. The goal of the supplier evaluation is to develop the performance of key suppliers [29]. Companies have some advantages through evaluating their suppliers. They have better visibility into supplier performance, decrease risk, reduce order cycle times and inventory, and thus increase competitive advantage and coordinate practices between themselves and their suppliers [29].

In the last two decades, there is increasing attention to evaluate suppliers' green performance. There are lots of studies related this topics in the literature. A detailed literature search was performed about the concepts of GSC.

Table 1: Criteria used to evaluate green suppliers.

Author(s)	Azzone and Noci, 1996 [42]	Noci, 1997 [4]	Humpreys et al., 2003 [30]	Zhu and Sarkis, 2004 [43]	Humphreys et al., 2003 [31]	Tuzkaya et al., 2009 [10]	Lee et al., 2009 [1]	Kuo et al., 2010 [2]	Bai and Sarkis, 2010 [12]	Fu et al., 2012 [14]	Büyüközkan and Çiftçi, 2012 [5]
Evaluation criteria	(i) "External" environmental effectiveness (ii) Environmental efficiency (iii) "Green" image (iv) Environmental flexibility	(i) Green competencies (ii) Current environmental efficiency (iii) Supplier's green image (iv) Net life cycle cost	(i) Environmental competencies (ii) Management decisions (iii) Green image (iv) Design for environment (v) Environmental management system	(i) Internal environmental management (ii) ISO 14001 certification (iii) External GSCM practices (iv) Investment recovery (v) Ecodesign	(i) Environmental costs (pollutant effects) (ii) Environmental costs (improvement) (iii) Management competencies (iv) Green image (v) Design for environment (vi) Environmental management systems (vii) Environmental competencies	(i) Pollution control, (ii) Green process management (iii) Environmental and legislative management (iv) Environmental costs (v) Green product (vi) Green image	(i) Quality (ii) Technological capability (iii) Total product life cycle cost (iv) Green image (v) Pollution control (vi) Environmental management (vii) Green product (viii) Green competence	(i) Quality (ii) Cost (iii) Delivery (iv) Service (v) Corporate social responsibility (vi) Environment	(i) Green knowledge transfer and communication (ii) Investment and knowledge transfer (iii) Management and organizational practices	(i) Green knowledge transfer and communication (ii) Investment and resource transfer (iii) Management and organizational practices	(i) Organization (ii) Financial performance (iii) Service quality (iv) Technology (v) Green competencies
Focus of the study	Evaluate the environmental performance of a company's existing operation system	Evaluate suppliers' environmental performance	Evaluation of supplier performance and environmental issues		Evaluate suppliers' environmental performance	Evaluation of suppliers environmental performance		Selecting of green suppliers	Evaluating green supplier development programs for organizations		
Industry	An illustrative example	An illustrative example	An illustrative example		An illustrative example	White goods manufacturer Turkey	LTF-LCD industry Taiwan	Electronic company Taiwan	An illustrative example	Telecommunications equipment provider China	Automotive industry Turkey
Evaluation methods	Comparison of some techniques such as AHP, scoring methods, and DCF techniques		Knowledge-based system		Knowledge-based systems (KBS) and case-based reasoning (CBR), multi-attribute analysis (MAA)	a hybrid fuzzy analytic network process and fuzzy PROMETHEE	Delphi method and the fuzzy extended AHP	Data envelopment analysis (DEA) and ANP	Rough set theory		

Table 2: Factors and subfactors for ANP.

Criteria	Definition
EC1	To respond in time to product or process modifications when customer demands from supplier to reduce supplier's environmental impact
EC2	Capabilities related with clean production technology
EC3	Materials used in the supplied components that reduce the impact on natural resources
EC4	Ability to alter process and products for reducing the impact on natural resources
ECO1	Cooperation with customers for ecodesign to develop green products
ECO2	Cooperation with customers for decreasing energy usage in supplied products and their manufacturing process, that is, cleaner production
ECO3	Cooperation with customers for green logistics and transportation
ECO4	Cooperation with customer about environment management system and technologies
EMS1	Environment-related certificates (i.e., ISO 14000)
EMS2	Continuous monitoring and compliance with related environmental legislation and legal regulations
GP1	Design of products for reuse, recycle, and recovery of materials, component parts
GP2	Design of products for reduced consumption of materials/energy
GP3	Design of products to avoid or reduce use of hazardous products and their manufacturing process
PC1	In order to prevent existence air pollution, air-pollution-control systems
PC2	Decrease water consumption and sufficiency of water refining plants
PC3	Evaluation and disposal system for solid wastes
PC4	Disposal of hazardous wastes according to legal regulations

Some concepts and elements were found as the basis for a decision framework for evaluating and prioritizing supplier by the company that would help to select green suppliers. Some of these concepts and elements are summarized as follows in Table 1.

Noci [4] designed a conceptual approach that firstly identifies measures for assessing a supplier's environmental performance and, secondly, suggests effective techniques for developing the supplier selection procedure according to an environmental view point. Humpreys et al. [30] developed a framework from an analysis of environmental management practices in a number of companies along with a through literature survey. Then they outlined how the most important parts of the framework were computerized using knowledge based systems (KBS) techniques with an evaluation of the system implemented in a multinational company. Humphreys et al. [31] developed a KBS which integrates environmental factors into the supplier selection process. The system employs both case-based reasoning (CBR) and decision support components including multiattribute analysis (MAA).

Hsu and Hu [32] proposed an ANP approach to incorporate the issue of hazardous substance management (HSM) into supplier selection. They presented an illustrative example in an electronics company to demonstrate how they select a most appropriate supplier in accordance with the requirements of hazardous substance for environmental regulations. Lee et al. [1] proposed a model to select the factors for evaluating green suppliers and to evaluate the performance of suppliers. First they applied the Delphi method to select the most important subcriteria for traditional suppliers and for green suppliers. Then, they developed a fuzzy extended AHP model to evaluate green suppliers for a TFT-LCD manufacturer in Taiwan. Tsai and Hung [11] proposed a fuzzy goal programming (FGP) approach that integrates activity-based costing (ABC) and performance evaluation in a value-chain structure for optimal green supplier selection and flow allocation. Then they provide an illustrative example via a green supply chain of a mobile phone.

Tuzkaya et al. [10] evaluated the environmental performance of suppliers with a hybrid fuzzy multicriteria decision approach: fuzzy ANP and fuzzy PROMETHEE methodology. They used evaluation criteria such as pollution control, green process management, environmental and legislative management, environmental costs, green product, and green image. To foster the better understanding and the validation of the proposed methodology, they presented a real-life case study from a white goods manufacturer of Turkey.

Bai and Sarkis [12] developed a formal model using rough set theory to investigate the relationships between organizational attributes, supplier development program, involvement attributes, and performance outcomes. The performance outcomes focused on environmental and business dimensions. Their methodology generated decision rules relating the various attributes to the performance outcomes. Kuo et al. [2] proposed a green supplier selection model which integrates artificial neural network (ANN) and two multi-attribute decision analysis (MADA) methods: data envelopment analysis (DEA) and ANP. The model is called ANN-MADA hybrid method.

Fu et al. [14] proposed a formal structured managerial approach for organizations to help evaluate the influence of relationships amongst green supplier development programs (GSDPs). Utilizing GSDP categorizations they acquire multifunctional managerial inputs within a telecommunication systems provider to evaluate the GSDPs. Büyüközkan and Çiftçi [5] examined GSCM and GSCM capability dimensions to propose an evaluation framework for green suppliers and used a fuzzy hybrid MCDM model based on fuzzy DEMATEL, fuzzy ANP, and fuzzy TOPSIS techniques in order to evaluate green suppliers. Also they proposed application of the methodology for green supplier evaluation in a specific company in the automotive industry in Turkey. The major five evaluation criteria for green suppliers are organization, financial performance, service quality, technology, and green competencies. Green competencies criteria contain social

Table 3: Weighted supermatrix.

	EC1	EC2	EC3	EC4	ECO1	ECO2	ECO3	ECO4	EMS1	EMS2	GP1	GP2	GP3	PC1	PC2	PC3	PC4
EC1	0.01387	0.01387	0.01387	0.01387	0.01994	0.12282	0.12500	0.05714	0.01556	0.05460	0.02138	0.00000	0.01866	0.10460	0.11969	0.00822	0.00000
EC2	0.10117	0.10117	0.10117	0.10117	0.06904	0.01104	0.02500	0.02857	0.02496	0.02830	0.06413	0.07150	0.06001	0.00000	0.03512	0.04946	0.07753
EC3	0.05676	0.05676	0.05676	0.05676	0.03701	0.02535	0.02500	0.05714	0.09837	0.06018	0.06413	0.21451	0.06001	0.03168	0.02275	0.08671	0.07753
EC4	0.02205	0.02205	0.02205	0.02205	0.07401	0.04078	0.02500	0.05714	0.06111	0.05693	0.02138	0.07150	0.03233	0.05756	0.01628	0.04946	0.03877
ECO1	0.00796	0.04658	0.04321	0.03594	0.05576	0.06154	0.02942	0.03630	0.07797	0.09063	0.01658	0.00000	0.03487	0.01084	0.00823	0.04254	0.03527
ECO2	0.03893	0.00583	0.00825	0.01328	0.09425	0.06153	0.10975	0.11421	0.03047	0.02483	0.01190	0.00000	0.01162	0.03463	0.03662	0.00826	0.00720
ECO3	0.01430	0.00604	0.00825	0.00446	0.01112	0.01539	0.02912	0.01084	0.01359	0.02013	0.02036	0.00000	0.01162	0.01295	0.02240	0.00522	0.01208
ECO4	0.01430	0.01702	0.01578	0.02180	0.03887	0.06154	0.03171	0.03865	0.07797	0.06441	0.02091	0.00000	0.01162	0.01706	0.00823	0.01944	0.02092
EMS1	0.03774	0.05661	0.06469	0.05032	0.10000	0.13333	0.05000	0.13333	0.06667	0.06667	0.14461	0.00000	0.07231	0.03774	0.02516	0.05661	0.05661
EMS2	0.03774	0.01887	0.01078	0.02516	0.10000	0.06667	0.15000	0.06667	0.13333	0.13333	0.00000	0.00000	0.07231	0.03774	0.05032	0.01887	0.01887
GP1	0.16380	0.16380	0.17677	0.10920	0.06667	0.10000	0.13333	0.10000	0.10000	0.00000	0.20123	0.42071	0.14184	0.16380	0.10920	0.16380	0.24571
GP2	0.00000	0.00000	0.09729	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.02930	0.06125	0.02364	0.00000	0.00000	0.00000	0.00000
GP3	0.16380	0.16380	0.05354	0.21840	0.13333	0.10000	0.06667	0.10000	0.10000	0.20000	0.07679	0.16053	0.14184	0.16380	0.21840	0.16380	0.08190
PC1	0.15120	0.00000	0.03474	0.08869	0.04541	0.08571	0.06756	0.10316	0.04488	0.10924	0.03273	0.00000	0.02723	0.14480	0.14480	0.14480	0.14480
PC2	0.15120	0.02907	0.02606	0.03948	0.02447	0.08571	0.09580	0.03788	0.01315	0.04646	0.08036	0.00000	0.13327	0.01958	0.01958	0.01958	0.01958
PC3	0.02520	0.18315	0.17923	0.13699	0.08472	0.01429	0.01421	0.03788	0.10939	0.01675	0.05693	0.00000	0.07341	0.06516	0.06516	0.06516	0.06516
PC4	0.00000	0.11538	0.08757	0.06245	0.04541	0.01429	0.02243	0.02108	0.03258	0.02755	0.13729	0.00000	0.07341	0.09806	0.09806	0.09806	0.09806

responsibility, cleaner/environmental production and technologies, and environmental management system.

3. Proposed Green Supplier Evaluation Framework

This study proposes a hybrid approach based on the ANP and TOPSIS methodologies to evaluate and select suppliers in the context of GSCM. The general view of the proposed methodology related with green supplier evaluation and selection is shown in Figure 1. ANP technique is applied to handle the relationships and dependence of selection criteria and subcriteria. TOPSIS technique is applied to sequence the suppliers for ideal solution of the green supplier performance evaluation problem.

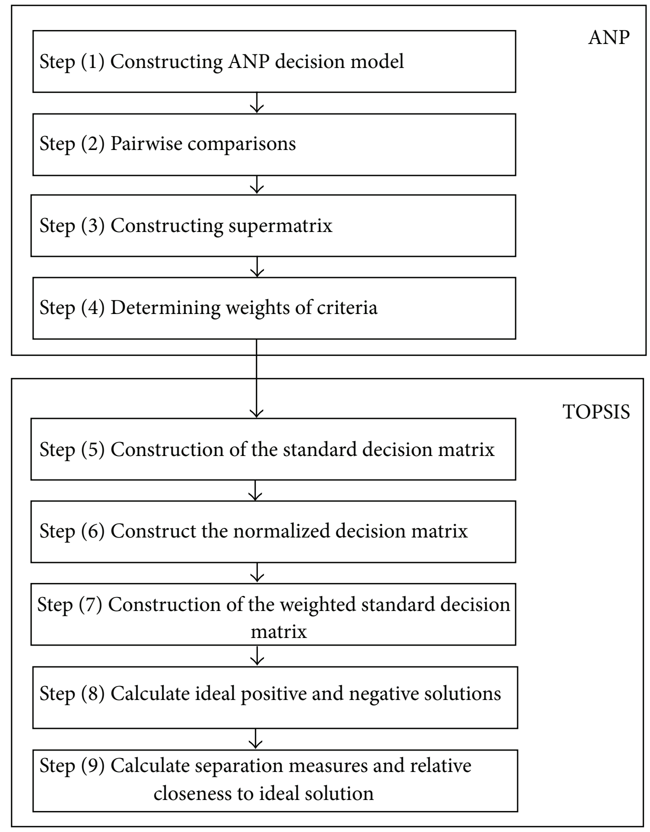

Figure 1: Methodology of the study.

3.1. Analytical Network Process (ANP). The ANP developed by Saaty, and it provides a way to input judgments and measurements to derive ratio scale priorities for the distribution of influence among the factors and groups of factors in the decision [33]. ANP is an extension of AHP. In reality, the factors within the hierarchy are often interdependent. The ANP method presents the network relationship between factors and between groups of factors and computes the relative weightings of each factor. The result of these computations constructs a supermatrix. Finally, after computing the relationship of the supermatrix and the comprehensive evaluations, it is possible to derive the interdependence of each evaluation factor and options and the weighting of priorities. Factors/alternatives are sequenced according to higher the priority weightings. In this way, it is possible to select the most appropriate alternative [34]. See Tsai and Chou [34], Lin et al. [35], and Saaty [17, 33] for further details.

3.2. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The TOPSIS method is based on the idea that the chosen alternative should have the shortest distance from the positive ideal solution, and the farthest distance from the negative ideal solution [36].

First a decision matrix is established for the ranking. The normalized decision matrix $R(= [r_{ij}])$ is calculated. Then the weighted normalized decision matrix is calculated by multiplying the normalized decision matrix by its associated weights. After the positive ideal solutions (PIS) and negative ideal solutions (NIS) are determined, respectively, the separation measures are calculated using the m-dimensional Euclidean distance. Finally, the relative closeness to the idea solution (C_i) is calculated and the alternatives are ranked in descending order. The index value of C_i lies between 0 and 1. The larger the index value, the better the performance of the alternatives. You can see Chu et al. [37], Jahanshahloo et al. [38] for further details. The TOPSIS method will be applied to a case study, which is described in detail in the application section.

3.3. Criteria of Green Supplier Evaluation Framework. When traditional studies are investigated, there are three main criteria to evaluate and select suppliers; cost, quality, and delivery [39]. Additionally, criteria such as customer satisfaction, flexibility, and after-sales service that are used to evaluate suppliers are used [40]. An organization may use traditional selection criteria because of the organization's core processes requirements. These criteria generally cover issues such as quality, cost, delivery, capacity in terms of finance, services, and equipments, quantity, and responsiveness. Green supplier selection criteria are derived from an organizational tendency to respond to any existing trends in environmental topics related to business management and processes.

Most of the studies in the literature about evaluation of green supplier performance integrates environmental criteria into traditional supplier evaluation criteria. They utilize traditional evaluation criteria and environmental criteria together. For example Humpreys et al. [30], Büyüközkan and Çiftçi [5], Kuo et al. [2], and Lee et al. [1] integrated environmental criteria into supplier selection process and used environmental criteria and classical supplier development criteria together. In the literature, there is in only one study using environmental criteria for evaluating supplier performance, Shenc et al. [41]. Because of expanding studies about this area and making contribution to the literature, in this study we use only environmental criteria to evaluate supplier performance in order to develop environmental performance of the main company.

In this study, we used qualitative environmental criteria, and five evaluation criteria were determined to evaluate

Figure 2: Distribution of the local suppliers.

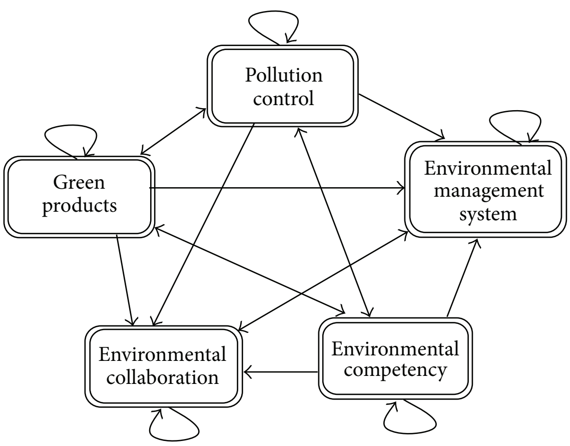

Figure 3: ANP hierarchy for the green supplier evaluation.

environmental performance of suppliers. These are environmental technologies and pollution control (PC), environmental management system (EMS), green products (GP), environmental collaboration (ECO), environmental competency (EC).

4. Application

4.1. Application of the Proposed Supplier Evaluation Methodology. The application was performed in the company which is a multinational company and one of the most important and biggest pioneer companies in the Turkish automobile industry. The company implements green practices at all stages of the manufacturing process. The company works with more than 60 local suppliers performing in Turkey. Distribution of the local suppliers of the company can be seen in Figure 2.

4.2. The Computational Steps of the Proposed Integrated Framework

Step 1 (constructing ANP decision model). ANP decision model was constructed based on opinions of five experts working in the company. This model is presented in Figure 3. The model consists of five main factors; environmental competency, environmental collaboration, environmental management system, green products, and environmental technologies and pollution control. Environmental competency contains four sub-factors (EC1, ..., EC4), environmental collaboration contains four sub-factors (ECO1, ..., ECO4), environmental management system contains two sub-factors (EMS1, EMS2), green products contains three sub-factors (GP1, ..., GP3), and environmental technologies and pollution control contains four sub-factors (PC1, ..., PC4). These criteria are shown in Table 2.

Step 2 (pairwise comparisons). The pairwise comparisons (cluster comparisons and element comparisons) were performed using the 9-point scale of Saaty [17], where 1, 3, 5, 7, and 9 indicate equal importance, moderate importance, strong importance, very strong importance, and extreme importance, respectively; 2, 4, 6, and 8 are used for compromise between the above values. The ANP model is solved using "Super Decisions" software. All inconsistency ratios are below 0.1, which indicates acceptable levels of consistency across pairwise comparisons.

Step 3 (constructing supermatrix). In this step the unweighted supermatrix, weighted supermatrix and limit supermatrix were constructed. The unweighted supermatrix was calculated with priority vectors obtained from pairwise comparison matrices for interdependencies among the sub-factors. The unweighted supermatrix cannot reflect the normalized weights as the sum of the column values is not equal to 1. Accordingly, the unweighted matrix was transformed to the weighted supermatrix to reveal influences on a 0-1 scale. The weighted supermatrix is presented in Table 3. Finally, the limit matrix was obtained by means of increasing the power of the weighted supermatrix. The limit matrix is presented in Table 4.

Step 4 (cetermining weights of criteria). Weights of criteria to be used in TOPSIS method are determined based on the limit matrix as shown in Table 4.

Table 4: Limit supermatrix.

	EC1	EC2	EC3	EC4	ECO1	ECO2	ECO3	ECO4	EMS1	EMS2	GP1	GP2	GP3	PC1	PC2	PC3	PC4
EC1	0.03410	0.03410	0.03410	0.03410	0.03410	0.03410	0.03410	0.03410	0.03410	0.03410	0.03410	0.03410	0.03410	0.03410	0.03410	0.03410	0.03410
EC2	0.05703	0.05703	0.05703	0.05703	0.05703	0.05703	0.05703	0.05703	0.05703	0.05703	0.05703	0.05703	0.05703	0.05703	0.05703	0.05703	0.05703
EC3	0.06220	0.06220	0.06220	0.06220	0.06220	0.06220	0.06220	0.06220	0.06220	0.06220	0.06220	0.06220	0.06220	0.06220	0.06220	0.06220	0.06220
EC4	0.03777	0.03777	0.03777	0.03777	0.03777	0.03777	0.03777	0.03777	0.03777	0.03777	0.03777	0.03777	0.03777	0.03777	0.03777	0.03777	0.03777
ECO1	0.03645	0.03645	0.03645	0.03645	0.03645	0.03645	0.03645	0.03645	0.03645	0.03645	0.03645	0.03645	0.03645	0.03645	0.03645	0.03645	0.03645
ECO2	0.02468	0.02468	0.02468	0.02468	0.02468	0.02468	0.02468	0.02468	0.02468	0.02468	0.02468	0.02468	0.02468	0.02468	0.02468	0.02468	0.02468
ECO3	0.01313	0.01313	0.01313	0.01313	0.01313	0.01313	0.01313	0.01313	0.01313	0.01313	0.01313	0.01313	0.01313	0.01313	0.01313	0.01313	0.01313
ECO4	0.02613	0.02613	0.02613	0.02613	0.02613	0.02613	0.02613	0.02613	0.02613	0.02613	0.02613	0.02613	0.02613	0.02613	0.02613	0.02613	0.02613
EMS1	0.07441	0.07441	0.07441	0.07441	0.07441	0.07441	0.07441	0.07441	0.07441	0.07441	0.07441	0.07441	0.07441	0.07441	0.07441	0.07441	0.07441
EMS2	0.04723	0.04723	0.04723	0.04723	0.04723	0.04723	0.04723	0.04723	0.04723	0.04723	0.04723	0.04723	0.04723	0.04723	0.04723	0.04723	0.04723
GP1	0.15308	0.15308	0.15308	0.15308	0.15308	0.15308	0.15308	0.15308	0.15308	0.15308	0.15308	0.15308	0.15308	0.15308	0.15308	0.15308	0.15308
GP2	0.01451	0.01451	0.01451	0.01451	0.01451	0.01451	0.01451	0.01451	0.01451	0.01451	0.01451	0.01451	0.01451	0.01451	0.01451	0.01451	0.01451
GP3	0.13050	0.13050	0.13050	0.13050	0.13050	0.13050	0.13050	0.13050	0.13050	0.13050	0.13050	0.13050	0.13050	0.13050	0.13050	0.13050	0.13050
PC1	0.07690	0.07690	0.07690	0.07690	0.07690	0.07690	0.07690	0.07690	0.07690	0.07690	0.07690	0.07690	0.07690	0.07690	0.07690	0.07690	0.07690
PC2	0.05370	0.05370	0.05370	0.05370	0.05370	0.05370	0.05370	0.05370	0.05370	0.05370	0.05370	0.05370	0.05370	0.05370	0.05370	0.05370	0.05370
PC3	0.07829	0.07829	0.07829	0.07829	0.07829	0.07829	0.07829	0.07829	0.07829	0.07829	0.07829	0.07829	0.07829	0.07829	0.07829	0.07829	0.07829
PC4	0.07988	0.07988	0.07988	0.07988	0.07988	0.07988	0.07988	0.07988	0.07988	0.07988	0.07988	0.07988	0.07988	0.07988	0.07988	0.07988	0.07988

Table 5: Standard decision matrix.

Supplier	Pollution control				Environment management system		Green products			Environmental collaboration				Environmental competency			
	pc1	pc2	pc3	pc4	ems1	ems2	gp1	gp2	gp3	eco1	eco2	eco3	eco4	ec1	ec2	ec3	ec4
S1	6.33	5.00	6.67	6.00	6.00	4.67	6.33	5.00	5.33	5.67	6.33	4.33	5.67	5.33	6.33	5.67	5.67
S2	4.75	4.50	5.25	6.25	4.00	5.00	5.75	4.00	5.50	4.75	4.25	4.25	4.50	4.25	6.25	5.25	4.50
S3	5.33	4.67	5.67	5.67	5.67	5.33	5.33	4.33	5.00	5.67	5.67	4.33	5.33	5.67	6.33	5.67	5.33
S4	5.33	5.67	4.67	5.33	5.00	5.00	6.33	5.00	6.33	4.67	6.00	4.00	4.67	4.67	5.00	5.33	4.33
S5	5.50	5.50	5.00	5.25	5.00	5.00	6.00	6.25	6.00	5.00	6.25	3.75	5.00	5.00	5.50	5.25	5.00
S6	6.80	5.60	6.20	6.20	6.00	6.00	6.40	5.60	5.40	5.60	6.00	5.80	6.20	6.00	6.20	6.20	5.40
S7	5.00	3.33	4.00	4.33	3.00	5.67	4.00	5.67	3.67	4.33	3.67	4.00	4.00	4.00	4.33	3.67	3.33
S8	5.75	5.75	5.25	5.00	5.25	6.00	5.75	5.75	6.00	6.00	5.75	4.75	6.25	5.25	5.50	5.50	6.00
S9	6.00	4.50	5.00	4.50	3.50	5.25	4.75	5.00	4.25	4.25	6.00	5.00	5.00	5.75	5.25	4.75	5.50
S10	6.40	4.80	6.40	6.20	6.00	5.40	5.80	5.40	5.80	5.80	5.60	4.80	5.00	5.40	5.80	6.00	5.60
S11	5.67	5.67	5.33	6.67	5.33	6.33	6.33	6.00	6.33	6.00	6.00	4.67	6.00	4.33	6.33	5.67	5.67
S12	5.40	4.80	5.80	5.20	5.40	5.00	6.00	5.00	6.00	5.00	4.60	4.60	5.20	4.60	5.80	5.80	5.00
S13	4.33	3.33	5.67	6.00	4.00	4.33	5.67	5.33	5.33	4.33	3.33	3.67	4.00	4.00	6.00	5.00	4.00
S14	5.75	4.75	6.25	5.75	6.00	5.50	5.50	5.75	5.75	5.75	5.50	3.50	5.25	4.75	6.25	6.00	6.00
S15	6.25	4.75	6.00	4.25	6.50	5.50	5.75	3.75	5.50	5.50	5.25	5.00	6.00	5.50	6.00	6.00	4.75
S16	5.33	4.33	5.67	4.67	4.67	4.33	6.00	5.67	5.33	4.33	3.67	3.67	4.33	3.33	5.67	5.33	5.33
S17	6.50	5.00	6.00	5.50	6.50	5.50	6.00	6.00	5.00	4.00	6.50	3.00	6.00	6.00	5.00	6.50	6.50
S18	6.67	5.33	6.33	6.33	6.33	5.67	6.33	5.00	5.67	5.67	6.33	5.67	5.33	5.33	5.67	6.00	5.33

Step 5 (construction of the standard decision matrix). For this, first alternatives were determined. We aimed to evaluate environmental performance of suppliers manufacturing chassis and its components. The company has 18 suppliers manufacturing chassis and its components. Suppliers were evaluated using a 1–7 scale (1-lowest performance, …, 7-highest performance) by five decision makers working in purchasing (2 members), quality (2 members), and manufacturing (1 member) departments, and mean values for each suppliers were calculated. Than initial decision matrix for TOPSIS was constructed based on these mean values as presented in Table 5.

Step 6 (construct the normalized decision matrix). In this step, the normalized decision matrix $R = [r_{ij}]$ is calculated. The normalized value r_{ij} is calculated

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{n} f_{ij}^2}}, \tag{1}$$

where $j = 1, \ldots, n$; $i = 1, \ldots, m$. Normalized decision matrix for the evaluation of green supplier performance (GSP) problem is shown in Table 6.

Step 7 (construction of the weighted standard decision matrix). The weighted normalized decision matrix is calculated by multiplying the normalized decision matrix by its associated weights. The weighted normalized value v_{ij} is calculated from (2). Here w_{ij} represents the weight of the jth attribute or criterion. The Weighted normalized matrix for the GSP evaluation problem is shown in Table 7:

$$v_{ij} = w_{ij} r_{ij}. \tag{2}$$

Step 8 (construction of ideal positive (V^+) and ideal negative (V^-) solutions). The positive ideal solutions (V^+) and negative ideal solutions (V^-) are determined as follows:

$$V^+ = \{v_i^+, \ldots, v_n^+\} = \{(\text{Max}\, v_{ij} \mid j \in J), (\text{Min}\, v_{ij} \mid j \in J')\}, \tag{3}$$

$$V^- = \{v_i^-, \ldots, v_n^-\} = \{(\text{Min}\, v_{ij} \mid j \in J), (\text{Max}\, v_{ij} \mid j \in J')\}, \tag{4}$$

where V^+ is associated with the positive criteria and V^- is associated with the negative criteria. PIS and NIS for the GSP evaluation problem are presented in Table 7.

Step 9 (calculation of separation measures and relative closeness to ideal solution). The separation measures are calculated using the m-dimensional Euclidean distance. The separation measure S_i^+ of each alternative and the separation measure S_i^- of each alternative are calculated, respectively, as follows:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2}, \quad i = 1, \ldots, m, \tag{5}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2}, \quad i = 1, \ldots, m. \tag{6}$$

Table 6: Normalized decision matrix of TOPSIS.

Supplier	Pollution control				Environment management system		Green products			Environmental collaboration				Environmental competency			
	pc1	pc2	pc3	pc4	ems1	ems2	gp1	gp2	gp3	eco1	eco2	eco3	eco4	ec1	ec2	ec3	ec4
S1	1.114	1.270	0.789	1.551	0.455	1.203	1.239	0.857	1.298	1.221	1.038	1.263	1.228	0.994	1.506	0.902	1.199
S2	1.241	0.882	1.402	1.140	1.217	0.728	1.239	0.857	0.920	1.089	1.297	0.739	1.095	0.994	1.233	1.019	1.069
S3	0.698	0.714	0.870	1.237	0.541	0.836	1.021	0.549	0.979	0.765	0.584	0.711	0.691	0.631	1.201	0.874	0.674
S4	0.936	0.796	0.444	0.445	0.475	0.754	0.626	0.695	0.655	0.477	0.808	0.416	0.480	0.788	0.555	0.642	0.602
S5	0.880	0.768	1.013	1.017	1.086	0.951	0.879	0.644	0.809	1.089	1.038	0.739	0.970	1.122	1.233	1.019	0.947
S6	0.880	1.132	0.687	0.900	0.845	0.836	1.239	0.857	1.298	0.739	1.164	0.630	0.743	0.761	0.769	0.902	0.625
S7	0.495	0.474	1.136	1.140	0.455	0.628	0.992	0.644	1.039	0.543	0.359	0.437	0.379	0.248	0.987	0.793	0.625
S8	1.375	0.768	1.402	1.407	1.086	0.836	1.373	1.524	1.165	1.089	1.164	1.263	0.970	0.994	1.107	1.019	0.947
S9	1.241	1.132	1.136	1.140	1.503	1.203	1.373	0.857	1.039	0.739	1.164	0.857	1.228	1.258	0.874	1.410	1.199
S10	0.559	0.714	1.043	0.873	0.541	0.754	1.112	1.449	1.165	0.848	0.655	0.482	0.418	0.369	1.016	0.960	0.918
S11	0.936	1.067	0.789	0.873	0.845	0.836	1.112	1.340	1.165	0.848	1.263	0.553	0.853	0.873	0.930	0.874	0.833
S12	1.430	1.106	1.213	1.217	1.217	1.203	1.265	1.076	0.943	1.064	1.164	1.324	1.311	1.258	1.182	1.220	0.971
S13	0.773	0.392	0.505	0.594	0.304	1.073	0.494	1.101	0.435	0.637	0.435	0.630	0.546	0.559	0.577	0.427	0.370
S14	1.023	1.166	0.870	0.791	0.932	1.203	1.021	1.134	1.165	1.221	1.069	0.888	1.332	0.963	0.930	0.960	1.199
S15	1.241	1.003	1.266	1.017	1.356	1.203	0.673	0.747	0.809	1.360	1.164	0.630	0.970	1.122	1.233	1.273	1.480
S16	1.114	0.714	0.789	0.641	0.414	0.921	0.697	0.857	0.584	0.613	1.164	0.984	0.853	1.155	0.847	0.716	1.007
S17	1.267	0.812	1.293	1.217	1.217	0.975	1.039	1.000	1.088	1.141	1.014	0.907	0.853	1.019	1.034	1.142	1.044
S18	1.023	1.166	0.955	0.873	0.685	0.470	0.935	1.134	0.892	0.765	1.164	0.711	0.940	1.258	0.930	0.874	0.674

The relative closeness to the ideal solution is calculated from (7) and then alternatives are ranked in descending order, where the index value of $\overline{C}_i$ lies between 0 and 1. The larger the index value, the better the performance of the alternatives:

$$\overline{C}_i = \frac{S_i^-}{S_i^+ + S_i^-}. \quad (7)$$

Separation measures (S_i^+ and S_i^-) and relative closeness to ideal solution ($\overline{C}_i$) for GSP evaluation problem are shown in Table 8. Then classes of the suppliers (A, B, C, D) were determined according to the scale presented in Table 9.

Four of the suppliers are at "A" class, and their environmental performance are perfect. Seven of the 18 evaluated firms are at "B" class. Their environmental performances are good. But in order to have better performance they should develop their environmental issues. one of the suppliers are at "C" class. Their environmental performance is inadequate and needs improvement. They perform some activities related with environment. Five of the suppliers are at "D" class. Their environmental performance is so bad. They need to improve and develop their environmental performance very urgently in order to do business with their customers.

5. Conclusions

The need to continuously improve the corporate performance will force firms to select and evaluate their suppliers according to their environmental performance and involve also suppliers in their environmental programs. Thus companies emphasizes the importance of methodologies which allow the purchasing team to select only environmentally efficient suppliers. In order to develop their environmental performance, firms need to work together with the suppliers which have high environmental performance, and they have to work their suppliers cooperatively.

This paper presents a framework of environmental criteria that a company can consider during their supplier selection process. This study proposes a hybrid MCDM approach to evaluate performance of green suppliers because there is an increasing need to develop GSCM practices. After a comprehensive literature research and with the validation of industrial experts, possible green supplier evaluation criteria were defined and an evaluation model was developed. The proposed model was applied in an automobile company which is one of the best companies considering environmental issues in Turkey. In this study, 18 suppliers of the company that are manufacturing chassis and components were evaluated by a model that integrates ANP and TOPSIS into the context of green performance. Furthermore, TOPSIS method was used to sequence the suppliers for ideal solution of this problem efficiently.

Also this study has some limitations. One of the limitations of the study is that we use only qualitative factors to evaluate suppliers' environmental performance. In future studies, evaluation criteria should be expanded including qualitative environmental factors for example carbon footprint and quantity of emissions, and so forth.

This research suggests further studies in order to extend the scope of this study. This study can be extended to

Table 7: Weighted matrix.

Supplier	Pollution control				Environment management system		Green products			Environmental collaboration				Environmental competency			
	pc1	pc2	pc3	pc4	ems1	ems2	gp1	gp2	gp3	eco1	eco2	eco3	eco4	ec1	ec2	ec3	ec4
S1	0.038	0.072	0.049	0.059	0.017	0.030	0.016	0.022	0.097	0.058	0.159	0.018	0.160	0.076	0.081	0.071	0.096
S2	0.042	0.050	0.087	0.043	0.044	0.018	0.016	0.022	0.068	0.051	0.199	0.011	0.143	0.076	0.066	0.080	0.085
S3	0.024	0.041	0.054	0.047	0.020	0.021	0.013	0.014	0.073	0.036	0.089	0.010	0.090	0.049	0.064	0.068	0.054
S4	0.032	0.045	0.028	0.017	0.017	0.019	0.008	0.018	0.049	0.023	0.124	0.006	0.063	0.061	0.030	0.050	0.048
S5	0.030	0.044	0.063	0.038	0.040	0.023	0.012	0.017	0.060	0.051	0.159	0.011	0.127	0.086	0.066	0.080	0.076
S6	0.030	0.065	0.043	0.034	0.031	0.021	0.016	0.022	0.097	0.035	0.178	0.009	0.097	0.059	0.041	0.071	0.050
S7	0.017	0.027	0.071	0.043	0.017	0.015	0.013	0.017	0.077	0.026	0.055	0.006	0.049	0.019	0.053	0.062	0.050
S8	0.047	0.044	0.087	0.053	0.040	0.021	0.018	0.040	0.087	0.051	0.178	0.018	0.127	0.076	0.059	0.080	0.076
S9	0.042	0.065	0.071	0.043	0.055	0.030	0.018	0.022	0.077	0.035	0.178	0.012	0.160	0.097	0.047	0.110	0.096
S10	0.019	0.041	0.065	0.033	0.020	0.019	0.015	0.038	0.087	0.040	0.100	0.007	0.055	0.028	0.055	0.075	0.073
S11	0.032	0.061	0.049	0.033	0.031	0.021	0.015	0.035	0.087	0.040	0.193	0.008	0.111	0.067	0.050	0.068	0.067
S12	0.049	0.063	0.075	0.046	0.044	0.030	0.017	0.028	0.070	0.050	0.178	0.019	0.171	0.097	0.063	0.095	0.078
S13	0.026	0.022	0.031	0.022	0.011	0.026	0.006	0.029	0.032	0.030	0.067	0.009	0.071	0.043	0.031	0.033	0.030
S14	0.035	0.066	0.054	0.030	0.034	0.030	0.013	0.030	0.087	0.058	0.164	0.013	0.174	0.074	0.050	0.075	0.096
S15	0.042	0.057	0.079	0.038	0.049	0.030	0.009	0.020	0.060	0.064	0.178	0.009	0.127	0.086	0.066	0.100	0.118
S16	0.038	0.041	0.049	0.024	0.015	0.023	0.009	0.022	0.043	0.029	0.178	0.014	0.111	0.089	0.046	0.056	0.080
S17	0.043	0.046	0.080	0.046	0.044	0.024	0.014	0.026	0.081	0.054	0.155	0.013	0.111	0.078	0.056	0.089	0.083
S18	0.035	0.066	0.059	0.033	0.025	0.012	0.012	0.030	0.066	0.036	0.178	0.010	0.123	0.097	0.050	0.068	0.054
V^+	0.042	0.050	0.087	0.043	0.044	0.018	0.016	0.022	0.068	0.051	0.199	0.011	0.143	0.076	0.066	0.080	0.085
V^-	0.024	0.041	0.054	0.047	0.020	0.021	0.013	0.014	0.073	0.036	0.089	0.010	0.090	0.049	0.064	0.068	0.054

Table 8: Environmental performance of suppliers.

Suppliers	S_i^-	S_i^+	$\overline{C}_i$	Ranking	Class
S1	0.02296	0.00382	0.85747	6	B
S2	0.01670	0.00297	0.84877	7	B
S3	0.01376	0.01685	0.44958	14	D
S4	0.00961	0.02152	0.30866	16	D
S5	0.02790	0.00572	0.82987	9	B
S6	0.02233	0.01026	0.68508	13	C
S7	0.00835	0.02886	0.22442	17	D
S8	0.03235	0.00385	0.89367	5	B
S9	0.04175	0.00223	0.94931	2	A
S10	0.01293	0.01889	0.40646	15	D
S11	0.02717	0.00712	0.79237	10	B
S12	0.04153	0.00206	0.95268	1	A
S13	0.00535	0.03106	0.14704	18	D
S14	0.03673	0.00366	0.90931	4	A
S15	0.03815	0.00290	0.92946	3	A
S16	0.02451	0.00994	0.71145	12	C
S17	0.02824	0.00504	0.84861	8	B
S18	0.02756	0.00734	0.78955	11	B

other industries. Evaluation criteria can be changed from one sector to an other. Appropriate evaluation criteria of green performance should be selected according to the sector.

Table 9: Classification scale.

$\overline{C}$	Class	Definition
0.900–1.000	A	Environmental performance is perfect
0.700–0.899	B	Environmental performance is good
0.500–0.699	C	Environmental performance is inadequate. It needs improvements
0.000–0.499	D	Environmental performance is bad. It has to be certainly developed

Therefore, the green supply chain that is already a hot topic could become the new trend of the future.

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