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INSTITUTE OF GRADUATE STUDIES

LOGISTIC AND SUPPLY CHAIN MANAGEMENT

DEVELOPING NEW SUSTAINABLE SUPPLIER EVALUATION METRICS TO MEASURE AND IMPLEMENTING A SUPPLIER EVALUATION PORTAL TO IMPROVE SUPPLIER PERFORMANCE

PHD DISSERTATION

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DECLARATION

I declare that this thesis is my own work. All data, knowledge and information in this document has been obtained, processed and presented in accordance with academic rules and ethical conduct. Based on these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

Recently, sustainable supplier selection has become one of the prominent issues in both academy and practice. Due to the multidimensional nature of sustainability, the evaluation models mostly remain in a limited framework. In this study, however, we set forth a holistic approach covering financial, social and environmental indicators in the supplier performance evaluation process. Our proposed approach contains three stages (setting the criteria, setting the network, evaluating the suppliers) and eleven steps. In this procedure, criteria are determined with a comprehensive literature review and focus group interviews. Additionally, materiality analysis is applied in focus group interviews to clarify the importance levels of sustainability criteria. After that, ANP methodology is used for constructing the interdependencies and prioritizing the criteria according to sustainability strategy. A web portal is developed to collect real time information shared by suppliers, and calculate the performance scores. K-Means algorithm is then run for obtaining the performance segments of suppliers. By testing with the ANOVA method, it is observed that the distances between the central points of the segments are statistically significant. Tailored strategies are further developed for each segment such as increasing the order frequency or terminating the relationship. Furthermore, the sensitivity analysis is applied to judge what extent the performance segments are robust against manipulations on criteria weights. The proposed approach is applied as a case study in chemical industry. This study, which combines digitalization and sustainability issues in the supply chain, is thought to fill an important gap in the literature as well as provides benefit for practical applications.

Keywords: Sustainable Supply Chain Management, Supplier Performance Evaluation, Analytic Network Process (ANP), K-Means Algorithm, Case Study

ÖZET

Son zamanlarda, sürdürülebilir tedarikçi seçimi hem akademide hem de uygulamada öne çıkan konulardan biri haline gelmiştir. Sürdürülebilirliğin çok boyutlu doğası nedeniyle, değerlendirme modelleri çoğunlukla sınırlı bir çerçevede kalmaktadır. Bu çalışmada ise tedarikçi performans değerlendirme sürecinde finansal, sosyal ve çevresel göstergeleri kapsayan bütüncül bir yaklaşım ortaya konulmuştur. Önerdiğimiz yaklaşım üç aşama (kriterlerin belirlenmesi, ağın belirlenmesi, tedarikçilerin değerlendirilmesi) ve on bir adımdan oluşmaktadır. Bu prosedürde kriterler, kapsamlı bir literatür taraması ve odak grup görüşmeleri ile belirlenmiştir. Ek olarak odak grup görüşmelerinde önemlilik analizi uygulanmış ve sürdürülebilirlik kriterlerinin önem düzeyleri belirlenmiştir. Sonrasında, sürdürülebilirlik stratejisine göre karşılıklı bağımlılıkları oluşturmak ve kriterleri önceliklendirmek için Analitik Ağ Süreci (AAS) metodolojisi kullanılmıştır. Tedarikçiler tarafından paylaşılan gerçek zamanlı bilgileri toplamak ve performans puanlarını hesaplamak için bir web portalı geliştirilmiştir. Daha sonra tedarikçilerin performans segmentlerini elde etmek için K-Means algoritması kullanılmıştır. ANOVA yöntemiyle test edilerek de, elde edilen segmentlerin merkez noktalarının birbirinden istatistiksel olarak anlamlı bir şekilde ayrıştığı gözlemlenmiştir. Ayrıca, performans segmentlerinin kriter ağırlıklarındaki manipülasyonlara karşı ne düzeyde dayanıklı olduğunu değerlendirmek için duyarlılık analizi uygulanmıştır. Her bir segment için sipariş sıklığını artırmak veya ilişkiyi sonlandırmak gibi özel stratejiler geliştirilmiştir. Önerilen yaklaşım kimya endüstrisinde bir vaka çalışması olarak uygulanmıştır. Tedarik zincirinde dijitalleşme ve sürdürülebilirlik konularını birleştiren bu çalışmanın, pratik uygulamalara sağlayacağı faydanın yanısıra literatürdeki önemli bir boşluğu dolduracağı düşünülmektedir.

Anahtar Kelimeler – Sürdürülebilir Tedarik Zinciri Yönetimi, Tedarikçi Performans Değerlendirmesi, Analitik Ağ Süreci (AAS), K-Means Algoritması, Vaka Çalışması.

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LIST OF ABBREVIATIONS

ANOVA	: Analysis of Variance
AHP	: Analytic Hierarchy Process
ANP	: Analytic Network Process
B2B	: Business-to-Business
EDI	: Electronic Data Interchange
ERP	: Enterprise Resource Planning
EFFAS	: European Federation of Financial Analysts Societies
ELECTRE	: Environmental, Social and Corporate governance
GRI	: Global Reporting Initiative
GrSCM	: Green Supply Chain Management
IT	: Information Technology
ISO	: International Organization for Standardization
MCDM	: Multi Criteria Decision Making
MRP	: Material Resource Planning
SC	: Supply Chain
SCM	: Supply Chain Management
SSCM	: Sustainable Supply Chain Management
TBL	: Triple bottom line
3PL	: Third Party Logistics
TOPSIS	: Technique for Order Preference by Similarity to Ideal Solution
UN	: United Nations
USA	: United States of America
VMI	: Vendor Managed Inventory

1. INTRODUCTION

Supply chain management is accepted as one of the most fundamental approaches that provides competitive advantage for companies. In order to meet customer requirements more effectively and efficiently, companies need to improve the coordination by the information sharing and IT (Information Technology) infrastructure.

Managing supplier relationships constitute the major part of such coordination. Manufacturers prone to evaluate their suppliers with respect to certain criteria in a continuous manner. Evaluating a supplier actually means making a decision about the mutual relations existing between buyer and supplier. The output of evaluation process mostly comes up as a mathematical score. This score is called “performance”. According to performance levels of suppliers, manufacturers can increase the order frequencies, sustain the existing situation, or even terminate the contract. When such decisions become institutional as if each supplier compulsory face to, these decisions are defined as the “strategy”.

To ensure the validation of strategies which implemented for a specific supplier, there need to be a mechanism that the manufacturers apply in practice. These mechanisms are the supplier evaluation models. The overall objectives of evaluation models might be selecting a supplier or just monitoring the performance level to provide feedback. Such feedbacks are believed to stimulate suppliers for going towards the development.

Scientific ingredients of supplier evaluation models widely include multi-criteria decision making methods such as AHP, ANP, PROMETHEE, TOPSIS, ELECTRE and so on. These methods provide a deterministic approach for performance evaluation and supplİer selection. The truthness of outcomes that a multi-criteria based performance evaluation model depends upon two pillars. One is picking up the true criteria which reflect the organization’s overall strategy and culture. Lack of effective criteria may fails the decision makers on seeing the real performance.

The other pillar is collecting the true performance data from the evaluated suppliers. Without ensuring the performance data flow from suppliers to manufacturers in an timely manner, performance evaluation models cannot work. The performance data is the raw shape of performance information. Shared data has to be converted into shared information by analysing with evaluation models which mentioned above. Therefore, there are a technical dimension of data and information sharing. IT Technologies and web portals used in supply chains make up the technical dimension of data and information sharing. To sum up, selecting right criteria and developing a digital platform for collecting data regarding these criteria are the basic duties in founding a supplier performance evaluation model.

For selecting the effective and efficient evaluation criteria, sustainability theory provide a comprehensive guidelines for manufacturers. In recent years, sustainable management strategies have become a major issue for companies (Ho, Xu, & Dey, 2010). Past researches posits several sustainability metrics related to economic, social and environmental criteria under sustainable performance evaluation frameworks (Baxter, Gram-Hanssen, Askham, Brodal Hansen, & Rubach, 2018; Osiro, Lima-Junior, & Carpinetti, 2018).

Not only had companies within corporate strategies, but supply chains also adopt sustainability criteria for evaluating the supplier performance. However, the biggest challenge on this task is to assure the interrelationships between the sustainability indicators on the assessment process (Giannakis, Dubey, Vlachos, & Ju, 2020). Since companies depend upon the performance of their suppliers, there is an increasing need for monitoring and evaluating suppliers based on an interrelated network between the performance criteria. Thus, decisions for choosing the sustainable supplier or making investments to develop suppliers on sustainability metrics are the remarkable problems of organizations (Rashidi & Cullinane, 2019). According to Chai, Liu, & Ngai (2013) selecting the sustainable suppliers is one of the most important decision associated with the sustainability performance of the company, because of this performance has also a close relationship with vendor's performance. Beside that, Abdel-Basset et al. (2020) emphasis sustainable supply chain finance since this field remains poorer. Yadav, Garg, & Luthra (2020) develop sustainable supply chain metrics for agriculture supply chain, based on Internet of Things. Saeed & Kersten (2020) state a novel sustainability and performance assessment framework to increase consumer awareness towards minimizing the ecological and social impact of their supply chain business.

In order to fulfill the supplier selection task, there are plenty of techniques that proposed by past researchers. These methodologies can be range from data envelopment analysis, total cost ownership (Bhutta & Huq, 2002), linear programming and statistical data analysis (De Boer, Labro, & Morlacchi, 2001) to multi criteria decision making (Ho vd., 2010). However, the existing models are far from combining with the dimensions of sustainability and setting the relative priorities of these dimensions (Luthra, Govindan, Kannan, Mangla, & Garg, 2017). For example, in case of that the company adopt the cost leadership strategy as well as environmental sustainability goals together, a supplier that uses expensive technologies for measuring the carbon footprint may cause a tradeoff for the company. In this situation the decision makers have to take the relative importance of these criteria into account for properly assessing the supplier performance.

The other limitation of these methodologies is that the supplier evaluation process is separately conducted from the practical business environment. Digitalization of supply chain provide state of art opportunities to collect real time information from the suppliers on sustainability indicator.

Therefore, the aim of this study is twofold. One is building a conceptualize framework for evaluating suppliers based upon environmental social and economic dimensions of sustainability, that express the interrelationships between the indicators. The other is developing a portal that allows suppliers to share real time information on these indicators, so that the focal company can evaluate suppliers and return feedbacks on sustainability performance.

Besides providing guidance for supply chain managers for selecting the appropriate supplier, one of the main benefit of the proposed model is that it reflects the sustainability performance back to the suppliers so that they can align their strategies with the focal firm as well as take precautions for improving the relationships with focal firm.

To assure the first aim, we have applied the Analytical Network Process (ANP) which calculates the interdependencies of criteria and measure the performance score. Moreover, we have carried out a case study in which we collaborate with the IT crew of a company to develop a web portal and integrate the ANP methodology on this portal.

The rest of this study is organized as follow. In the 1st chapter, we review the existing literature on sustainable supply chain management. In 2nd chapter, we explain the multi criteria decision making methodology and particularly Analytic Network Process. In 3rd chapter, we explain the details of the proposed model and express the results of application.

2. SUSTAINABLE SUPPLY CHAIN MANAGEMENT

In this chapter, we introduce the supply chain management with basic concepts. Subsequently, we combine the sustainability issue with the supply chain management.

2.1. The History of Supply Chain

The origins of supply chain management dates back to the 1960s. At that time, a decentralized logistics function focused on enhancing operational performance with storage, inventory control and transportation efficiency. Even if, the development stages go back to earlier times, the concept of supply chain was first introduced by Oliver Kith in 1982 to separate production, marketing and distribution functions from each other (Özdemir, 2004).

With the development of MRP (Material Resource Planning) systems in the 1970s, managers centralized logistics activities. Instead of optimizing the activities of each unit separately, such as marketing, production and financing, they focused on gaining competitive advantage by handling the entire system. This period has been accepted as the total cost management or material management and physical distribution period. With the introduction of computers in the 1980s, the logistics management function expanded further and became integrated with other business functions. This period is also called logistics integration or logistics phase. In the logistics phase, the logistics focus was combined with the strategic decisions of businesses and the concept of supply chain management was introduced for the first time (Christopher, 2016).

After the 1990s, quality alone was not enough to stand out in the competition. Offering products quickly and flexibly with quality and keeping costs at a reasonable level while doing so have become new indicators of success. Managers realized that in order to achieve these goals, they need to cooperate closely with suppliers that provide production inputs and with retailers that are in closest contact with the end consumer. In the literature, this period is called the supply chain management phase (Özdemir, 2004). Previously, logistics included activities that took place within the boundaries of a single organization, while the supply chain represents the network of organizations that coordinate the actions of the customer to distribute the product requested (Başkol, 2011).

In the 2000s, new administrative units were started to be established in large enterprises with the title of supply chain. In this period, a synchronized supply chain became possible with the introduction of the internet. Information sharing has become easier in the expanding supply chain networks. With the analysis of shared information, supply chains have had the chance to achieve an agile structure (Ross, 2008).

2.2. The Structure of Supply Chain

In 1990's, after the end of cold world war, the phenomena of globalization removed the economical borders between the countries and even continents. This new situation opened new doors for international trade and provide offshore options for manufacturers. Along with the expansion of international trade, competitiveness has also created a huge pressure upon companies. Consequently, companies have sought innovative solutions to increase productivity and keep surviving against competitors.

We should also acknowledge that China's attendance of World Trade Organization in 2001 has accelerated the global movements in international trade. Thus, the supply chain phenomena comes up on the basis of these two triggers, namely globalization and competition.

By the supply chain idea, companies extend the within-organization activities to the network of organization that they exist in. Customers, service providers, distributors and suppliers are the participants of this organization network. The supply chain network is actually a system that each element is expected to coordinate and collaborate with others. There are many problems worth for study in supply chains such as allocation of created value, optimal movements of finished goods or information sharing decisions. In this study, however, our main research field is supplier evaluation and supplier selection based on sustainability criteria.

In figure 2.1, the evolution of supply chain structure is shown. Indeed, the supply chain concept derives from the partnership relations of economic agents. As organizations are open-systems, the basic supply chain constitutes long term coordination with customers and suppliers, more than an ordinary buyer-seller relations.

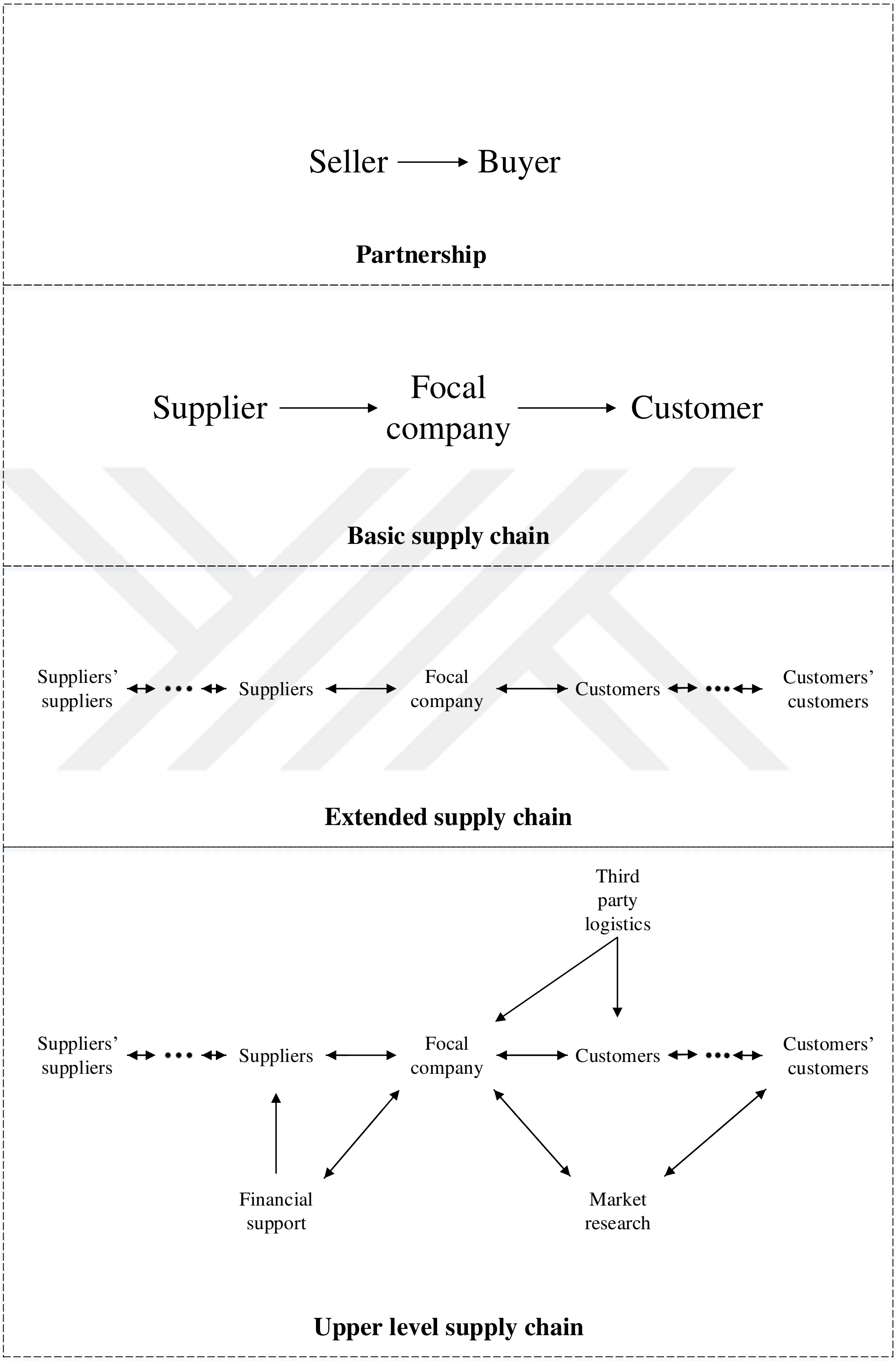


Figure 2.1. Types of Channel Relationships in Supply Chain

Source: Defining Supply Chain Management (Mentzer vd., 2001)

As long as the size of business expands, the variety of member type enriches as in extended supply chain. Eventually, the upper level supply chain includes research companies, financial funding agencies and 3PL (Third Party Logistics) service provides. Messiness of such system requires sophisticated IT use and complicated analysis to fit decisions on optimum.

Now that the supply chain concept is a novel approach in literature, there are a number of definitions that do not consistent yet. Some of which are as follow. Supply chain refers to the network that consists of service and delivery channels in which raw material is supplied and transferred into semi-product and finished goods (Lambert & Cooper, 2000a). Supply Chain Council stated that the concept of supply chain covers all endeavors related to the production and distribution of the end product (from the supplier of the supplier to the customer's customer). These endeavors are carried out in four categories: planning (supply and demand management), sourcing (supply of raw materials or semi-finished products), producing (manufacturing and assembly), delivering those products (storage and stock tracking, order taking and management, distribution throughout the entire channel and delivery to the customer) (Özdemir, 2004). APICS dictionary puts definition down the supply chain as all of the operations inside and outside the enterprise, where the value chain that connects supplier-user businesses and provides products and services to customers, from gathering raw material to the consuming the finished goods (Lummus & Vokurka, 1999). Lee & Billington (1992) posits that the supply chain is a network of structures that obtain raw materials, convert them into semi and finished products, and then deliver these products to customers through a distribution system. Handfield & Nichols (1999) states that the supply chain includes all duties related to material flow and transformation from the raw material phase to the ultimate user and the information flow associated with them (Elagöz, 2008).

2.3. Supply Chain Management

As the supply chain is a system that assembly different components, supply chain management can be depicted as ruling of these components to maximize the utility and minimize the hazardous outcomes that the system generates. Inventory costs, sub-optimal location decisions, high planning expenses and order costs, and uncertainties and risks in product shipment are the examples of such hazardous outcomes. Satisfied customers, reduced lead times and high quality of products are also some of the embodied utilities of supply chain management.

There are three main flows need to be optimized along with supply chain management tasks; namely material, information and money flows. These substances move between the units of supply network, such as sales, production, assembly facilities and distribution centers (Elagöz, 2008). In order to achieve these utilities, supply chain managers collaborate with partners within the network and coordinate the relationships by watching the process from a control tower.

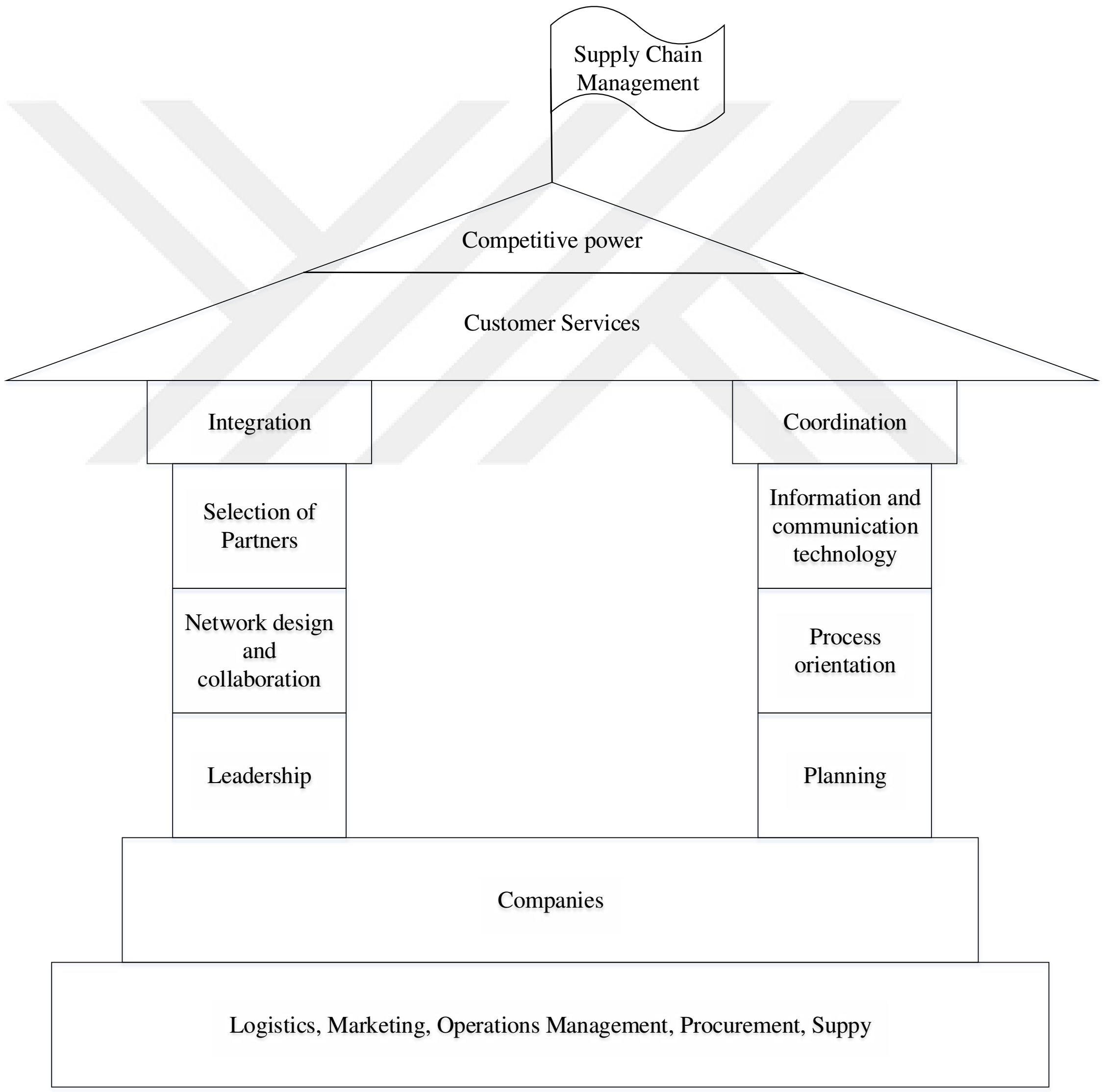


Figure 2.2. House of Supply Chain
Source : Supply Chain Management and Advanced Planning (Stadtler & Kilger, 2000)

Figure 2.2 shows the house of supply chain metaphor (Stadtler & Kilger, 2000) which consists of fundamental activities within the supply chain. The overall objective of supply chain management is gaining a competitive power against rivals. The unique way to obtain this power passes through the customer satisfaction. Apart from understanding the customer needs and aligning with the competitive strategy on the gist of demand, it is impossible that a company is able to survive forever. Thus, customer services is the forefront component of competitive power.

There are two basic tasks that supply chain leaders have to complete for holding the customer services above. These fundamental tasks are integration and coordination which constitute the main columns of the supply chain house.

Supply chain integration means the constitution of the network and synchronizing the participants. In other words, a number of organizations that represents different functions are gathered by a leader company to share the same goals and same strategies. Therefore, the biggest part of supply chain integration consists of selecting the appropriate business partners. Supplier selection is also the main problem of this thesis study.

After setting the supply network, leadership mechanism should work for keeping the relationships. To ensure the relationships among the supply chain entities, partners regularize their business activities considering the inner customers. So, the coordination is the other essential part of a healthy operating supply chain system. In order to streamline the coordination, supply chain managers underline the connectivity. Connectivity means that each economic agent within the network is accessible and ready to get in touch whenever required. To ensure connectivity, supply chains have to yield from communication technologies and artificial assistants such as robots and cobots.

What we talk about by supply chain partners are the entities that ownerships are all separated. Instead of vertical integration with legal regulations, supply chain thinking suggests the coordination which streamlines the operations with less costs. So, the ground floor of supply chain house consists of different trade partner companies and their sub-systems such as logistics, marketing, operations management etc. These sub-systems are the connection hubs that the companies within the network bound to each other.

In supply chain management, there are six different paradigms that researcher approach to basic concepts; namely functional paradigm, procurement paradigm, logistics paradigm, business process reengineering paradigm, information paradigm and strategy paradigm (Ayers, 2002; p.7-11). There paradigms are ranged according to from the least to most comprehensive point of view. Thus the strategy paradigm, for example, covers what all the others posit.

The functional paradigm is the simplest and most fundamental paradigm. In businesses that adopt the functional paradigm, each department acts independently from each other. The goals and optimums of each department are different. Supply chain success is measured by indicators such as input costs, productivity and sales performance.

Supply chain functions are also known as supply chain mix. Supply chain functions or mix; strategic planning and marketing segmentation, procurement, manufacturing planning, storage and material holding, stock management, warehouse and stores, transportation, customer service and technical support (Quayle, 2006; s. 107-108).

The functional paradigm accepting low cost as a success criterion has made raw material and material costs gain importance. Thus, the purchasing paradigm was born. The purchasing paradigm considers supply chain management as the management of upward relations in the supply chain. Especially in the manufacturing sector, the purchasing profession has become synonymous with supply chain management. Those who carry out this profession perform tasks such as creating a supplier portfolio, negotiation, contract management and supplier evaluation. While performing these tasks, they take into account the balance of power with suppliers and the level of dependency on suppliers. In addition, they try to minimize input costs with applications such as vendor managed inventory (Vendor Managed Inventory-VMI).

The main element that connects businesses to each other in supply chains is logistics activities. Within the scope of these activities, the physical movement of products between the supply chain layers also constitutes an important part of the country's economies. Logistics is depicted as supply chain processes that ensure effective and efficient planning, implementation and control of flow and storage of goods, services and associated info from the starting point to the point of consumption in order to meet customer needs. The logistics and transportation paradigm focuses on cost-oriented activities such as organizing storage activities, establishing distribution centers and shipping networks.

Not only physical flows but also data flows create connections within the business and in the supply chain. The information processing paradigm focuses on processing this data and transforming it into information. It also cares about technological tools that provide information flow. For example, blockchain technology has gained popularity in the field of supply chain in recent years, as it enables the sharing of information between parties securely by emerging intermediary elements in communication. Such technologies ensure standardization among chain members. Thus, planning and coordination becomes easier (Ayers, 2002).

Types of information sharing in the supply chain include sales forecasts, inventory information, customer complaints or investment decisions. For example, by sharing the data of Wall-Mart sales points with its suppliers, it enables them to plan production more effectively.

The process restructuring paradigm focuses on the radical restructuring of business processes to increase quality and prevent waste. Six Sigma is the most used methodology in process renewal. The process innovation approach should not be confused with using technology. The use of new technologies only plays a catalyst role in process renewal.

The strategy paradigm focuses on the integration of the supply chain with competitive strategies. These strategies should cover not the core product offered to the customer, but also the operations within the expanded product. In this approach, supplier inter-relations, logistics and information processing tools feed the satisfaction perception of customers. This results in an increase in market share and profitability. Costs are secondary according to this point of view (Ayers, 2002).

Managerial activities in the supply chain are examined in three categories: strategic, operational and tactical levels (Hwang & Rau, 2006). The strategic level is the phase in which the allocation of resources is planned for the long term. Selection of the establishment locations of facilities such as warehouses, factories or distribution centers and planning their capacities are activities carried out at a strategic level. Customer and product segmentation, determination of operation and channel strategies are also examples of this planning. However, when determining these strategies, the stage of the product life cycle of the product or industry promised to the customer should be taken into account. Thus, long-term relationships with suppliers, producers and customers can be established. In summary, long-term planning generally aims to harmonize the general objectives of the business with the supply chain strategies.

Production planning is done at tactical level. Suppliers are selected and purchasing contracts are signed by considering criteria such as cost, quality, delivery and flexibility. It is decided in what quantity and where to keep the stock of raw materials, semi-finished products and finished products. Shipping routes and frequency are determined. The success of the operations carried out is compared with the competitors in the sector and process improvement is made if necessary. By making use of information systems, customers' needs and expectations are followed and complaints are resolved. Progress payments are also made at the end of the processes.

At the operational level, the daily activities of all units in the supply chain are carried out routinely. Demand estimates are made and these estimates are shared with suppliers and coordination is ensured. Orders from the customer are recorded and accounted for. Products from suppliers are accepted. The flows of raw materials and semi-finished products used in manufacturing are regulated within the enterprise. The delivery of the manufactured products to the warehouse, retailer or customer is planned and applied (Hwang & Rau, 2006).

Subsequently, we are going to explain the types of supply chains and then elaborate on the integration and coordination issues with more details.

2.4. Supply Chain Types

Supply chain studies discriminate the types of supply chains according to number of echelons existing in the supply chain map. Figure 2.3 shows the construct of a single echelon supply chain (Stadtler & Kilger, 2000). In such systems, downstream relations contain distribution and delivery, whereas upstream relations are made up of material orders. Production operations remain within focal company. Direction of money flows occur from demand side to supply side, while material flows do vice versa way. Information is also shared towards every directions from every entity.

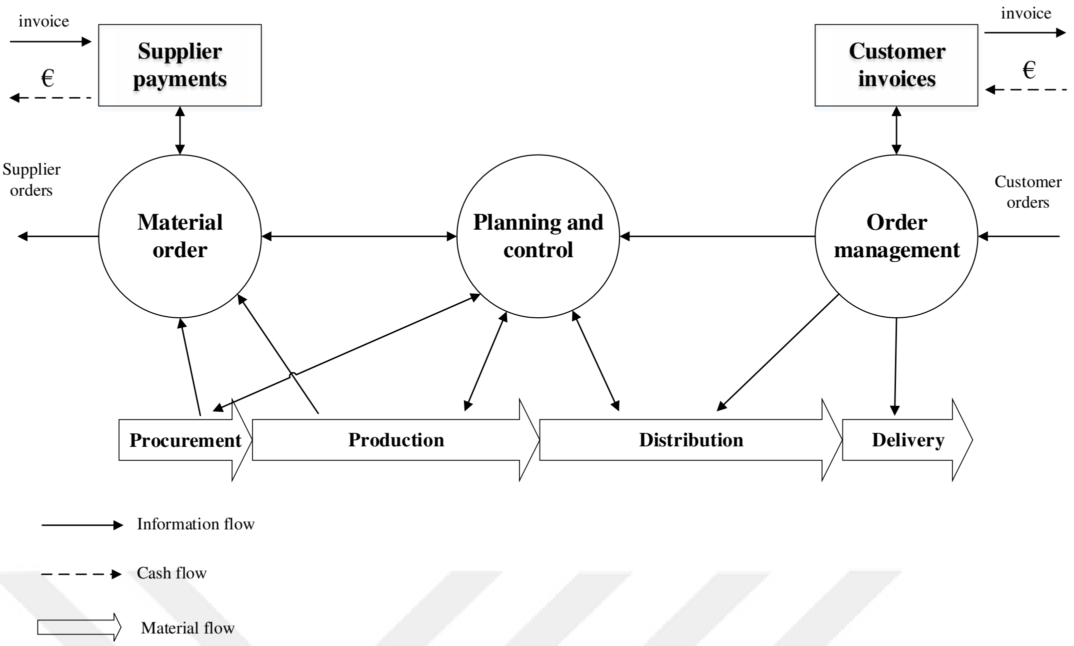


Figure 2.3. Single Echelon Supply Chain

Source : Supply Chain Management and Advanced Planning (Stadtler & Kilger, 2000)

As the level of uncertainty become higher in the marketplace, companies begin to include suppliers' suppliers or customers' customers within the planning activities. Hence, as a new type, the multi-echelon supply chain idea born. Figure 2.4 shows the basic structure of a multi-echelon supply chain. Considering the supply chain constitutes a system itself, we may define the multi-echelon supply chain structure as the system of systems.

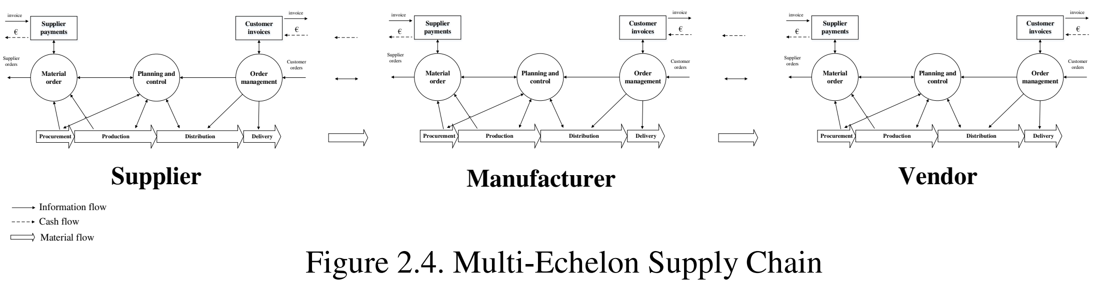


Figure 2.4. Multi-Echelon Supply Chain

Source : Supply Chain Management and Advanced Planning (Stadtler & Kilger, 2000)

The number of organizations aligning with a range as supplier, manufacturer, distributor etc. comprise the length of supply chain. The number of organizations within a single echelon displays the width of supply chain. Wideness of supply chain generally depends on the number of vendors such as in retail industry. These two indicator determine the level of complexity in a supply chain. The coordination and collaboration become more difficult when the complexity rise. However, multi-echelon supply chain approach enable managers to foresee the movements beyond suppliers or customers and reduce the uncertainty within the marketplace.

2.5. Supply Chain Coordination

The biggest trap on the way of achieving supply chain performance is accepted as the complexity of supply chain systems (Arshinder, Kanda, & Deshmukh, 2008). Complexity makes the coordination of different elements difficult within any system, let alone supply chains. Yet, in supply chain management, coordination effectiveness is the main driver of average performance, along with integration (combination to a total whole), coordination (jointly operating) and collaboration (jointly working).

There are no consensus on the definition of coordination in supply chain literature. However, Arshinder vd. (2008) states that lack of coordination makes felt itself by poor performance. Furthermore, mismatch of supply and demand, excessive inventory, low capacity utilization, high stock costs, inaccurate forecasts are the other negative consequences of lack of coordination.

Coordination exists when all supply chain members behave as if they are a part of a unified whole. This situation is the indicator of a collaborative supply chain which means the environment that companies receive more utility by jointly operating their business than they do in an isolated way (Simatupang, Sandroto, & Lubis, 2004). It is actually a win-win strategy and more beneficial than a zero-sum game. These benefits are reduction of lead times, increased revenues and sales, better customer services, low manufacturing costs and so on.

In order to coordinate the supply chain activities, Arshinder vd. (2008) suggests four coordination mechanism; namely info-techs supply chain contracts, information sharing and making decisions with communalities. Supply chain contracts are used for managing mutual relationships such as supplier-buyer relationship or manufacturer-vendor relationship. Contracts specify the amount of goods, lead time, and level of quality and place where to transmit happens. Thanks to contracts, partners can escalate the total revenue, diminish overstock or understock costs, and share the risks (Wang, 2002).

Information technologies provide a platform to streamline the supply chain activities for partners. EDI (Electronic Data Interchange), VMI (Vendor Managed Inventory), and ERP (Enterprise Resource Planning) systems are the most used IT (Information Technology) systems. EDI makes sending documents available via intranet so that it accelerates the business and reduces the official burdens. ERP systems provide a holistic approach to manage whole supply chain functions by one center. VMI is the way of monitoring and deciding the manufacturer's finished good inventory by vendor's replenishment policy.

To strengthen the coordination, supply chain members should unify the overall objectives. By the joint decision making, supply chains can cope with the duty of keeping the supply chain members standing on the same direction and prevent the conflict of interest. Supply chain members can be persuaded to share strategic information and knowledge with others only if such a trustworthiness environment is ensured. Thus, the information sharing is the fourth mechanism contributing the supply chain coordination.

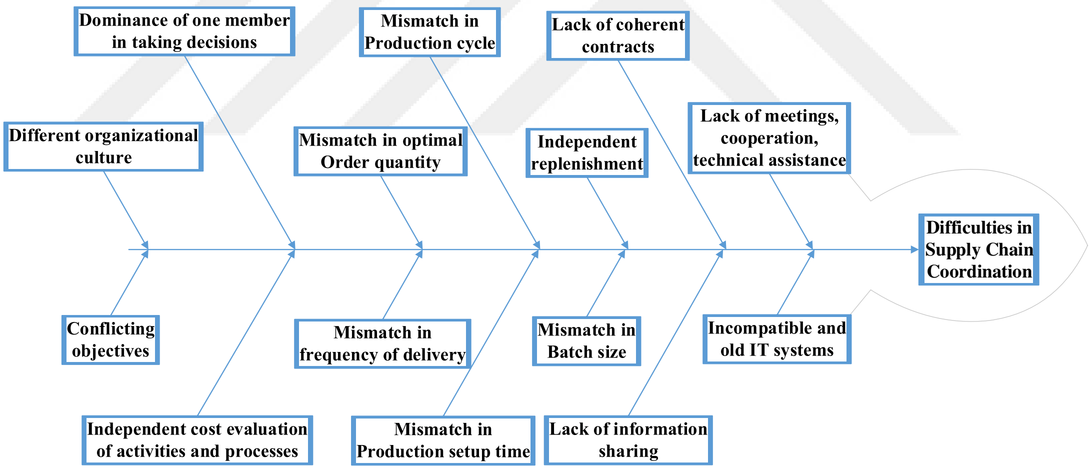


Figure 2.5. Difficulties in Supply Chain Coordination

Source: Supply Chain Coordination: Perspectives, Emprical Studies and Research Directions (Arshinder vd., 2008)

Figure 2.5 shows the various difficulties that companies may face when founding the coordination in supply chains (Arshinder vd., 2008). These difficulties are mostly derived from the disturbances on the executing the coordination mechanisms. To exceed these difficulties, there need to be a dominant company within the network who regularize the conditions and relations. Otherwise, the conflicting problems may undermine the coordination as leading some partners to leave from the network.

As we mentioned earlier, one of the most significant component of supply chain coordination is supply chain integration. Thus, we explain this concept next.

2.6. Supply Chain Integration

Integration as a supply chain strategy gives a firm the advantage of winning competitive superiority, diminishing operational costs, and boosting coordination with partners in the supply chain. Supply chain management; It is a common management philosophy in which the supply, production and distribution systems gradually turn into an integrated system, and that helps the main producers and sub-producers to develop common strategies and structure them in a way that provides competitive advantages.

The integration issue is related to flow of information and flow of material within the supply chain. So, there are two types of integration, namely information integration and logistics integration (Prajogo & Olhager, 2012). Both significantly contributes the operational performance, yet requires a long-term relationships based on a trustworthy environment.

Logistic integration is coordination of the flow of concrete things from suppliers to end customers to create time and space utilities. This coordination ensures the availability of goods in terms of required amount just in the right place and right time. It is done by switching the same logistic functions of different organizations between each other. Logistic integration is also called as forward integration, because of that the direction of flow is from supplier to customers.

Information integration refers to sharing the key information among the supply chain network. It is a backward integration because the direction of flow goes by customer to supplier. Key information can potentially be used for supporting critical decision making within the supply chain. Vendor managed Inventory (VMI) systems are the typical examples of such decision making as determining the level of inventory according to demand fluctuations of vendors. The aim of such systems are reducing the bullwhip effect along with supply chain echelons.

There are two components of information integration which are IT technologies and information sharing (Prajogo & Olhager, 2012). IT technologies are the hard side of information integration. IT capabilities constitute a platform to streamline communication, coordination and problem solving. They require a fair amount of investment and enable to transmit the information among member institutions. However, sufficient commitment of information integration cannot come true merely by setting the technical infrastructure. There are also social aspect of the information integration. Information sharing stands for this side of the medallion. To achieve the information integration, supply chain partners must be willing to share information. The willingness depends on the wellness of relationships. Unless members do not trust to others, they might refuse to share information or, in a worse scenario, they might mislead others by incorrect information.

2.7. Business Process in Supply Chain Management

As discussed until here, the supply chain concept refers to the extended type of a single organization towards a bunch of organizations. The Global Supply Chain Forum defines eight business process within a supply chain (Özdemir, 2004). These process are illustrated in Figure 2.6.

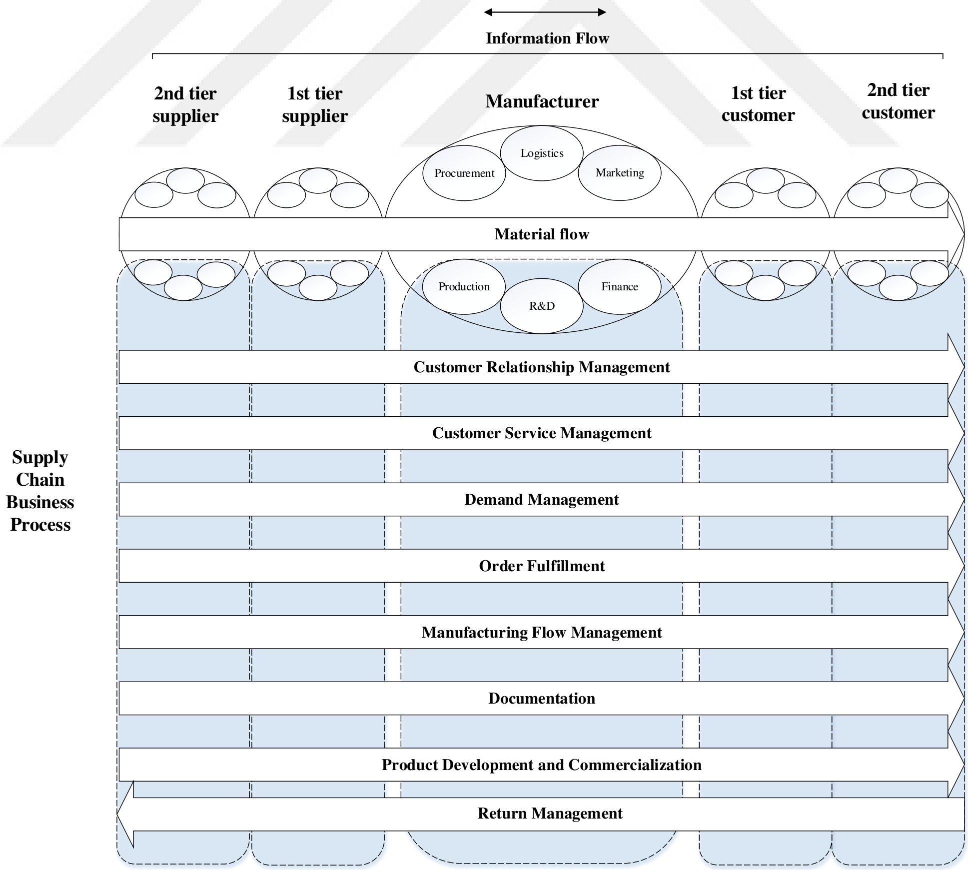


Figure 2.6. Managing Business Process within Supply Chain

Source: Issues in Supply Chain Management (Lambert & Cooper, 2000b)

The Customer Relationship Management Process is a construct that addresses the methodology for improving and keeping the relationships with customers. As part of the mission of the firm, it is determined that which customer groups should be targeted. Consumer management prepares "product and service agreements" to meet the targeted and other customers' needs. Customer managers study with identified important customers to develop processes, diminish risks in demand and non-value added activities. Additionally, claimed department prepares reports for leading this process in that measuring the profitability of customers and putting together with the financial consequences of applied strategies against customer groups (Özdemir, 2004).

The process of Customer Service Management is the connection hub of the company towards customers. The working people in this department generates services for informing customers regarding the product availability, order situations or lead times. Within the production and logistics procedures, a joint connection is carried out providing real time information to customers. Besides that, the working people in customer service management are responsible for the agreements and contracts with customers committed in the markets (Bolumole, Knemeyer, & Lambert, 2003).

The process of Demand Management aims to match the requirements of the consumers with the supply facilities of company. The people working in demand management procedures conduct forecastings for harmonizing manufacturing, procurement and distribution. These men also develop contingency strategies that provide alternative scenarios in case of ceasing activities for some reasons (Croxton, Lambert, García-Dastugue, & Rogers, 2002).

The key factor in an effective supply chain management is to meet customer needs in terms of fulfilling orders. In order to make betterments on order processing, it is required that the focal company cope with integrating production, logistics and marketing activities. There are two main pillars of order processing such that meeting customer needs better via developing partnerships with key members of the supply chain and reducing the total cost ownership of product delivery. Only if these indicators are fulfilled, we can mention an effective order processing procedure within the supply chain that the firm is locate in.

The fundamental objective of Manufacturing Flow Management is ensuring the flexibility within the manufacturing procedures. Product flexibility, amount flexibility and range flexibility are the types of flexibility. The length of such a range is for ensuring the best services for the target market segment. The manner of flexibility starts with acquiring raw material. Then it goes beyond the manufacturing plant to reach customers (Goldsby & García-Dastugue, 2003).

Supplier relationships management concerns about being a lovely friend with customers. It resembles the customer relationship management, but the reverse one. Companies must not only improve their relationships with customers but also with suppliers. It is done by splitting the supplier portfolio into sub-groups (Goldsby & García-Dastugue, 2003).

The product development process is crucial for the firm to continue its success. The most important component of business success is to rapidly develop new products and to present them to the bazaar in an efficient way. The notable purpose of this process is to enter the market in the right time. Supply chain management contains the inclusion of customers and suppliers in the product development process in order to diminish the time to introduce new products to the market. Due to the short product life cycles, companies need to improve the true goods and successfully offer them to the market in short time frames in order to standardize the competitiveness (Goldsby & García-Dastugue, 2003).

A productive returns management is a crucial fraction of supply chain management. Although many companies neglect the return process because their managers believe that this process is insignificant, this process can help the company gain a sustainable competitive advantage. An effective returns management process can help companies find ways to increase their productivity and realize their projects (Goldsby & García-Dastugue, 2003).

2.8. Supply Chain Performance

The fundamental aim of supply chain management is to enhance productivity and profitability by supporting competitive strategy. The performance of a supply chain indicates what extent the supply chain meets the expectations from the endeavor spent for designing it. In order to improve the overall supply chain success, firstly the performance need to be assessed. Thus, performance should be defined as a measurable concept (Beamon, 1999).

As discussed earlier, organizations aim to improve supply chain coordination to reduce the uncertainty and to take control of distribution channels. By such alliances, supply chain members increase the operational and financial performances. Unless measuring the level of performance, it is not possible having the control over supply chain process. Thus, some tools are developed so far in academy and practice to sustain the continuous improvement in supply chain.

In order for building up such a performance measurement mechanism, there need to be some metric and non-metric performance dimensions. Gunasekaran, Patel, & McGaughey (2004) summarize these dimensions and indicators in the context of plan, source, assemble, and delivery. Then, strategic, tactical and economic levels are determined, which contain several indicators. Strategic level reflects the decisions and policies of top managers. Organizational goals, competitive strategy, financial plans are the example of strategic level indicators of performance dimensions. Tactical level indicators explain the strategic level in a rather quantitative way. Resource allocation, target setting etc. are certain tactical level indicators. Operational level is the most data-driven stage lead by daily performance. To obtain a clear reflection, operational level performance assessment metrics require validity and reliability.

One of the most crucial part of supply chain performance measurement is the supplier evaluation. Managing the relations between the main industry-supplier, developing the suppliers in the long term and determining the strategic relations with the supplier are the fundamental problems in supplier evaluation field. The purpose of supplier gauging is not only to select a new supplier or cancel the agreement with an existing supplier, but also to assess the performance of suppliers in a specific time period and based on certain criteria. Such a performance measurement provides feedback to suppliers so that they can take further steps on improvement (Dağdeviren, Dönmez, & Kurt, 2006).

Supplier performance evaluation is also the basic problem of this thesis study. However, we apply sustainability metrics to fulfill evaluations based on current research trends, instead of barely conventional criteria such as cost, quality, velocity etc.

2.9. Green Supply Chain Management

As for the deterioration of natural sources since 90s, both practitioner and academics charge the supply chains with the responsibilities to take more actions to protect the environment. The concept of green supply chain management (GrSCM) comes up in this sense. Srivastava (2007) depics the GrSCM as follow:

"Integrating environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life"

As it is seen, GrSCM penetrates every activity in the supply chain. Furthermore, the aim of GrSCM is not only protecting the environment but also providing good business and high profitability by reactive monitoring programs or proactive implementations. From the reactive point of view, firms can use labels for making the products recyclable and start 'end of pipeline' initiative to reduce the waste against escalating pollution. From the proactive perspective, they can take new environmental laws into account over operations for realizing a modest resource commitment. From the value-based approach, organizations can integrate the green thinking into their competitive strategy. For example, companies reposition their brands based on the green slogan. Thus, green potentially hides a strategic advantage rather than being a burden. In a nutshell, the common side of green activities such as green operations, reverse logistics, waste management, green purchasing or green design is the endeavor to operate as generating less waste and to consider the hazardous outputs for each steps (Srivastava, 2007).

The product life-cycle analysis is another important issue in GrSCM literature. According to this approach, environmental, occupational health and resource-related outputs of a product need to be investigated from extracting and processing the raw material to recycling and final disposal (Gungor & Gupta, 1999). Trancing the journey of product life and integrating remanufacturing with internal operations are the key challenges.

During the past twenty years, environmental topics have received great deal of attention from governments, public and scholars. Green Supply Chain Management (GrSCM) has gained much more attention in the last few years in universities and sectors

(Jayant & Azhar, 2014). Due to the fact that customers are now more conscious in environmental problems and governments also put some more restrictive precautions and regulations, companies need to diminish the pollutionalization during their activities within or without plants. Thus, we can say that the green supply chain management term had started in this content in literature (Amindoust, 2018; Jayant & Azhar, 2014). It should be noted that if organizations focus on sustainability strategies and want to meet sustainability requirements, they must consider it in their supply chains too. Suppliers are a major part of any supply chain, so if selected suppliers follow sustainability strategies, they can deliver services and products in accordance with sustainability criteria of the buyer's organization (Vahidi, Torabi, & Ramezankhani, 2018).

Green supplier selection is a fundamental breakthrough within the transition to design and manage a sustainable supply chain in environmental perspective (Banaeian et al., 2018). Environmental management pulls attention from all over the World including governmental organizations as well as NGOs. Considerable amount of pressure is applied on the decision makers so that they take precautions. One of this precautions is supplier selection task. In this task, procurement managers have to pick the best supplier for environment and business (Gupta & Barua, 2017).

Regarding practices, we can count participation in ISO 14001 standart and several environmental award systems, putting environmental management criteria together, collaboration with consumers, green based supplier selection, water proof recycling systems constructions, and so on and on (Islam, Tseng, Karia, & Lee, 2018).

By the way, these problems cause researchers to study on these issues so that they can figure out the reasons and find out remedies and solutions to that problems. Various quantitative and qualitative approach have been developed so far, to analyse green related supplier selection problems. However, few researchers focused on sustainable supplier selection and assessment procedures. That’s why we pay more attention on such a problem in this study. With giving more energy, we believe that a lot of simple problem can be solved in the green context.

2.10. Sustainability

Sustainability is an interdisciplinary issue that is rooted in the physical and social sciences (Y. Liu, Wan, & Su, 2019). It requires a balance between economic, environmental and social factors (Büyüközkan & Berkol, 2011).

There is no longer a tendency for companies towards a commodity and price based supplier selection particularly for critical materials. Issues related to innovative supply chain management make sustainability important for every institutes (Bai & Sarkis, 2010b). Since there is a growing consciousness on green questions, the biggest challenge of green based supply chain studies is making a decision about the trade-off between financial costs and environmental costs (Batabyal, 1995). Thus, there are two pillars explaining the reason why industries pay a growing attention on green based points, namely environmental protection responsibilities and social pressure (Memari, Dargi, Akbari Jokar, Ahmad, & Abdul Rahim, 2019).

Industrial revolutions play a crucial role in shaping the life conditions of mankind. The first of industrial revolution covers the period when mechanical looms that work with water and steam power began to take place in production, replacing workshop-style management and handicrafts, and also production based on human and animal power. In the second industrial revolution, Henry Ford made the transition to mass production by using electrical energy in production and became the symbol of this period. In the third industrial revolution, with the combination of electronics and information technologies, programmable machines were used for the first time in production and the automation era started (Karakoç vd., 2020).

These revolutions have caused many social, economic and environmental damage beside benefits. However, humanity has an awareness of sustainable environment, society and economy in the age of Industry 4.0. The fourth industrial revolution, which started in 2011, is a digital era in which all kinds of objects can communicate and interact, smart production is made, and cyber-physical systems are used with the widespread use of chips and the internet (Hofmann & Rusch, 2017).

Subsequently, thanks to the facilities that the Industry 4.0 bring about, the issue of sustainability is adopted and process improvement mechanisms are developed to compensate for the damages occurred in the past century. Today, companies pay more attention on sustainability problems as much as quality and costs. This is not only because of legal restrictions, but also of competitive pressure. Consumers do not ignore any longer if the brands omit sustainability criteria. Violating sustainability criteria notably erode the brand image and profitability. For example, after the detection of fraudulent carbon emissions in approximately 9 million diesel-powered vehicles produced by the

Volkswagen group between 2009 and 2015, the company suffered a loss of $ 20 billion in the USA alone (Özcüre, 2018). Therefore, being profit-oriented is not enough for surviving in today's business life. Companies also have to minimize their negative effect on the environment. Besides, companies should oversee the attitudes of suppliers along with safety, health, child labor, pollution and so on.

In this sense, sustainability has become a remarkable competitive strategy for business organizations. Eventually we define the sustainability as the efficient use of resources to meet today's needs without exposing future generations to any difficulties in fulfilling their own needs (Daly, Cobb Jr, & Cobb, 1994). This definition is mentioned in the WCED report for the first time (WCED, 1987). Based on sustainability dimensions, companies also prepare sustainability reports. By these documents, companies reflect their sustainability performances and provides information for the stakeholders.

Sustainability concept is not only studied in organization theory, but also belongs to economy literature. Sustainable development studies are interested in interactions and connections between three pillars of sustainability for industrialized and developing countries. The "Triple Bottom Line (TPL)" approach is designed to explain those pillars (Elkington, 1998). According to TPL idea, financial bottom line does not provide efficient basement for the success, but economic agents also need to ensure the social and environmental performance. The central part of supplier selection query is economy. We can understand the reason why majority of papers eager to solve sustainability related problems (Awasthi, Govindan & Gold, 2018). No matter how various had the criteria included in research models, there is a strict consensus that cost, quality, flexibility and velocity are the key performance indicators on sustainability research (Dou & Sarkis, 2010).

Along the history the supply chain management, sourcing decisions used to made on financial aspects (Memari et al., 2019). Yet, policies on environmental and social concerns have let companies increase outsourcing according to triple bottom line (TBL) attributes (social, economic and environmental) (Ghayebloo, Tarokh, Venkatadri, & Diallo, 2015). For a more competitive power in the market, companies take other dimensions into consideration along with financial performance (Gülçin Büyüközkan, Kayakutlu, & Karakadilar, 2015). Assessments limited to economic aspects only do no longer hold their former strength and applicability (Kannan, 2018). In today's struggling business arena, organizations have to align their strategies with the environmental performance indicators. Furthermore, governmental regulations and the impact of pushing social groups force organizations to adopt sustainable performance measures which draw and edge between the company and it’s rivals (Gupta & Barua, 2017).

By the time the concept of sustainability emerged from an international political discussion (WCED, 1987), the discipline of business management quickly penetrated the novel theory just as the field had already interested in the environmental side for a long time. Thanks to the green issue, lots of global sustainable supplier selection frameworks have been integrated to the dimensions of sustainability along with the environment branch. The engagement of supplier selection frameworks with the environment factor mostly relies upon several categories (Awasthi, Govindan & Gold, 2018). However, we seek the environmental indicators as stated by the GRI G4 sustainability reporting guidelines. This guide indicates the dimensions ranging from materials to emissions and waste.

2.11. Sustainable Supply Chain Management

Govindan, Khodaverdi, & Jafarian (2013) and Lin & Tseng (2016) defines sustainable supply chain management as the management of various kind of flows and executing the cooperation among firms across the network of supply chain as such taking the environmental, social and financial dimensions into account. In order to assure the long term objectives of the company, the financial, economical and environmental goals are coordinated under sustainable supply chain management activities. To assess if the company is able to complete this coordination task, there must be a number of performance indicator (Carter & Liane Easton, 2011). Measuring such performance is the essential problem of sustainable supply chain studies in recent (W. Song, Xu, & Liu, 2017).

To achieve sustainability goals, not only the organization itself, but the interacting partners should also consider sustainability issues. This is because the organizations exist in a network of other organizations that each element influences others in some extent. This phenomena makes the sustainability important for supply chains as long as organizations. From the initial process of raw materials to delivery of finished goods, supply chain covers a number of business activities. Thus the sustainability of chain is as much as the least sustainable circle in the supply chain (Ageron, Gunasekaran, & Spalanzani, 2012).

Recently, sustainability has begun to integrate into several missions and duties in supply chain activities. For example, companies tend to carefully evaluate their suppliers with respect to sustainability criteria. Along with the financial performance, there is a growing interest in environmental and social performance for supply chain leaders thanks to corporate social responsibility, depletion of natural resources and climate change (Özçelik & Avcı Öztürk, 2014). Thus, there are several terminologies generated the reflect the sustainability related activities in supply chains, such as socially responsible purchasing, green purchasing, green supply chain, reverse logistics etc. (Krause, Vachon, & Klassen, 2009). Regarding these terminology, packaging decisions, supplier selection, transport mode and carrier choices, plant location selections are the activities under sustainable supply chain management umbrella (Carter & Easton, 2011). The aim of those activities are reducing the amount of packaging, more efficient design for reusing and recycling, rehabilitation of working conditions, ensuring safety in storage and transportation and so on. For the companies who follow those activities and seek the sustainability goals are expected to gain lower health and safety costs, reduced turnover and recruitment costs, less absenteeism, lower labor costs, shorter lead times, improved product quality, lower disposal costs, high level of motivation resulting from improved working conditions, productivity, and increased organizational reputation (Carter & Easton, 2011; Özçelik & Avcı Öztürk, 2014).

Sustainable supplier selection is the most significant issue in sustainable supply chain management (SSCM)(Song, Montabon, & Xu, 2018). Sustainable supplier selection is the working procedure of defining the good supply partners of an organization with the best financial value, by the time reducing the various impacts of its operations on society and environment (Moheb-Alizadeh & Handfield, 2019). Due to the extra ordinary attention on protecting the trees and social aspects, the term of sustainable supply chain management is mentioned in various industries. It is a new topic of debate even a hot one (Zhang, Xu, Song, Huang, & Wu, 2019).

The value-chain thinking have the supply chain leaders involved in the suppliers' initiatives in sustainability branches. This is mainly because more than 50% of the value of a product is created by suppliers (Paulraj, 2011). Therefore, sustainable supply chain management strategy, which supports the development and growth of businesses, has become one of the most important success factors. At the same time, businesses are quickly learning to manage their supply chains from the perspective of sustainability.

Sustainable supply chain management is the management of material, information and money flows to maximize the profitability and social welfare while minimizing the environmental impact (Hassini, Surti, & Searcy, 2012). Sustainable supply chain management activities aim to reduce the environmental impacts of products throughout their life cycle. This strategies contribute to increase in quality, efficiency and productivity. For the next generations, companies that protect their resources and realize their core competencies without harming the environment will be able to gain competitive advantages (Şişman, 2018).

Srivastava (1995) defines sustainable supply chain management as reducing long-term risks related to waste management, pollution, product reliability, fluctuations in energy costs and consumption of resources (Şişman, 2018). Carter & Rogers (2008) define the sustainable supply chain as the integration of the traditional supply chain with social, environmental and economic activities. According to Seuring & Müller (2008), sustainable supply chain management is the management of material, information and capital flow as well as inter-institutional cooperation throughout the supply chain while fulfilling the social, economic and environmental objectives that constitute the three dimensions of sustainable development and vary according to the needs of the stakeholders. Sustainable supply chain management is considering the sustainability criteria based on customers' and stakeholders' requirements along with the management of material, information and capital flows as well as coordination the relationships inside the supply network (Özçelik & Avcı Öztürk, 2014).

As it is emphasized above, supply chains are as sustainable as their weakest performing chain. So, there are always some barriers to achieve sustainability goals. In the next section, we examine those barriers.

2.12. Barriers to Sustainable Supply Chain Management

As open systems, organizations influence and shaped by the environment vice versa. Sustainability decisions are also taken mostly associated with those effects namely incentives and pressures. As it is shown in Figure 2.7., triggers of incentives and pressure may be customers, government, NGOs or different stakeholders. These agents may expect more commitment to authoritative demands and regulations or responsibility towards stakeholders. Although, the size of stakeholders spread over the largest part of these influencers, the government regulations with law, have the greatest weight (Ageron vd., 2012).

Accordingly, the right-hand-side factors encourage the organizations to commit the new product development and supplier evaluation decisions based on sustainability criteria. This is actually the transferring the pressures and incentives from the influencers to suppliers. Some authors states those triggers as enablers and barriers (Özçelik & Avcı Öztürk, 2014). These factors might be internal or external.

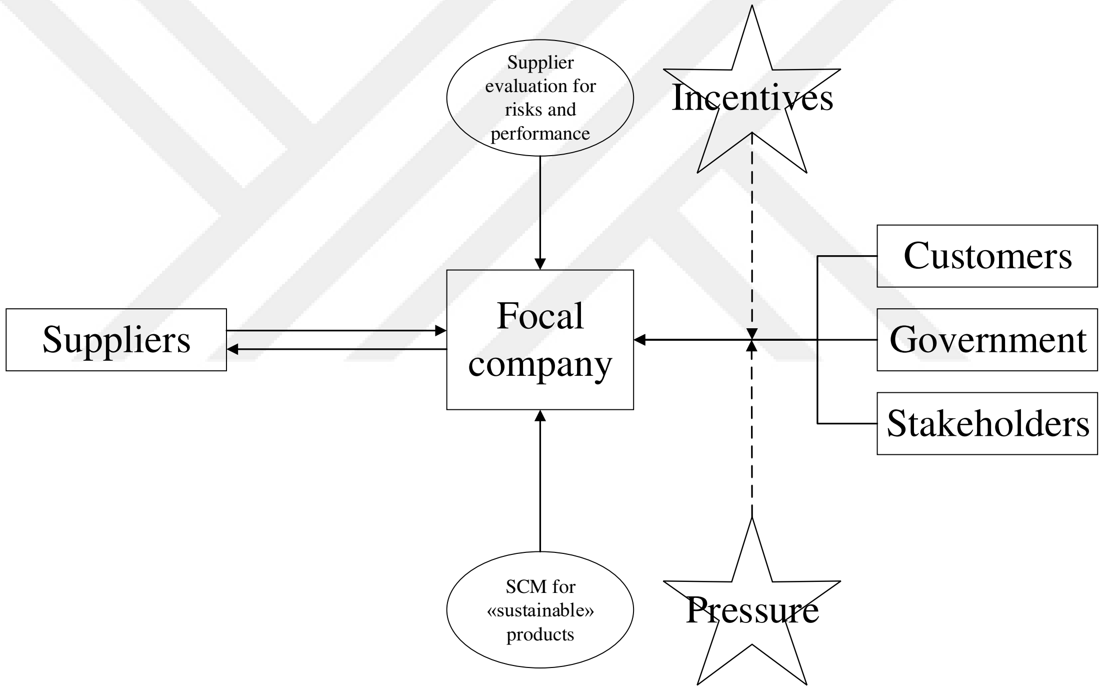


Figure 2.7. Triggers for Sustainable Supply Chain Management

Source: From A Literature Review to A Conceptual Framework for Sustainable Supply Chain Management (Seuring & Müller, 2008)

Top management commitment, supportive culture, and involvement of employees can be counted as the internal enablers. External enablers are mostly related to adopting an environmental management system. Through these systems, organizations can cooperate with suppliers. On the other hand, the success of such systems mostly depends on top management support, cross-functional teams, enhanced communication, and a win-win situation. Otherwise, managers may come across barriers instead of enablers (Özçelik & Avcı Öztürk, 2014).

Barriers that supply chain managers may face in sustainable supply chain activities range from lack of supportive corporate structures and processes, lack of management commitment, and traditional accounting methods, price pressure from consumers to competitive pressure (Ageron vd., 2012). Moreover, lack of official and government intervene, lack of commitment from supplier side, sector type, material prices, manufacturing capacity, supply chain configuration and location are the additional barriers that prevent supply chains from achieving sustainability goals (Seuring & Müller, 2008).

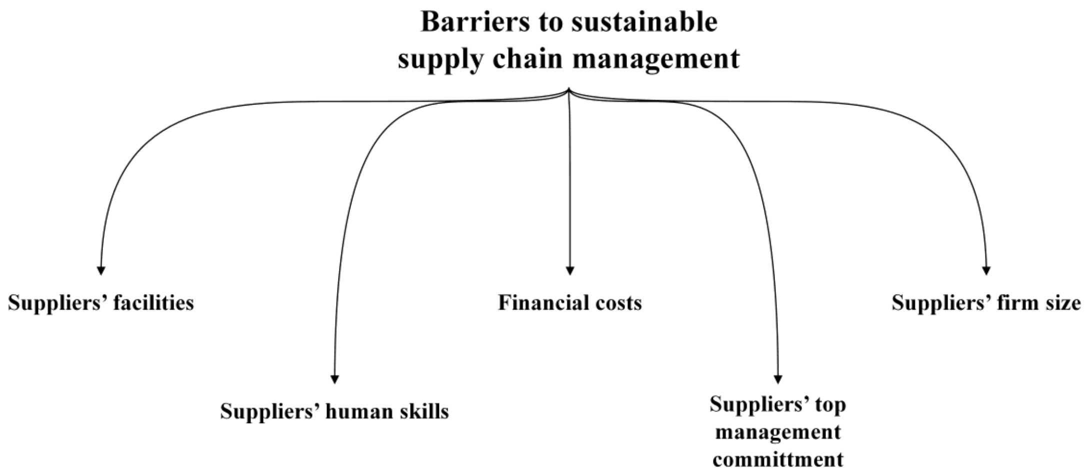


Figure 2.8. Barriers to sustainable supply chain management
Source: From A Literature Review to A Conceptual Framework for Sustainable Supply Chain Management (Seuring & Müller, 2008)

Figure 2.8 summarizes the antecedents of barriers that undermine the sustainability performance of supply chains. The first antecedent is suppliers' facilities regarding information and technology infrastructure. This infrastructure is necessary for catalyzing the sustainability activities during various phases of product life-cycle (Zhu & Geng, 2013). Thus, the resistance on adoption of technology by workers may constitute a significant barrier. To overcome such a barrier, innovation must be a part of organization culture and this culture has to encourage the entrepreneurs from inside the corporation who attempt to bring technological novelties.

In this sense, suppliers' human skills are perhaps the most important factor for reaching the sustainability targets. Without efficient skills, individuals cannot initiate innovation towards change. Thus, poor knowledge is a remarkable pitfall on sustainability. To overcome this, organizational learning must be a part of organizational culture, similarly. On the basis on former performance and future requirements, training programs and educative activities can be organized (Zhu & Geng, 2013).

However, constituting such training programs and adopting technology requires sharing financial funds from budget. Since the net benefit of those investments are not concrete and only comes up in long term, upper-echelon managers and leaders may not willing to adopt those activities. Particularly when the economic crisis happen, or the company come across a bottleneck in the industry, financial costs of such activities irritate some leaders. So, they tend to diminish such expenses. Therefore, financial costs is one of the major barriers in front of sustainability goals.

In order to keep continuing on sustainability activities during harsh conditions, suppliers' top management commitment is the indispensable factor. Top managers determine long-term strategies for the organization. These strategies shed light on department managers and seniors to make decisions align with finding the global optimum. Therefore, suppliers' top management commitment is the significant point of sustainable strategies.

The last pitfall is regarding the size of organization. The organizational structure of SMEs are rather flexible than the big ones. This feature brings some advantages such as the capability of focusing on niche markets, yet it does not allow corporations to adopt many of sustainability activities because of scale economy concern (Gupta & Barua, 2017).

3. SUSTAINABLE SUPPLIER EVALUATION

In this chapter, we explain why we need supplier evaluation and the ANP technique, taking from the roots of multi criteria decision making methodology.

3.1 The Need for Supplier Evaluation and Selection

Every day, human-being make numerous decisions. Either consciously or not, some of those constitute turning points in the lifespan, such as marriage, school or job decisions. Quality of life mostly depends upon how perfectly the decisions meet the existing needs and overlap with the long-term goals.

Not only individuals but organizations also make crucial decisions. Supplier selection, for example, is the key point for achieving the competitive strategy of a manufacturer. A cost-leadership seeker concerns the monetary performance of the suppliers, whereas a lean manufacturer search for the flexible suppliers who align with the just-in-time replenishment policy. A retailer expects velocity from the food supplier for the products which have a shorter shelf life, while a chemical manufacturer underlines the sustainability criteria to overcome the supply side risks that may cause huge damages.

However, it is incrementally difficult to make optimal decisions for managers because of today’s volatile and turbulent business environment. Tradeoff between the criteria such as quality and cost leads the decision makers’ benefit from the quantitative methods for coping with the contradictions. In this sense, multi criteria decision making (MCDM) is a research field where supportive tools are developed and served for users.

3.2 MCDM and Its Techniques

Various techniques are used in decision analyses. Figure 3.1 shows the classification of decision analysis techniques. Among these techniques MCDM techniques take a special part and are widely used in selection problems. Gök (2006) defines MCDM as a process where the decision maker tries to opt the most beneficial choice across tangible and intangible variables using scientific methodology. Along with the past research, a number of MCDM methods hybridize with ANP and ANP, such as TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), PROMETHEE, ELECTRE, etc (Kafa, et al. 2018; Phochanikorn & Tan, 2019; Shen, et al. 2013; Sipahi & Timor, 2010).

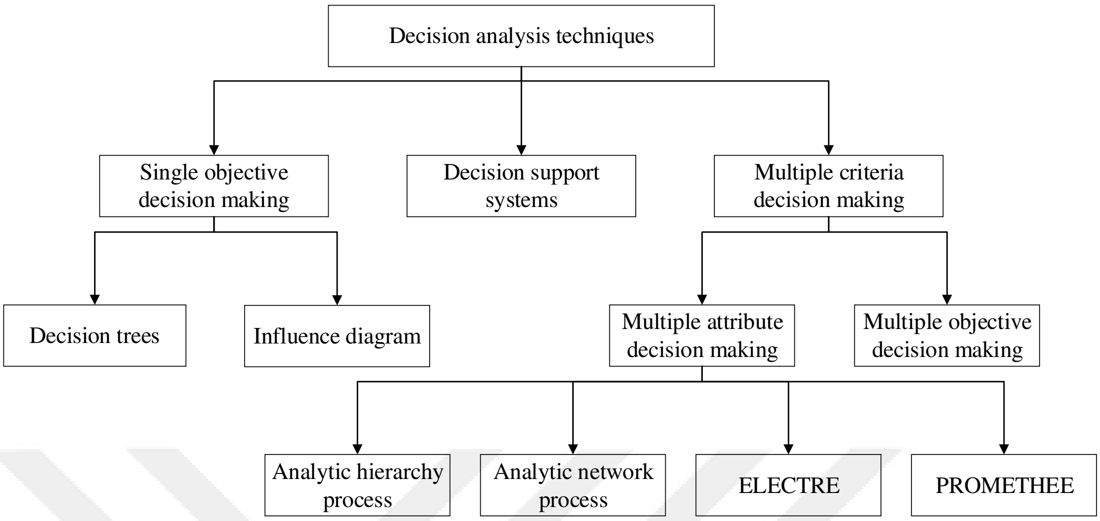


Figure 3.1. Classification of decision analysis techniques

Source: Decision Analysis in Energy and Environmental Modeling (Zhou, Ang, & Poh, 2006)

We can summarize the general purposes of MCDM methods as follow (Coşkun, 2015):

- Analyzing complex and totally difficult issues,
- To carry out the decision making processes systematically,
- To establish a transparent and accountable management model,
- To spread systematic thinking in the decision-making process in the public sector,
- Creating a common platform, facilitating communication and enabling negotiations in an environment with multiple decision makers,
- Combining the expert opinions required in the criterion evaluations of alternatives with the subjective evaluations of decision makers,
- Considering huge amounts of scattered data

MCDM methods are widely used in the problems of the political field, strategy determination, consumer preference, performance evaluation, warehouse location selection, supplier selection in communication systems, evaluation of university education quality, analysis of transformational leadership perspective and so on (Sipahi & Timor, 2010).

Although these methods are applied in different fields, the decision processes they use are similar. Accordingly, the decision problem must first be determined. At this stage, the problem situation should be clearly defined and the elements related to the decision problem should be revealed. Thus, it is determined what the problem covers and what affects the final goal. After determining the constraints for the purpose, it is time to establish the decision model. Then alternatives are determined. Thus, alternative solutions are obtained by evaluating these alternatives in the decision model (Coşkun, 2015).

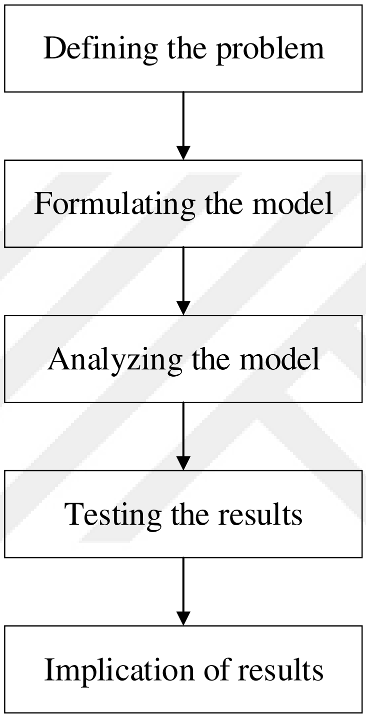


Figure 3.2. Problem solving steps across the decision process
Source: Analitik Hiyerarşi Prosesi (Timör, 2011)

The most frequently used MCDM techniques are AHP (Analytic Hierarchy Process), ANP (Analytic Network Process), Electre (Elimination and Choice Translating Reality), and Promethee (Preference Ranking Organization Method for Enrichment Evaluation). Detailed information about AHP and ANP is given in the following sections.

In this study, we use ANP methodology to attain the criteria weights and obtain the performance rank. We combine the ANP with the K-Means clustering algorithm. The main reason why we do so is that ANP is the unique MCDM technique that allows for modeling the network base interdependencies among the criteria. According to the sight we obtain from the literature review, this is the first study that both methodology is hybridized on the supplier selection problems. One can note that AHP is a simpler type of ANP, by a linear tree structure of hierarchies. Yet, the majority of mathematical basis are same for both methodology. ANP only has some more details above the AHP. Therefore, we prefer first explaining the AHP, and then we keep going with ANP with redundant details.

3.3 AHP

Analytical Hierarchy Process (AHP) is a multi-criteria decision making method developed by Thomas L. Saaty. The history of the method goes back to the 1970s. For the last few couple of decades, AHP has been widely adopted by business management community thanks to its applicability on everyday-life problems as well as robust mathematical structure (Saaty, 2004).

The structure of AHP consists of a main objective, criteria, sub-criteria, and alternatives. The gist of AHP depends on that it attains relative importance values to evaluation criteria. Either tangible or intangible, evaluation criteria are ranked according to the main objective. Then, we can make sure if the rank of criteria is logically coherent by judging the consistency ratio (CR). Management scientists have been appreciating this opportunity in their research since the early 21st century. Because thanks to this opportunity, many kinds of tradeoff situations could analytically be handled (Coşkun, 2015).

AHP basically consists of 4 main steps (Timör, 2011):

- Establishing a hierarchical structure,
- Pairwise comparisons,
- Calculation of consistency,
- Calculation of priority values of alternatives.

Subsequently, we elaborate each of these steps with mathematical foundations.

3.3.1 Establishing a Hierarchical Structure

The first task in the AHP is establishing the hierarchical structure according to the goal.

In order for the problem to be solved correctly, the purpose should be set out as clearly as possible. This determined goal is at the top of the hierarchy. In the second stage, the criteria are embedded into the model. These criteria stand for the reference units that the performance scores are calculated against. In the third stage, there are sub-criteria that will be placed under each criterion. Finally, decision alternatives are at the bottom of the hierarchy.

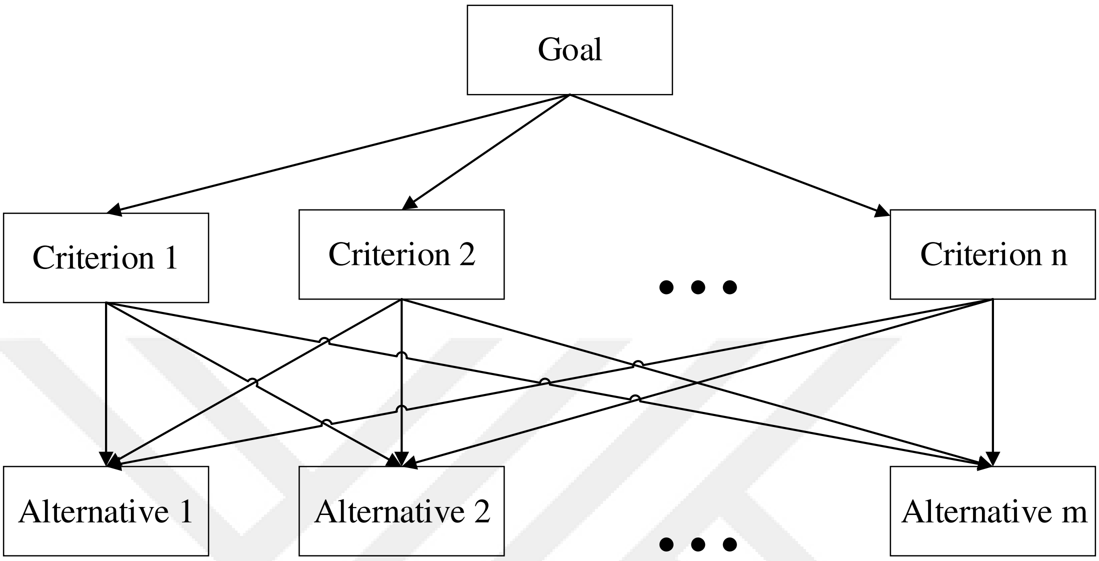


Figure 3.3. Hierarchy structure

Source: Analitik Hiyerarşi Prosesi (Timör, 2011)

3.3.2 Pairwise Comparison and Determining the Priorities

After creating the hierarchical structure, the next step is determining the priorities of the criteria. This is the most important part of AHP algorithm. Let m is the number of criteria, each R_i and R_j in $P = [p_{ij}]$ is a square matrix that contains the comparisons of criteria with each other for $(i, j = 1,2, \ldots, m)$. Considering P is and inverse-symmetric such as $p_{ij} = {}^{1}/_{p_{ji}}$ the relationship between the matrix elements is as follow:

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1m} \\ p_{21} & p_{22} & \cdots & p_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mm} \end{bmatrix} = \begin{bmatrix} {}^{w_1}/_{w_1} & {}^{w_1}/_{w_2} & \cdots & {}^{w_1}/_{w_m} \\ {}^{w_2}/_{w_1} & {}^{w_2}/_{w_2} & \cdots & {}^{w_2}/_{w_m} \\ \vdots & \vdots & \ddots & \vdots \\ {}^{w_m}/_{w_1} & {}^{w_m}/_{w_2} & & {}^{w_m}/_{w_m} \end{bmatrix} \quad (3.1)$$

Table 3.1 shows the standard priority scale (Saaty, 2001; p.73). According to this scale, decision makers attain importance scores for each criteria comparisons.

Table 3.1. Standard Priority Scale

Importance Rate	Definition	Explanation
1	Equally important	The two activities contribute equally to the goal.
3	One has moderate important than the other.	Experience and judgment favor one activity over another moderately.
5	Strongly important	Experience and judgment make a strong preference for one activity over another.
7	Very strongly important	An activity is strongly favored and its dominance is readily apparent in practice.
9	Absolutely important	The evidence for choosing one activity over another has tremendous credibility.
2,4,6,8	Intermediate values	Falls within the intervals listed above to be used when reconciliation is required.

In an ideal inverse symmetric matrix, for example, if the first object is 5 times superior than the second, the second is also 1/5 times inferior than the first. In this case, there should be a proportional relationship between any two rows or columns of the matrix as follow.

$$\frac{p_{i1}}{p_{i2}} = \frac{\frac{w_i}{w_1}}{\frac{w_i}{w_2}} = \frac{w_2}{w_1} \tag{3.2}$$

Calculating the importance of criteria is the next step after creating the P matrix. This is done by using eigenvector. Accordingly, the matrix is normalized by dividing all the elements in any column by the sum of the column. Then the average of the row totals is taken. Thus, the eigenvector of the P matrix is obtained.

The column vector m is obtained after repeating the above process for each evaluation criterion. Through the combination of all vectors, the C matrix is obtained as follow.

$$C = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1m} \\ c_{21} & c_{22} & \cdots & c_{2m} \\ \vdots & \vdots & & \vdots \\ c_{m1} & c_{m2} & \cdots & c_{mm} \end{bmatrix} \tag{3.3}$$

Now the arithmetic average of the row components that make up the C matrix is taken and the column vector called the "priority vector" is obtained.

$$w_i = \frac{\sum_{i=1}^{m} c_{ij}}{m} \tag{3.4}$$

Hence, $\vec{w}$ column vector is obtained, that represents the criteria weightings.

$$\vec{w} = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_m \end{bmatrix} \tag{3.5}$$

3.3.3 Calculation of Consistency

One can appreciate that the gist of weightings mostly derive from judgemental decisions. For this reason, the consistency between the transactions must be convenient prior to further analysis.

In order to compute the consistency ratio (CR), AHP offers a solution. Initially, the P_{m*m} matrix is multiplied with the $\vec{w} = (w_1, w_2, \ldots, w_n)^T$. Hence, we obtain the following equation.

$$P\vec{w} = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1m} \\ p_{21} & p_{22} & \cdots & p_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mm} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_m \end{bmatrix} = \begin{bmatrix} {w_1}/{w_1} & {w_1}/{w_2} & \cdots & {w_1}/{w_m} \\ {w_2}/{w_1} & {w_2}/{w_2} & \cdots & {w_2}/{w_m} \\ \vdots & \vdots & \ddots & \vdots \\ {w_m}/{w_1} & {w_m}/{w_2} & \cdots & {w_m}/{w_m} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_m \end{bmatrix} =$$

$$\begin{bmatrix} mw_1 \\ mw_2 \\ \vdots \\ mw_m \end{bmatrix} = m \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_m \end{bmatrix} = m\vec{w} \tag{3.6}$$

In this equation, from the $P\vec{w} = \lambda\vec{w}$ we set $P = \lambda$ is the eigenvalue and $\vec{w}$ is the eigenvector. The m is the size of vector, namely the number of criteria.

Let, λ_{max} is the maximum eigenvalue of $\vec{w}$ weight vector. Then,

$$P\vec{w} = \lambda_{max}\vec{w} \tag{3.7}$$

According to Saaty (2001), $\lambda_{max} > m$ for the maximum eigenvalue of m size inverse symmetric matrix. However, in case of absolute consistency, we see that $\lambda_{max} = m$ situation. Thus, $\lambda_{max} - m$ is the measure of consistency.

In order to accept the consistency between the criteria, the Consistency Ratio should be smaller than 0,1. Otherwise, we cannot ensure the reliability of results (Saaty, 2006). The Consistency Ratio (CR) is calculated as follow.

- The total weight of the elements in the column is calculated for each row of the comparison matrix,
- Dividing the element in each column of the matrix by the total weight, the "normalized matrix" is obtained,
- The "vector of priorities" is calculated by taking the average of each row of the normalized matrix,
- After the priority vector is calculated, the resulting vector is multiplied by the comparison matrix given initially, and the "all priorities matrix" is calculated,
- The consistency index CI is calculated according to the formula:

$$CI = (\lambda_{max} - n)/(n - 1) \tag{3.9}$$

- The following formula is used when calculating the consistency ratio CR:

$$CR = \frac{CI}{RI} \tag{3.10}$$

RI is an index of random values selected according to the table below.

Table 3.2. Random Value Index (Saaty, 2006; p.65)

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

3.3.4 Calculation of Priority Values of Alternatives

Pairwise comparison matrices are used to determine the priority values of the options, just like criteria weighting. This time, the relative priorities of the alternatives are determined by comparing them separately for each criterion. Thus, comparisons are made as much as the number of criteria. After each comparison, a 1-dimensional S vector is obtained, showing the priorities (percent values) of the alternatives over a certain criterion.

$$S_i = \begin{bmatrix} s_{11} \\ s_{21} \\ \vdots \\ s_{m1} \end{bmatrix} \tag{3.11}$$

In the phase of determining the final priorities, firstly, the $m * n$ dimensional K decision matrix consisting of the n piece $m * 1$ dimensional S column vectors mentioned above is created.

$$K = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n} \\ s_{21} & s_{22} & \cdots & s_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ s_{m1} & s_{m2} & \cdots & s_{mn} \end{bmatrix} \tag{3.12}$$

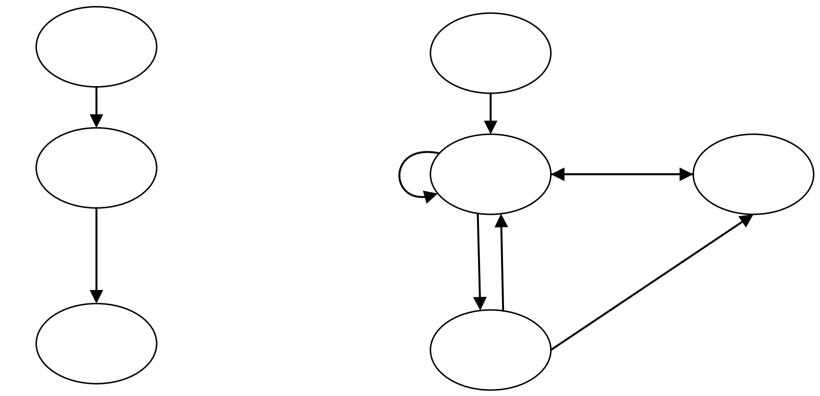
As a result, by multiplying the K decision matrix with the $\vec{w}$ criterion weight vector, a column vector with m elements containing the priority values of the alternatives is obtained. The element with the greatest value represents the best alternative.

$$R = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n} \\ s_{21} & s_{22} & \cdots & s_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ s_{m1} & s_{m2} & \cdots & s_{mn} \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} R_{11} \\ R_{21} \\ \vdots \\ R_{m1} \end{bmatrix} \tag{3.13}$$

Optionally, sensitivity analysis can be performed after the final ranking among the alternatives has been obtained. Sensitivity analysis is performed to see how the ranking is affected by the change in criterion weights in the model. If the change in a criterion affects the optimum solution obtained among the alternatives, it is concluded that the sensitivity of the model in that criterion is high (Coşkun, 2015).

3.4 ANP

Hierarchical models represent the acyclic relationships that the influences flow towards a single direction. For example, considering a manufacturer evaluating the supplier with respect to quality and cost, there is only one direction from quality to cost. That is, the more quality the higher costs. However, there may also be mutual relations in some cases. Let’s the manufacturer evaluate the suppliers with respect to quality and flexibility, instead of cost. In this case, there is a reciprocal relationship between the quality and flexibility just as they influence each other. For such cases, the network model instead of a hierarchical one may come up the goal more clearly. The ANP methodology is used for such situations.



AHP Structure ANP Structure

Figure 3.4. Difference between the AHP and ANP structures

Source: Analitik Hiyerarşi Prosesi (Timör, 2011)

The "effect" is the underlying concept of ANP. In case of one component is effecting another component in a network structure indicates that there is external dependence. Whereas, if there is a bidirectional arrow between the two components, it indicates that there is an interdependence or feedback between those two components. Figure 3.4 explains the difference between two structures.

Below, we are going to introduce the ANP steps (Baynal & Yüzügüllü, 2013).

- Defining the Decision Problem and Creating the Model Structure: In the first stage of the method, the criteria, sub-criteria and alternatives that will lead the decision maker to the results are determined. Then, it is necessary to create a network structure that shows the interaction of all elements that make up the model. Interactions between criteria are determined. Internal and external dependencies and feedback between criteria are associated.
- Binary Comparisons between Criteria and Calculation of Priority Vectors: After determining the alternatives, criteria and sub-criteria, paired comparison matrices should be created to determine the priority vector of the criteria and sub-criteria among themselves. This is the same process of AHP in section 2.2.2. Pairwise comparisons and determining the priorities.
- Calculating Consistency: At this stage, the "consistency ratio" (CR) is found for each matrix to see if the decision maker is consistent when making comparisons

between criteria. This consistency ratio of 0.10 or less is considered sufficient. If the consistency rate obtained as a result of the calculation is above the acceptable limit of 0.1, the evaluations should be renewed, the structure and process should be reviewed and the work carried out up to this stage should be repeated.

- Constructing the Unweighted Supermatrix: The "supermatrix" method has been developed to include all interactions between components and elements (criteria, sub-criteria, alternatives) in the calculation in determining the superiority in feedback systems. The supermatrix is generally a square matrix consisting of superiority vectors obtained from all possible binary comparisons in the network structure. If all elements in one set do not affect elements in another set, their effects are shown by giving zero values to the supermatrix. In the established mesh model, all items are displayed vertically on the left side of the matrix and horizontally on the top of the matrix.
- Creating Weighted Supermatrix: Although the column sum of each of the unweighted supermatrix's blocks is one, the supermatrix itself is not stochastic. So column totals are greater than one. The matrix must be stochastic in order to perform solution-oriented operations on the unweighted supermatrix. To ensure that the supermatrix is stochastic, the components are weighted according to their effect on each column of blocks. For this purpose, row components with non-zero elements in a column's block are compared according to their effect on the component in that column. Then, the weighted supermatrix is obtained by multiplying each block by the eigenvector coefficient corresponding to the components in that row. Thus, the sum of each of the columns of the supermatrix obtained will be equal to one. So the columns of the matrix will be normalized.
- Creating the Limit Supermatrix: To achieve global priorities in a system with interdependent effects, local priority vectors are allocated to the columns of a matrix known as the supermatrix. The relative long-term effects of the criteria on each other are determined by taking the strength of the supermatrix. Since the weighted supermatrix is a stochastic matrix, it has the property of convergence. The power of the super matrix (2n + 1) is taken to ensure the significance weights are equalized at one point. Here n is a randomly chosen large number. The resulting new matrix is called the limit supermatrix.

- Choosing the Best Alternative: With the obtained limit supermatrix, importance weights of alternatives and criteria are determined. The alternative, which has the highest importance in the selection problem, is the best alternative, and the criterion, which has the highest importance in the weighting problem, is the most important criterion that affects the decision process (Baynal & Yüzügüllü, 2013).

3.5 Literature Review

To release the current literature, we conduct a review on Web of Science Core Collection database. Entering the keywords of "supply chain management", "sustainability", "supplier evaluation", "Analytic Network Process"; we access 21 research papers. The publication year of those papers range from 2011 to 2020. Yet, the density of papers stack on the 2017-2020 interval.

Figure 3.5 indicates the journals and the number of studies published in those journals. As it is seen, Journal of Cleaner Production, International Journal of Production Economics and Sustainability are the prominent journals in this research field.

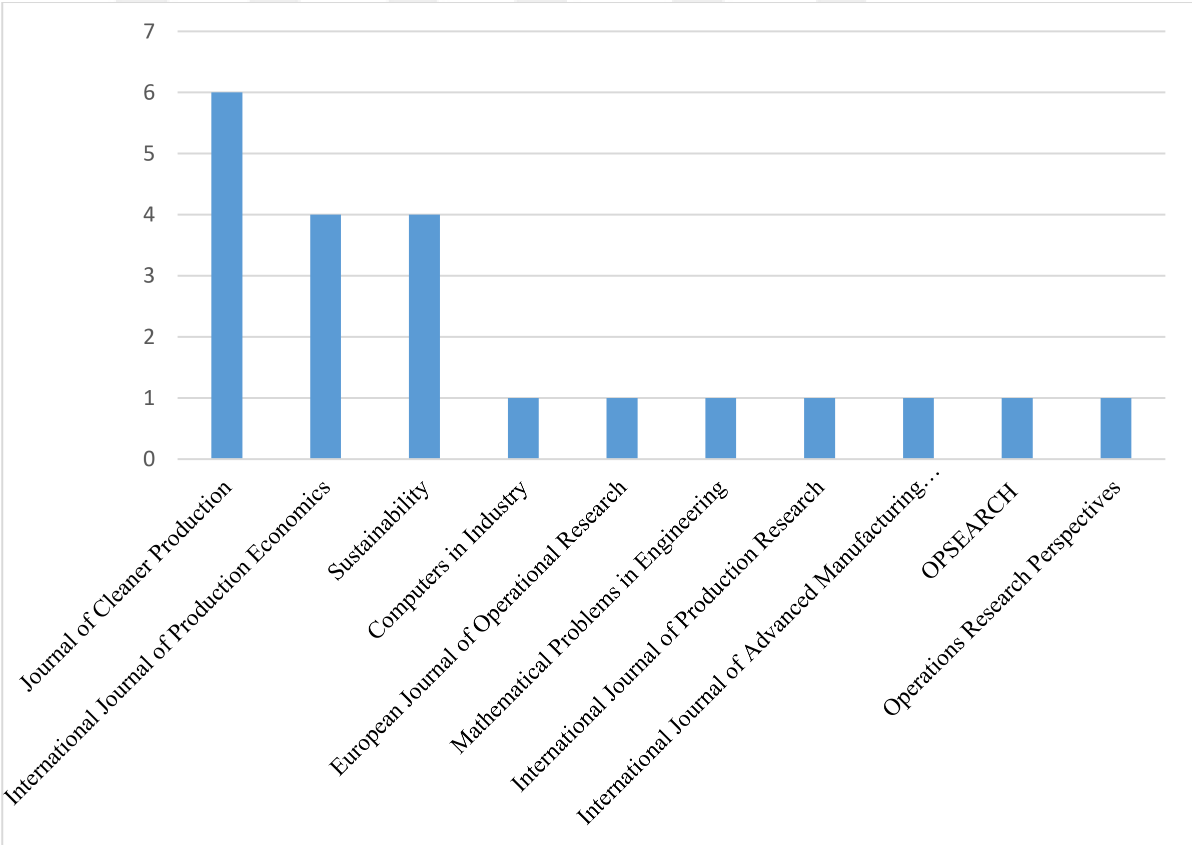


Figure 3.5. Number of Published Papers According to Journals

Table 3.3 shows the general features of these studies and summarizes the literature. In this table, along with authors, title and journal information, it is seen that which methods the ANP is hybridize with, and the keywords that provide insight on overall purpose of the study.

Table 3.3. Literature Review on Sustainable Supplier Evaluation with ANP

No	Authors	Title	Journal	Keywords
1	(Giannakis, Dubey, Vlachos, & Ju, 2020)	Supplier sustainability performance evaluation using the analytic network process	Journal of Cleaner Production	Analytical network process; Sustainability performance; Sustainable supplier selection
2	(Tirkolaee, Mardani, Dashtian, Soltani, & Weber, 2020)	A novel hybrid method using fuzzy decision making and multi-objective programming for sustainable-reliable supplier selection in two-echelon supply chain design	Journal of Cleaner Production	Fuzzy ANP; Fuzzy DEMATEL; Fuzzy TOPSIS; Reliable supply chain; Sustainable supplier selection; Weighted goal programming
3	(Chowdhury, Paul, Sianaki, & Quaddus, 2020)	Dynamic sustainability requirements of stakeholders and the supply portfolio	Journal of Cleaner Production	Dynamic optimization; Fuzzy analytical hierarchy process; Multi-criteria; Quality function deployment; Stakeholders; Supplier selection; Sustainability
4	(Gülçin Büyüközkan & Çifçi, 2011a)	A novel fuzzy multi-criteria decision framework for sustainable supplier selection with incomplete information	Computers in Industry	Analytic network process; Fuzzy logic; Incomplete preference relations; Supplier selection; Sustainable supply chain
5	(Sarkis, Meade, & Presley, 2012)	Incorporating sustainability into contractor evaluation and team formation in the built environment	Journal of Cleaner Production	AHP; ANP; Built environment; Supplier selection; Supply chain management; Sustainability
6	(Theißen & Spinler, 2014)	Strategic analysis of manufacturer-supplier partnerships: An ANP model for collaborative CO2 reduction management	European Journal of Operational Research	Analytic network process; Decision support systems; Environment; Multiple criteria analysis; Supply chain management
7	(Hashemi, Karimi, & Tavana, 2015)	An integrated green supplier selection approach with analytic network process and improved Grey relational analysis	International Journal of Production Economics	Analytic network process (ANP); Environmental sustainability; Green supply chain management (GSCM); Grey theory; Improved Grey relational analysis (GRA); Supplier selection
8	(Mahdiloo, Saen, & Lee, 2015)	Technical, environmental and eco-efficiency measurement for supplier selection: An extension and application of data envelopment analysis	International Journal of Production Economics	Data envelopment analysis; Eco-efficiency; Multiple objective linear programming (MOLP); Supplier evaluation; Undesirable output

9	(Wang Chen, Chou, Luu, & Yu, 2016)	A Fuzzy MCDM Approach for Green Supplier Selection from the Economic and Environmental Aspects	Mathematical Problems in Engineering	-
10	(Zimmer, Fröhling, & Schultmann, 2016)	Sustainable supplier management - A review of models supporting sustainable supplier selection, monitoring and development	International Journal of Production Research	decision support systems; evaluation criteria; literature review; purchasing; supplier selection; sustainability
11	(Luthra, Govindan, Kannan, Mangla, & Garg, 2017)	An integrated framework for sustainable supplier selection and evaluation in supply chains	Journal of Cleaner Production	AHP; Indian automobile industry; Supply chains; Sustainability; Sustainable supplier selection; VIKOR
12	(Mavi, Goh, & Zarbakhshnia, 2017)	Sustainable third-party reverse logistic provider selection with fuzzy SWARA and fuzzy MOORA in plastic industry	International Journal of Advanced Manufacturing Technology	Fuzzy multi-objective optimization on the basis of; Fuzzy step-wise weight assessment ratio analysis (; Risk; Supply chain management (SCM); Sustainable reverse logistics; Third-party reverse logistic provider (3PRLP)
13	(Mendoza-Fong, García-Alcaraz, Díaz-Reza, Diez Muro, & Fernández, 2017)	The role of green and traditional supplier attributes on business performance	Sustainability	Commercial benefits and green attributes; Structural equations model; Supplier selection; Traditional attributes
14	(Kannan, 2018)	Role of multiple stakeholders and the critical success factor theory for the sustainable supplier selection process	International Journal of Production Economics	ANP; COPRAS-G; Critical success factor; Fuzzy Delphi; ISM; Multi criteria decision making; Stakeholder theory; Sustainable supplier selection; Triple bottom line
15	(Awasthi, Govindan, & Gold, 2018)	Multi-tier sustainable global supplier selection using a fuzzy AHP-VIKOR based approach	International Journal of Production Economics	Fuzzy AHP; Fuzzy VIKOR; Global supply chain management; Multi-criteria decision making; Multi-tier suppliers; Risk mitigation; Sustainable supplier selection
16	(Kafa, Hani, & El Mhamedi, 2018)	Evaluating and selecting partners in sustainable supply chain network: a comparative analysis of combined fuzzy multi-criteria approaches	OPSEARCH	AHP; Comparative study; PROMETHEE; Partner selection; Sustainable supply chain; TOPSIS; Triple bottom line approach
17	(Gören, 2018)	A decision framework for sustainable supplier selection and order allocation with lost sales	Journal of Cleaner Production	Fuzzy DEMATEL; Lost sales; Optimization; Order allocation;

				Sustainable supplier selection; Taguchi loss function
18	(Lu, Jiang, Song, & Ming, 2018)	A rough multi-criteria decision-making approach for sustainable supplier selection under vague environment	Sustainability	ELECTRE; Rough set theory; Supplier selection; Sustainability; Vague information
19	(Yadavalli, Darbari, Bhayana, Jha, & Agarwal, 2019)	An integrated optimization model for selection of sustainable suppliers based on customers' expectations	Operations Research Perspectives	Customer sustainable expectations; FTOPSIS; Goal programming; Supplier selection; Z-numbers
20	(Konys, 2019)	Green supplier selection criteria: From a literature review to a comprehensive knowledge base	Sustainability	Criteria for green supplier selection and evaluati; Green supplier selection; Knowledge capturing and handling; Ontology
21	(Phochanikorn & Tan, 2019)	A new extension to a multi-criteria decision-making model for sustainable supplier selection under an intuitionistic fuzzy environment	Sustainability	Intuitionistic fuzzy set; Multi-criteria decision-making; Sustainable development; Sustainable supplier selection; Sustainable supply chain management

The study of Giannakis, Dubey, Vlachos, & Ju (2020) provide a fundamental guidemap to our study. This study rule out the silo approach in supplier evaluation and selection. Instead, a holistic approach is suggested including financial, environmental and social aspects of sustainability. Inter-relationships between the metrics are structured by the ANP methodology.

Tirkolaee, Mardani, Dashtian, Soltani, & Weber (2020) points out the reliability and sustainability together, to increase customer satisfaction. To achieve this, a three-level of supply chain is designed by means of order size identification, and order allocation.

Chowdhury, Paul, Sianaki, & Quaddus (2020) suggests a methodology to build a supply portfolio taking the variety of stakeholders' expectations into account. Based on dynamic capability theory, multi-phased quality function deployed in the framework of European apparel industries. A dynamic programming approach is combined with multi-criteria decision making methodology.

Gülçin Büyüközkan & Çifçi (2011a) offers a methodology based on multi-criteria decision making for supplier selection operations. Time pressure, lack of expertize and incomplete preference relations are the main issues of this study.

Sarkis, Meade, & Presley (2012) introduces a model for the subcontractor selection problem in the team formation framework in construction industry. The triple-bottom line forms the criteria for AHP and ANP methodology.

Theißen & Spinler (2014) introduce a decision-making framework to struggle against carbon emission problem in manufacturer industry. A collaborative CO2 emission reduction is aimed at fast moving consumer goods industry.

Hashemi, Karimi, & Tavana (2015) examines the purchasing practices of fashion and apparel industries in terms of sustainability criteria. Results indicate which criteria are respected most from social, economical and environmental perspectives. Also, some new criteria are proposed such as housing conditions and home working conditions.

Mahdiloo, Saen, & Lee (2015) criticise the existing models in the literature as they are computationally so intensive that they cannot produce utility in practice. So, a less intensive framework is offered decomposing efficiency indicators in terms of technical, environmental and eco-efficiency scores.

Wang Chen, Chou, Luu, & Yu (2016) propose a framework for selecting the green suppliers based on economic and environmental criteria. Fuzzy ANP and TOPSIS methods are used for ranging the potential suppliers. The proposed methodology is applied in Luminance Enhancement Film (LEF) industry.

Zimmer, Fröhling, & Schultmann (2016) conduct a content analysis after literature review to illustrate the methodologies used in supporting decision-making in sustainable supplier selection, monitoring and development.

Luthra, Govindan, Kannan, Mangla, & Garg (2017) develope a sustainability-focused supplier evaluation system. In this sense, 22 sustainable supplier selection criteria and three dimensions of criteria are determined. Results show that Environmental costs,' 'Quality of product,' 'Price of product,' 'Occupational health and safety systems,' and 'Environmental competencies' have been ranked as the top five sustainable supplier selection criteria.

Mavi, Goh, & Zarbakhshnia (2017) evaluate the third-party logistics service providers according to reverse logistics activities, sustainability and risk factors in plastic industry. Finding indicate that quality, recycling, health, and safety were the most important criteria in economic, environmental, and social dimensions of sustainability,

Kannan (2018) improve a decision support system based on critical success factors theory by considerin multi-stakeholders' view in a real-world textile industry. Factors are categorized like maintaining long-term relationships and alliances, stakeholder empowerment, equity labour sources, and individual human rights. Respondents are ranked in accordance with these criteria.

Awasthi, Govindan, & Gold (2018) propose a managerial decision making tool for companies to assess their suppliers with respect to sustainability criteria. In this study, sustainability issue is seen as a risk source. Fuzz AHP and fuzzy VIKOR methods are used for the analysis. Among economic, quality, environment, social, and global risk criteria, it is found that the global risk has the weakest weight.

(Kafa vd., 2018) offers a hybrid methodology based on fuzzy multi criteria decision making methods to improve the overall performance of supply chains. The proposed methodology is implemented in light bulbs recycling.

Gören (2018) presents a framework for the problem of order allocation and sustainable supplier selection. A three-stage methodology is developed and integrated in the case study.

Lu, Jiang, Song, & Ming (2018) underlines that sustainability topic involves subjectivity and vagueness. Thus, using rough set theory, this paper combines the ELECTRE method and sustainable supplier selection indicators. The proposed methodology is applied in solar-air conditioner manufacturer.

Konys (2019) conduct a bibliometric and meta analysis to capture the knowledge basis of sustainable supplier selection. Since, choosing the optimal green supplier has a multi-dimensional structure, this study offers a deep insight on green supply chain management.

Phochanikorn & Tan (2019) yields from intuitionistic fuzzy set theory (IFS) with a decision making trial and evaluation laboratory (DEMATEL) combined with an analytic network process (ANP) to determine uncertainties and interrelations among indicator as well as analyzing the criteria weights. The proposed framework is studied under sustainable supplier selection context.

Upon arrival to the current point, we conclude that our study fills an important gap in the literature as such combining a digital web portal and ANP methodology to assess supplier performance on the basis of sustainability theory. Furthermore, this might be the first study that hybridize the ANP with K-Means algorithm in that obtaining proper performance segments.

4. DEVELOPING NEW SUSTAINABLE SUPPLIER EVALUATION METRICS AND IMPLEMENTING AN EVALUATION PORTAL TO IMPROVE SUPPLIER PERFORMANCE

In this chapter, we conceptualize the proposed methodology as follows.

4.1 The Aim and Importance of the Study

The aim of this study is to develop a sustainability performance assessment framework for supplier evaluation and selection, based on ANP methodology. The proposed framework is then applied in a company which actively pursue sustainability strategies. In this implementation, the ANP is combined with a web portal so that the focal company receives the information shared by suppliers regarding the sustainability metrics. Thus, such real time evaluation framework distinguishes this study from the existing literature.

4.2 Limitations of the Study

The main limitation of this study is that the ANP methodology reduce the difference between the criteria weights when the number of criteria increase. Since there are 14 main criteria on the proposed model, the power of interdependencies may weakened.

4.3 Problem Statement

The aim of this study can be expressed by the research questions as follow.

Q1: What are the sustainability indicators that a company ought to pursue for supplier evaluation?

Q2: How the sustainability indicators can be prioritized according the main strategy of a company?

Q3: How can the suppliers be evaluated in a real time manner?

4.4 Methodology

In this section we present how to use the supplier evaluation model that we developed in this study.

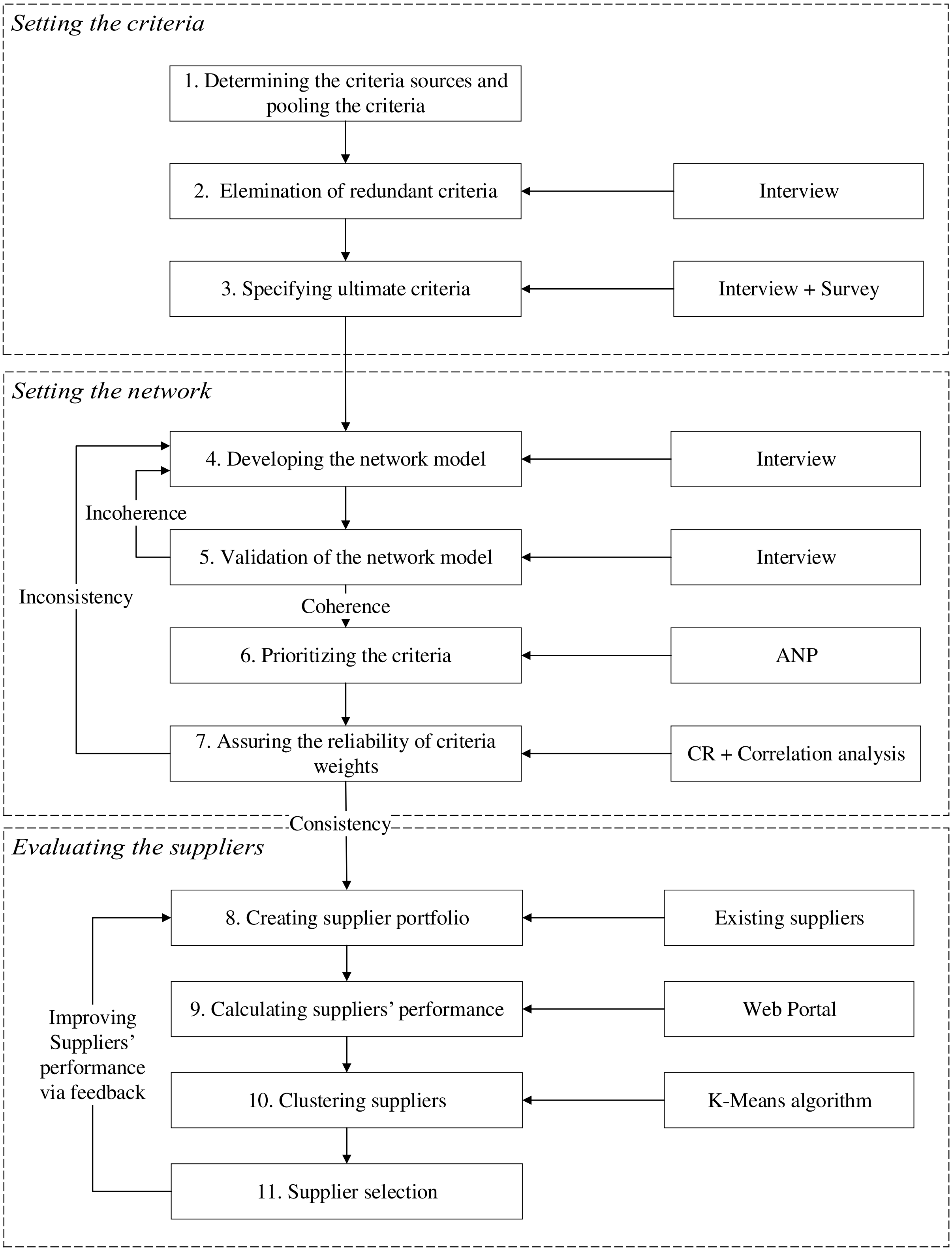


Figure 4.1. Proposed model

Scientific models are the systems that imitate the real world. Since it is very expensive to manipulate the variables on reality, researchers work on conceptual models. There are two types of scientific models that are descriptive and normative. Descriptive models aim to uncover the relationships between the variables that underpin the system. Hence they help us to understand how the existing systems work, which might be a physical system or more abstract one such as the economy. Whereas, normative models exceed beyond merely figuring out the mechanisms via establishing the rules and making proactive interventions.

What we set forth in this study, however, is a normative model that leads the decision makers to the optimal solution in terms of supplier selection problem based upon the sustainability goals. This model consists of three main stage and eleven steps as it is seen in Figure 4.1. Each step has designed as following the subsequent one. Loops invoke the users to sustain the supplier evaluation process in a continuous manner. Right hand side boxes indicate what has been done in each step.

4.5 Case Study

In this section we present how to apply the supplier evaluation model to a real-world business problem.

4.5.1 The Company

The proposed methodology has been applied on the supplier evaluation process of a real company as a case study.

Organik Kimya executes business in the fiel of specialty chemicals as one of the world's leading companies. It has been playing a crucial role in the economy as meeting the chemical needs of key sectors since 1924. It has 250 thousand production capacity per year with four production plant in Turkey, Nederland and Switzerland. By this capacity, Organik Kimya adds value with 6 different business units to more than 2000 customers from 80 different countries.

Organik Kimya shares at least 3% of its turnover for R&D activities to improve the product quality. These activities also includes many efforts to protect the environment and achieve the zero-loss target. Meanwhile, The Sustainable Development Goals of the United Nations (UN) have always been a notable and remarkable indicator in business understanding for Organik Kimya. However, there is always some new developments in both academia and industry regarding the sustainability indicators. Now that chemical industry is construed as one of the six most important sectors determined by the UN, Organik Kimya continuously needs for refreshing the supplier evaluation criteria and adopt state-of-art methodologies for assessment process. This study has been dedicated to assist the Organik Kimya on sustainability goals as well as contribute the scientific literature by its unique nature.

4.5.2 Setting the Criteria

In the first step, we determine 6 different criteria sources as it is seen in Figure 4.2.

Figure 4.2. Pooling the criteria

Materiality analysis consists of identifying relevant stakeholders (i.e. competitors, suppliers and customers) and determining which sustainability indicators are crucial and essential to get insights. It is conducted to identify and prioritize sustainability topics. After a comprehensive analysis of material items within the related industry, 21 main sustainability topics are included and prioritized.

There are participants from within the company where the case study is conducted, as well as without the company. Respectively 35 participants involved from out of the company. These stakeholders are such as specialty chemicals producers, manufacturers in construction and other chemicals, worldwide operating group of companies producing special chemicals, manufacturers of monomers raw materials suppliers for the industry, producer of chemicals for finishing of leather goods, customers to the specialty chemical industry, business partners and universities. Figure 4.3 indicates how the opinions coming up from inside the case company are aligned with those who are involving from the outside.

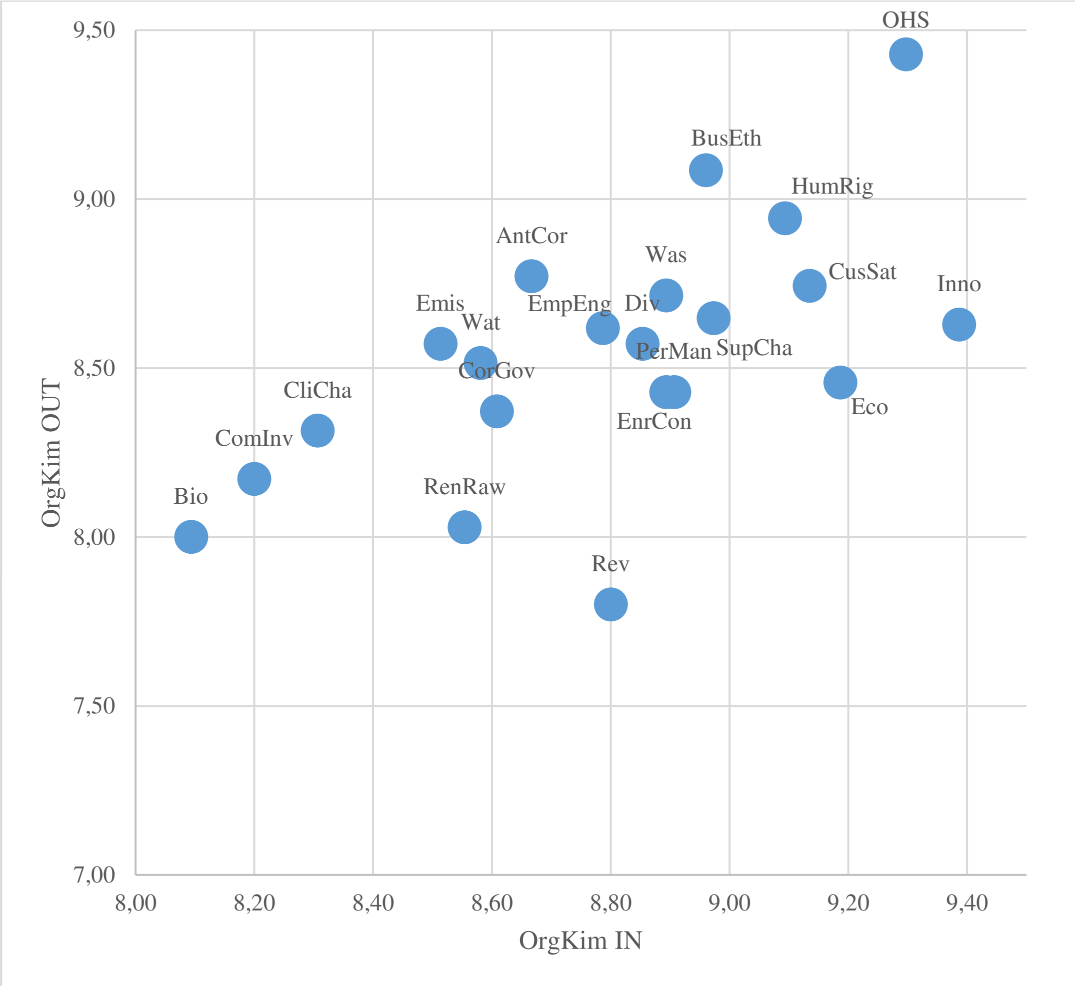


Figure 4.3. Materiality Analysis

EFFAS (European Federation of Financial Analysts Societies) is a non-profit organization and an umbrella association that embraces the national associations of investment professionals in Europe. EcoVadis is one of the world's most reliable source of business sustainability degrees, smart and collaborative performance development machines for global supply chains. Supported by a rigorous technology platform and a global team of domain experts, EcoVadis' user friend and useful sustainability scorecards provide detailed information into environmental, social and ethical risks. Global Reporting Initiative (GRI) is also a non-profit organization which provides guidance and support to organizations for assisting to create a sustainable global economy. Finally, we gather present supplier evaluation criteria that past researchers have reported in the literature.

By scanning these sources, we obtain 846 raw criteria. In the second step, redundant criteria are eliminated by the author after the first interview with experts. There are 14 experts in the focus group, whose title are all head of department. Hence, 14 criteria and 46 sub-criteria are determined.

In order to extract the essence of criteria, we conduct a survey as well as the second interview with the same focus group in the third step. There are 65 participants in the survey, all of whom from 6 different departments. Preliminary findings indicate that there is no more need for diminishing the number of criteria. After completing the third step, we pass to setting the network.

4.5.3 Setting the Network

After clarifying the ultimate list, we conduct an interview once again in order to construct the interdependencies between criteria. This is particularly important for understanding the gist of supplier performance. For instance, when a supplier possess a strong social management system, we may expect that this supplier also shows respect to human and labor rights at the same time. So, there should be a causality from social management system to human and labor rights criterion. Accounting for such relationships while calculating the performance scores assures the validity of the evaluation model. So, we confirm if the connections are coherent in the network structure by carrying out interview for the last time.

At the 6th step we prioritize the criteria using ANP methodology. Prioritizing the criteria is actually ranging the criteria according to relative importance in terms of the sustainability performance goal. The ANP is a multi-criteria decision making methodology proposed by Saaty (2004). We use ANP in Super Decision software (R. Liu, Yu, & Sun, 2003). After installing the network in the Super Decision, we calculate the criterion weights based on pairwise comparison matrix.

In order to make sure that the performance scores are trustworthy, the reliability of criterion weights must be satisfactory. There are two metrics that we apply for testing the reliability in the 7th step. The first metric is the Consistency Ratio (CR) that provided by the ANP mechanism (Ergu, Kou, Peng, & Shi, 2011). The second metric is the Spearman correlation coefficient using to test the consistency between the criteria rank obtained from both survey (3rd step) and ANP (6th step). In case either of metrics produce inconsistent results, research turns back to 4th step. Otherwise, it continuous with the next stage.

4.5.4 Evaluating the Suppliers

Supplier evaluation is an ongoing process in this methodology. As in 8th step, the supplier portfolio encapsulates the whole existing suppliers that the focal firm is already trading with. In 9th step, a web portal is developed and integrated into the ERP infrastructure so that suppliers share performance information on determined criteria and sub-criteria. Afterwards, suppliers are clustered using K-Means algorithm according to their performance scores in 10th step. K-Means is a non-hierarchical clustering algorithm that widely accepted by the literature. At the last step, the most appropriate suppliers are selected to fulfill the procurement decisions. Also necessary feedback is provided to suppliers in that the suppliers take precautions to improve their performance.

4.6 Results and Discussion

Previously, we have explained how the mechanism of the proposed model works. In this section, we exhibit the research findings obtained by applying on the supply chain process of the case company.

4.6.1 Elicited Criteria

In the first stage, 14 criteria and 46 sub-criteria have been elected from 846 raw criteria through interviews and survey. As it is seen in Table 4.1, criteria are classified to economic, social and environmental branches. One can come across most of the criteria in the sustainability literature. In addition to this, Information Security Management Systems and Energy Management Systems are the original criteria that contributed by the author specifically for this study.

Besides that, the evaluation criteria and sub-criteria have also been summarized with a mind map as Figure 4.4. We believe that this map makes straightforward to get insight on the evaluation framework of sustainability performance of suppliers.

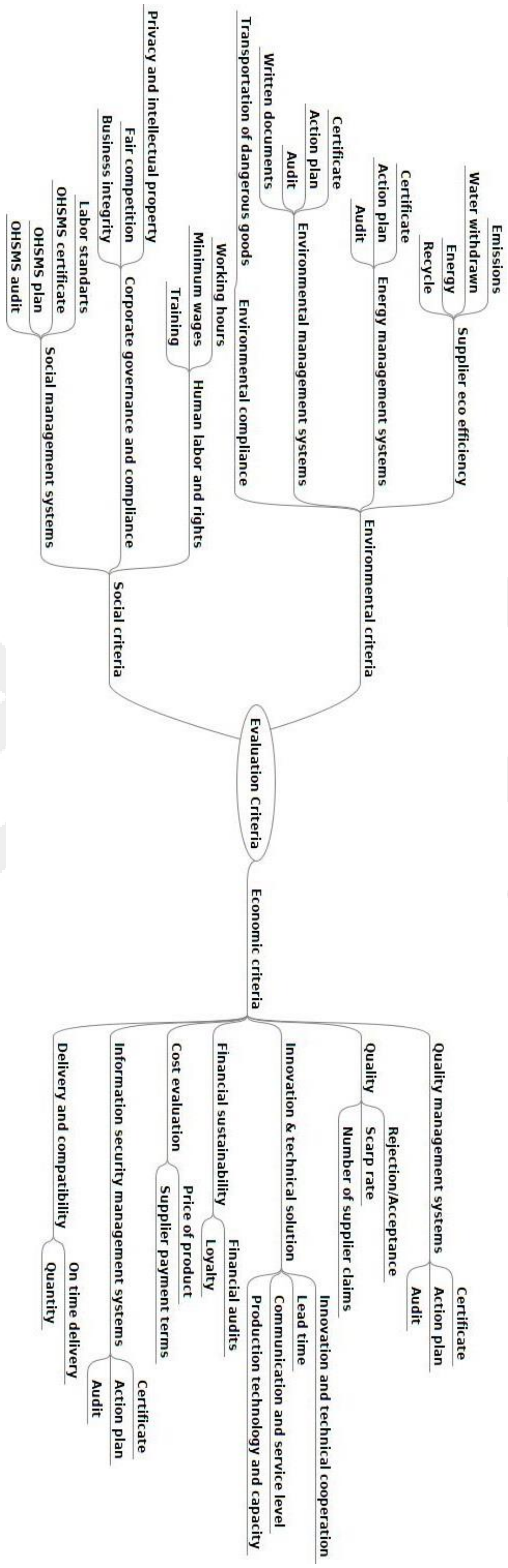


Figure 4.4. Ultimate evaluation criteria

Table 4.1. Evaluation Criteria

	Metrics	Definitions	References
Economic	Quality Management Systems	Implemented collection of rules based on quality management via policies, processes, documented procedures and records which are tracked by audits and action plans.	Govindan et al. (2013); (Hsu & Hu, 2009)
	Information Security Management Systems	Implemented collection of rules based on information security management via policies, processes, documented procedures and records which are tracked by audits and action plans.	Contributed by author
	Quality	A level of high-standart, a property of excellence in terms of customer's expectations	Amindoust et al. (2012); Fallahpour et al. (2016); (Sarkis & Talluri, 2002) and (Chan, 2003)
	Cost	A monetary valuation of material, resources, time and utilities consumed and delivery of a good or service.	(Amin & Zhang, 2012); (Amindoust vd., 2012); (Bai & Sarkis, 2010a); (Gülçin Büyüközkan & Çifçi, 2011b); (Chan, 2003)
	Innovation & Technical Solutions	Application and service of better solutions that meet new requirements and needs, or existing market needs	(Amin & Zhang, 2012); (Gunasekaran vd., 2004); (Tseng & Chiu, 2013)
	Delivery and Compatibility	The process of transporting goods with continuity or good fit of material	(Azevedo et al. 2011); (Gunasekaran vd., 2004)
	Financial Sustainability	The ability to start, grow and maintain short and long-term business with suppliers	(Bai & Sarkis, 2010b); (Gauthier, 2005), (Govindan, Kannan, vd., 2013); (Labuschagne, Brent, & Van Erck, 2005); (Presley, Meade, & Sarkis, 2007)
Environmental	Environmental Management Systems	Implemented collection of rules based on environmental management via policies, processes, documented procedures and records which are tracked by audits and action plans.	(Carter & Carter, 1998); (Dou & Sarkis, 2010); (Gauthier, 2005); (Klassen & Whybark, 1999); (Melnyk et al. 2003); (Zhu & Sarkis, 2006)
	Energy Management Systems	Implemented collection of rules based on energy management via policies, processes, documented	Contributed by author

		procedures and records which are tracked by audits and action plans.	
	Environmental Compliance	Conformity to environmental laws, regulations, standards and other requirements	(Bai & Sarkis, 2010a); (Handfield, Walton, Sroufe, & Melnyk, 2002); (Gazdar, Hassan, Safa, & Grassa, 2018); (Kannan, Govindan, & Rajendran, 2015); (A. H. I. Lee, Kang, Hsu, & Hung, 2009); (Mahmood vd., 2013); (Somsuk & Laosirihongthong, 2017)
	Supplier Eco Efficiency	Creating value with limited use of supplier resources in an efficient way	(Amin & Zhang, 2012); (Amindoust vd., 2012); (Bai & Sarkis, 2010b); (Govindan, Kannan, vd., 2013); (Kuo, Wang, & Tien, 2010); (A. H. I. Lee vd., 2009); (Shen et al. 2013)
Social	Social Management Systems	Implemented collection of rules based on social management via policies, processes, documented procedures and records which are tracked by audits and action plans.	(Huang & Keskar, 2007); (Kannan vd., 2015); (A. H. I. Lee vd., 2009); (Punniyamoorthy, Mathiyalagan, & Parthiban, 2011)
	Human and Labor Rights	Rights that all human beings have no matter which nationality, place of residence, sex, national or ethnic origin, color, religion, language, or any other status	(Gauthier, 2005); (Labuschagne vd., 2005); (Presley vd., 2007); (Bai & Sarkis, 2010a); (Govindan, Kannan, vd., 2013)
	Corporate Governance and Compliance	Conformity to a structured rules, policies, standards or laws	(Gauthier, 2005); (Presley vd., 2007); (Labuschagne vd., 2005); (Zhu, Sarkis, & Lai, 2007) and (Azevedo vd., 2011)

4.6.2 Pairwise Comparison

Pairwise comparison of the selected criteria is one of the three main steps of ANP methodology along with formulation of the limit supermatrix and calculation of the final priorities (Bottero & Mondini, 2008). Initially, the interconnections between the criteria are structured at the cluster and element level using Super Decision software. Figure 4.5 shows the network structure defined in the Super Decision.

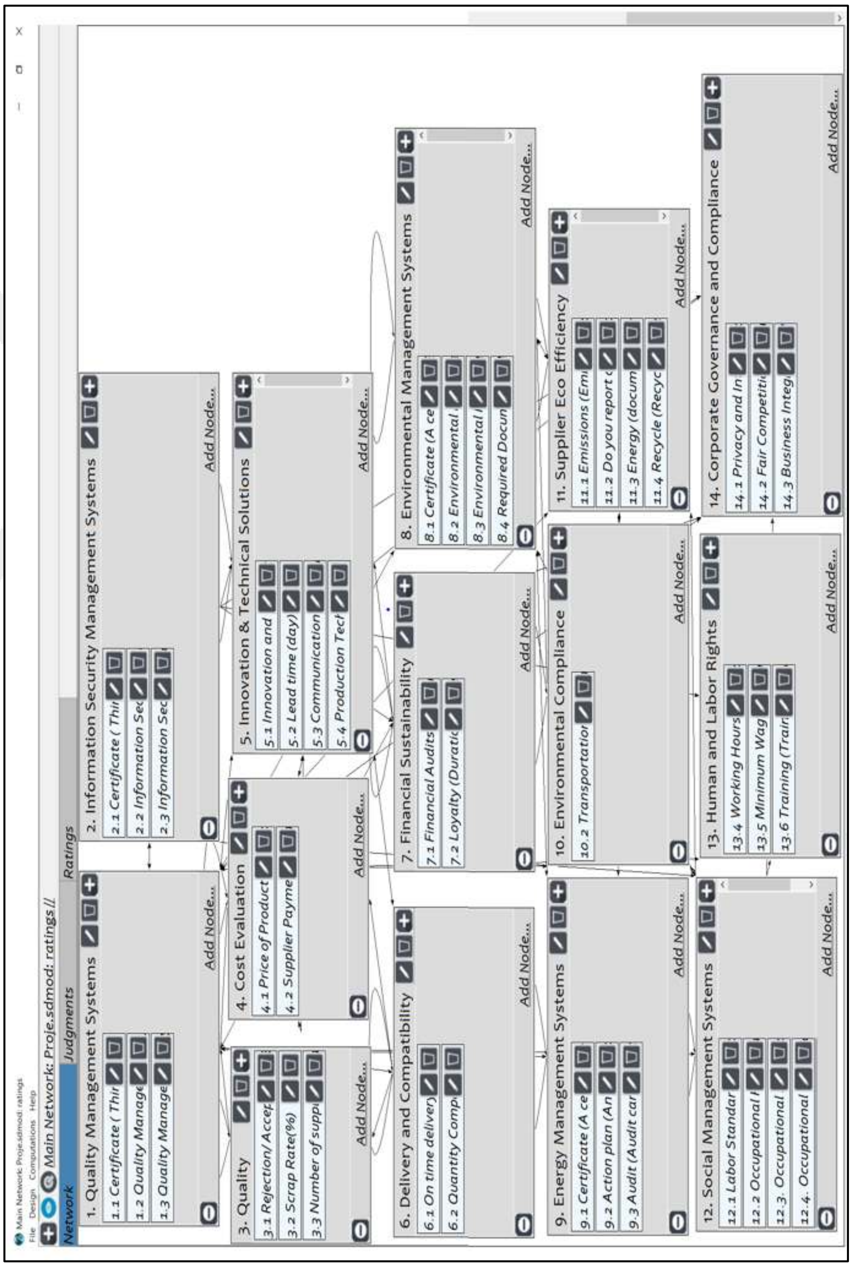


Figure 4.5 Network model in Super Decision software

After that, we form the pairwise comparison matrix in both cluster level and sub-criteria level. Hence, 14 pairwise comparison have been completed, one of which is shown as an example in Figure 4.6.

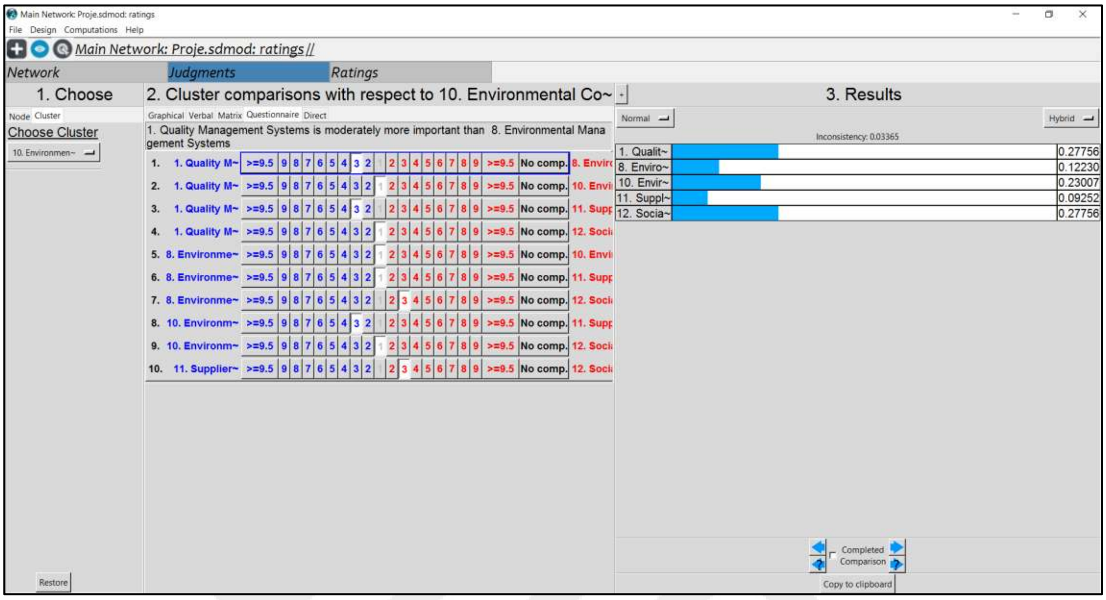


Figure 4.6 Cluster Comparisons

The aim of pairwise comparison is to obtain the priority vector. This vector contains the criteria weights that represent the relative importance. In order to determine the exact value of comparisons, we use simple geometric means of evaluation results. Eventually, the priority vector is incorporated into the supermatrix.

In Super Decision, it is possible to calculate unweighted and weighted supermatrix at the same time. The difference between both is that unweighted supermatrix displays the absolute measurement of criteria. While, the weighted supermatrix is derived from normalizing the absolute measurements to a hundred percent. Namely, it is the relative measurement of criteria importance with respect to each other. Yet, we prefer reporting only the weighted supermatrix in that relative measurements are rather straightforward to comprehend than absolute ones. Table 4.2 shows the pairwise comparison matrix and consistency ratios.

Table 4.2. Cluster Comparisons in Weighted Supermatrix

With respect to goal	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
Quality Man. Systems (C1)	0,041	0,105	0,068	-	0,062	0,051	0,159	0,25	-	0,277	0,333	0,232	0,041	0,041
Inf. Security Man. Systems (C2)	0,041	0,121	-	-	-	-	-	-	-	-	-	-	0,041	0,041
Quality (C3)	0,163	-	0,389	-	-	0,28	-	-	-	-	-	-	0,163	0,163
Cost (C4)	0,163	-	0,389	0,2	0,335	0,28	-	-	-	-	-	-	0,163	0,163
Innovation Tech. Solutions (C5)	0,122	0,283	0,152	0,8	0,109	0,107	0,359	-	-	-	-	-	0,122	0,122
Delivery and Compatibility (C6)	0,163	-	-	-	0,334	0,281	-	-	-	-	-	-	0,163	0,163
Financial Sustainability (C7)	0,122	0,268	-	-	0,121	-	0,399	-	-	-	-	-	0,122	0,122
Env. Man. Systems (C8)	0,021	-	-	-	-	-	-	0,083	0,5	0,122	0,111	0,096	0,021	0,02
Energy Management Systems (C9)	0,021	-	-	-	-	-	-	0,083	0,5	-	0,111	0,205	0,021	0,02
Environmental Compliance (C10)	0,041	-	-	-	-	-	-	0,25	-	0,23	0,333	-	0,041	0,04
Supplier Eco Efficiency (C11)	0,021	-	-	-	-	-	-	0,83	-	0,093	0,111	0,078	0,021	0,02
Social Management Systems (C12)	0,041	0,111	-	-	-	-	-	0,25	-	0,277	-	0,232	0,041	0,04
Human and Labor Rights (C13)	0,021	0,056	-	-	-	-	-	-	-	-	-	0,077	0,021	0,02
Corp. Gov. and Compliance (C14)	0,021	0,056	-	-	0,039	-	0,081	-	-	-	-	0,077	0,021	0,02
Consistency Ratio (CR)	0	0,012	0,016	0	0,04	0,009	0,043	0	0	0,033	0	0,016	0	0

In Table 4.3, the rank of criteria have been regularized according to magnitude of weight. This result indicates that the most important metrics for sustainable supplier selection are Quality and Cost Evaluation. Considering the competition strategy and the organization culture of the case company (Organik Kimya), the raise of quality and cost evaluation criteria undoubtedly inherent with the reality.

Table 4.3. Priority Vector (% weights)

Main Criteria	Weight (%)	Rank
Quality (C3)	16,33%	1
Cost Evaluation (C4)	16,33%	2
Delivery and Compatibility (C6)	16,33%	3
Innovation & Technical Solutions (C5)	12,25%	4
Financial Sustainability (C7)	12,25%	5
Quality Management Systems (C1)	4,08%	6
Information Security Management Systems (C2)	4,08%	7
Environmental Compliance (C10)	4,08%	8
Social Management Systems (C12)	4,08%	9
Environmental Management Systems (C8)	2,04%	10
Energy Management Systems (C9)	2,04%	11
Supplier Eco Efficiency (C11)	2,04%	12
Human and Labor Rights (C13)	2,04%	13
Corporate Governance and Compliance (C14)	2,04%	14
Total weight	100,00%	

Also, the less important criteria seem Human and Labor Rights and Corporate Governance and Compliance. Indeed, the sustainability report of the case company underlines the responsibilities associated with corporate social responsibilities, ethical rules and human health and safety, but the data indicates that the focus groups pay less attention to these criteria. In order to prevent prospective risks on these issues, leaders may subsequently develop novel contingency strategies.

4.6.3 Validity and Reliability

Quality of a scientific model refers what extent the model is capable of reflecting the reality in an abstract form. By means of validity and reliability tests, research findings need to be proven whether they are trustworthy enough.

In this study, we use two metrics for gauging the reliability. First is the consistency ratio that provided by ANP in Super Decision. As it is seen in Table 3.2 all consistency ratios are less than 0.10; this confirms that our results are reliable.

The other metric we use to prove reliability is the Spearman correlation coefficient. Analyzing the rank information of the variables, this test is the non-parametric version of the Pearson correlation. In order to implement the correlation analysis, another ranking of the criteria is required along with ANP ranks.

Section 3.5.1 remind us that the survey is applied at the end of first stage. This survey includes the items of criteria and sub-criteria as 1-7 point Likert type scale. Participants are expected to sign 1 point if they consider the aforementioned item has least importance, and to sign 7 point in case of vice versa. Google Forms is used for preparing the electronic version of the survey which is rather efficient on data collection. There are 65 participants returned us with the answers. Table 4.4 shows the survey results.

Table 4.4. Descriptive Statistics of Survey Results

Items	Mean	Std. Dev.	Rank
Cost Evaluation (C4)	6,539	0,954	1
Quality Management Systems (C1)	6,477	0,985	2
Information Security Management Systems (C2)	6,446	0,477	3
Quality (C3)	6,262	0,772	4
Financial Sustainability (C7)	6,031	0,723	5
Innovation & Technical Solutions (C5)	5,908	0,792	6
Environmental Management Systems (C8)	5,892	1,104	7
Corporate Governance and Compliance (C14)	5,862	0,850	8
Environmental Compliance (C10)	5,800	0,935	9
Energy Management Systems (C9)	5,569	0,795	10
Delivery and Compatibility (C6)	5,539	0,821	11
Human and Labor Rights (C13)	5,523	0,762	12
Supplier Eco Efficiency (C11)	5,169	0,903	13
Social Management Systems (C12)	5,169	0,827	14

We conduct the nonparametric correlation analysis using SPSS. Hypothesis are developed as follow.

H_0: *There is no meaningful relationship between the ANP rankings and Survey rankings.*

H_1: *There is a meaningful relationship between the ANP rankings and Survey rankings.*

We found that the Spearman's rho coefficient is 0,596* and this coefficient is statistically significant at the 0,05 level. Thus, we refuse the H_0 hypothesis and accept that our model generates reliable performance measurements.

In addition to reliability, there are concrete evidences convincing us to confirm the validity of our model. As we have seen in Table 3.1 and Figure 3.2, the criteria have been acquired from the literature through a comprehensive review. This endeavor satisfies the content validity in the setting the criteria stage. Furthermore, we conduct a redundant interview during the setting the network stage. Building the structure of the network by consulting the focus group aims to satisfy the construct validity of the performance evaluation model.

4.6.4 Supplier Evaluation Results

In the last stage, we carry out performance measurement of existing suppliers based on ANP model. To ensure the continuity of assessment, a web portal is developed. Figure 4.7 shows the dashboard of the portal. Users can access to the portfolio as the list of suppliers from the interface.

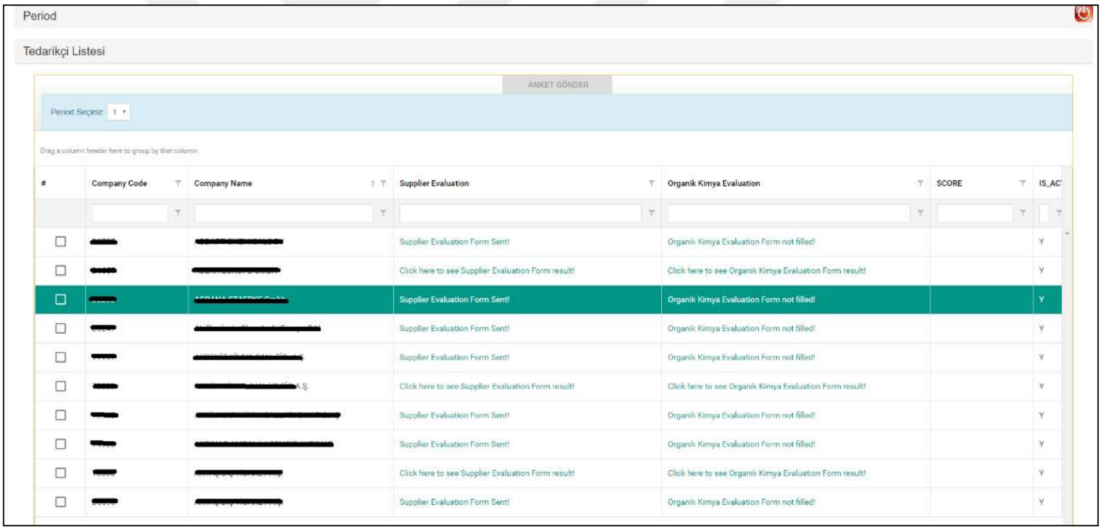


Figure 4.7 Web Portal Dashboard Interface

The portal is integrated in the existing ERP infrastructure of the supply chain. In other words, this is a digital platform where supply chain members share information within the direction form suppliers to manufacturers. Beyond the streamlining attribute on the flow of information, the forefront purpose of this web based system is improving the sustainability performance of the supply chain.

As it is shown in Figure 4.8 supplier firms are expected to fill the performance metrics in a regular basis. They are also supposed to add necessary documents related to each performance indicator. Thus, the performance measurement become an ongoing process in the supply chain.

Figure 4.8 Web Portal Performance Measurement System

After calculating the performance scores, the supplier portfolio is fragmented into four different segments via clustering analysis particularly using K-Means algorithm. The K-Means algorithm is a nonhierarchical clustering technique. It takes places not only in multivariate statistics literature, but also among unsupervised machine learning techniques.

The clustering analysis is conducted in SPSS. There are 69 supplier firms on the supplier portfolio. After 7 iterations, performance clusters converge from initial to final centers.

Table 4.5. Convergence to Cluster Centers

	Clusters			
	1	2	3	4
Initial centers	0,992	0,964	0,761	0,828
Final centers	0,957	0,898	0,789	0,858

Cluster analysis aims to ensure the homogeneity inside each cluster as well as heterogeneity outside each cluster. In other words, suppliers are expected to resemble each other in terms of sustainability performance for each cluster. Moreover, one supplier is expected to be far different from those who belong to other clusters. To ensure this phenomena, distances between the final cluster centers are tested whether these distances are far enough. Thus, the following hypotheses are put forward.

H_0: *There is no meaningful difference between the final cluster centers.*

H_1: *There is a meaningful difference between the final cluster centers.*

For testing these hypothesis, variance analysis is conducted within the cluster analysis framework. Since the p-value is smaller than 0.05; we are able to reject the H_0 hypothesis. Table 4.6 acknowledge that heterogeneity between the clusters is statistically significant.

Table 4.6. ANOVA Table

	Cluster		Error			
	Mean Square	df	Mean Square	df	F	Sig.
Performance	0,037	3	0	65	149,509	0

At the end of clustering analysis, we obtain four supplier segment, each of which requires tailored strategies. Table 4.7 indicates the frequency information of supplier memberships.

Table 4.7. Number of Cases in Each Cluster

Cluster	Membership frequency
1	5
2	31
3	7
4	26
Total	69

According to these results, cluster 1 encapsulates the best suppliers with the average performance of 0,957. So, the supply chain leaders may intensively prefer these suppliers for subsequent orders. On the other hand, the cluster 3 contains the worst performing suppliers with the average performance of 0,789. These suppliers should be warned for the poor performance results or the contract can simply be terminated. For the other clusters, however, supplier development programs should be designed and detailed feedback should be submitted to those suppliers.

The other point we need to emphasis is that the clusters disperse with imbalanced frequencies. The preferred supplier group (7%) and the black list supplier group (10%) embody only a small portion of portfolio (17%). Considering procurement managers prone to select preferred suppliers more, it is indispensable that these minor group will disrupt the order fulfillment process and reduce the service level. Therefore, it is a must for this company to initiate supplier development programs for middle-performing suppliers. Let us finally remind that the supplier performance evaluation is a cycling mechanism, so this study embraces only the initial iteration of the proposed approach.

4.6.5 Sensitivity Analysis

Previously, the supplier segments are obtained based on the sustainability performance scores. The preferred suppliers segment consists of 5 suppliers which are ranked according to performance scores as follow: t23-t24-t62-t9-t18.

The greatness of performance scores are determined by two antecedents. The first is by the endeavour that a specific supplier have spent for each criteria along the supply chain processes. The second is what extent this criteria is important for the sustainability goal in general. Since the importance of the criteria are determined by the decision-maker him/herself, the performance results need to be checked if/what extent they are fragile to the manipulations on importance weights.

In this study, we conducted the sensitivity analysis by Super Decision software as did the rest of the ANP steps earlier. Figure 4.9 shows the main screen of sensitivity analysis. The colorized horizontal lines represent the suppliers. Thus, there are 69 lines, each with a different color. The reason why they overlap each other, but not disperse on the plane is that the multitude of alternatives/criteria diminish the discrimination power of the ANP methodology, as it is stated in the section "4.2. Limitations of the Study". Yet, the Cluster analysis has already proved that there are fair amount of subsets which are significantly far between each other. Thus, we can rely on the results that the sensitivity analysis generates in this stage.

The vertical dashed line indicates the weight of the selected criterion. Initially it stands on 0,5 level so that the manipulation starts from here. As we move the line towards the left side, the weight of selected criterion gradually decreases. Conversely, when we slide the line towards right side, the weight of the selected criterion increases. Along with this operation, we can observe the change in the performance ranks, below the screen.

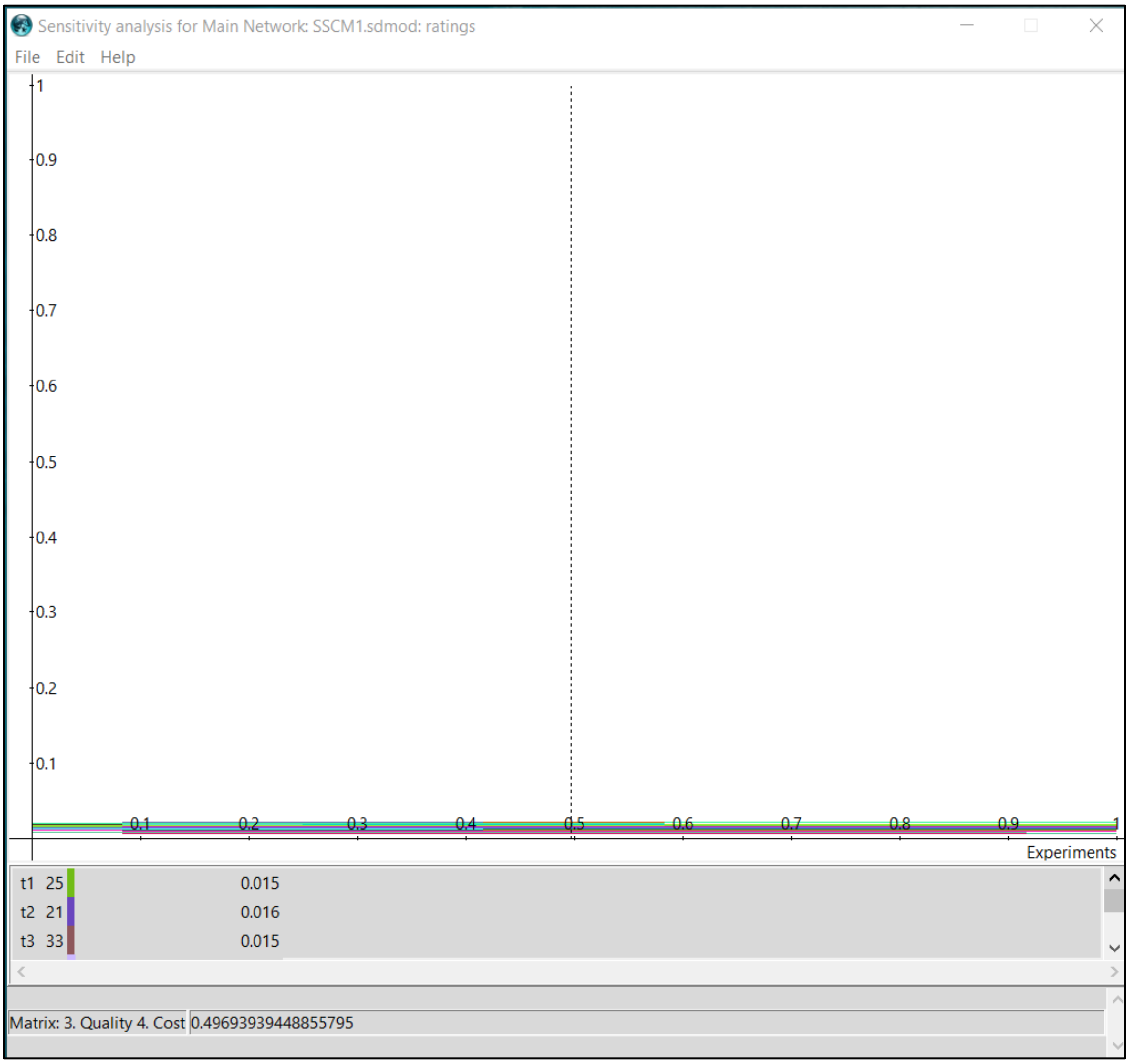


Figure 4.9 Sensitivity Analysis

Table 4.8 indicates the results of sensitivity analysis. As it is seen, the sensitivity of preferred suppliers segment is analyzed against 14 criteria. The right hand side shows how robust the ranks are when the weights approximate to 0% and 100% respectively for each criteria.

According to results, the Quality (C3) is not only one of the most important criteria, but it is also the robustest criterion with Human and Labour Rights (C13). That means no matter how big/small the weight we attend to these criteria, the preferred supplier rank does not change.

When we increase the importance of Information and Security Management Systems (C2), three novel suppliers (**t39-t48-t3**) enter the segment instead of formers. We can conclude that these suppliers must have better performance on C2, so the positive manipulation on C2 brings them in the preferred suppliers segment. Reversely, when we reduce the importance weight of Innovation and Technical Solution (C5), we see that **t41** and **t19** comes to the list, instead of t9 and t18. Thus, we can assert that t41 and t19 are so weak on the C5 and so strong on others that the reduction of weight on the C5 bring t41 and t19 to the list. One can make such conclusions for each of bold-characterized codes in the Table 4.8.

Table 4.8. Rank of Preferred Suppliers Based on Sensitivity Analysis

Criteria	Manipulated ranks	
	0.05	0.95
Quality Man. Systems (C1)	t23-t62-t24-t9-t18	t23-t9-t24-t18-**t4**
Inf. Security Man. Systems (C2)	t23-t24-t62-t9-t18	t9-**t39**-**t48**-**t3**-t18
Quality (C3)	t23-t24-t62-t9-t18	t23-t24-t62-t9-t18
Cost (C4)	t18-**t2**-t23-t24-**t12**	t23-**t41**-t62-t24-**t19**
Innovation Tech. Solutions (C5)	t23-t62-**t41**-t24-**t19**	t9-t62-t18-**t2**-**t12**
Delivery and Compatibility (C6)	t23-t9-t24-t62-**t19**	t23-t24-t18-t62-**t4**
Financial Sustainability (C7)	t23-t24-t62-t9-t18	t9-t23-t24-t18-t62
Env. Man. Systems (C8)	t23-t24-t62-t9-**t19**	t23-t9-t24-t18-**t34**
Energy Management Systems (C9)	t23-t24-t62-t9-t18	t23-t9-t24-t18-**t34**
Environmental Compliance (C10)	t23-t24-t62-t9-t18	t23-t9-t24-t18-**t34**
Supplier Eco Efficiency (C11)	t23-t24-t62-t9-t18	t23-t24-t9-t18-**t4**
Social Management Systems (C12)	t23-t24-t62-t9-t18	t9-t18-**t34**-**t2**-**t39**
Human and Labor Rights (C13)	t23-t24-t62-t9-t18	t23-t24-t62-t9-t18
Corp. Gov. and Compliance (C14)	t23-t24-t9-t62-t18	t62-t23-t9-t24-**t19**

5. CONCLUSION

The growing trend in the digitalization facilitates the selection of the most appropriate suppliers in a turbulent environment. It is also a challenging and complex task to evaluate suppliers in accordance with sustainability performance. Cost-focused or short-term sourcing decisions may cause certain upstream risks and undermine the product quality or the competitive strategy. So, there is a growing pressure for manufacturers particularly in chemical industry to pay more attention on economic, social and environmental factors in their supplier performance evaluation process.

To overcome these challenges, we develop a normative framework and provide a holistic approach on environmental, social and financial branches of sustainability. The proposed model consists of three main stages. In the setting the criteria stage, salient sustainable supplier selection criteria have been incorporated through a comprehensive literature review, a survey study and interviews with focus groups. Hence, we achieve the answer of first research question: *Q1: What are the sustainability indicators that a company ought to pursue for supplier evaluation?*

In setting the network stage, we construct the structure of network model. Decisive criteria are the building blocks of this structure as which pertinent aspects of sustainability intertwine in causalities. The content validity of the network model rely upon the comprehensive literature review. Additionally, we ensure the construct validity by the excess interview. The conceptual network is then transformed into the ANP methodology using Super Decision software. Afterwards we conduct pairwise comparisons and calculate the priority vector that reflects the relative importance of each evaluation metric. Thus, we achieve the answer of second research question: *Q2: How the sustainability indicators can be prioritized according the main strategy of a company?*

To satisfy the reliability concern, we investigate the consistency ratio (CR) as well as correlation coefficient of between the ANP and the survey ranks. Thanks to the sufficient test results, we pass to the last stage. Otherwise, we would turn back to beginning of the stage for redeveloping the network model.

In evaluating the supplier stage, a web portal is developed and integrated into the existing ERP infrastructure of the case company. Through this portal, the suppliers are expected to fill the performance metrics and attach the requisite materials for evidence.

As soon as the information flow from suppliers to the manufacturer occurs, performance scores of each supplier are calculated based on ANP methodology and collected data. Therefore, we achieve the answer of third research question: *Q3: How can the suppliers be evaluated in a real time manner?*

The supplier portfolio is then fragmented into four segments by clustering analysis. These segments are named “super stars”, “long-term friends”, “low-cost suppliers” and “headaches”. Each segments represent for a certain performance echelon that needs a tailored strategy. Supply chain leaders may approximate to each performance segments, for instance, with increasing the order frequency, scheduling a development program or terminating the relationship. It is notable to remind that the supplier selection is a cycling process with refreshing the supplier portfolio in a continuous manner.

As previously seen, our proposed approach has some theoretical, methodological and practical implications. From the theoretical perspective, our study combines the social, environmental and economic sustainability dimensions with the evaluation framework. Although, the literature is rife with supplier selections using multi-criteria decision making and specifically ANP technique, there is a scarcity of providing a holistic approach on full dimensions of sustainability. Therefore we think this study fills this gap by embracing whole aspects of sustainability in supplier evaluation problem.

From the methodological perspective, this study also has some originalities. What makes this study unique is that beside the consistency ratio, we run a statistical mechanism by Spearman correlation coefficient to ensure the reliability of criteria weightings. Because of the holistic viewpoint concern on representing full dimensions of sustainability, the number of criteria in measurement model respectively remains larger. Thus, the binary mechanism we set to test reliability brings an innovative solution on this problem.

From the practical perspective, this study carries invaluable contributions to the industrial applications. The web portal digitalize the data collection procedure from the suppliers. Also, calculation of the sustainability performance and returning feedback regarding that, is automatized. Hence, we believe that this study helps withdrawing the human intervention from the business process, complying with the Industry 4.0 movement. The feedbacks provided to suppliers create values for whole supply chain. These values range from decreasing unit costs, increasing negotiation power, ensuring supply continuity, increasing supplier loyalty, maintaining the integrity of brand, and to ensuring a sustainable supply chain.

Besides the effort of such contributions, this study have some limitations. First of all due to the nature of ANP mechanism, increase of the criteria number melts the differences of criteria weights from each other. There is also one single performance output making up the input of clustering analysis. However, the concept of supplier performance hides more complex issues and needs more dimensions for abstraction.

To remedy these weaknesses, we can make following suggestions for future research. The recent movements in global economy have shifted the management paradigm of supply chains from performance to risk direction. Supply chain leaders are no more expected to diminish costs in the expense of boosting risks. Therefore, the next studies may handle the sustainable supplier selection problem by approaching from the risk management point of view.

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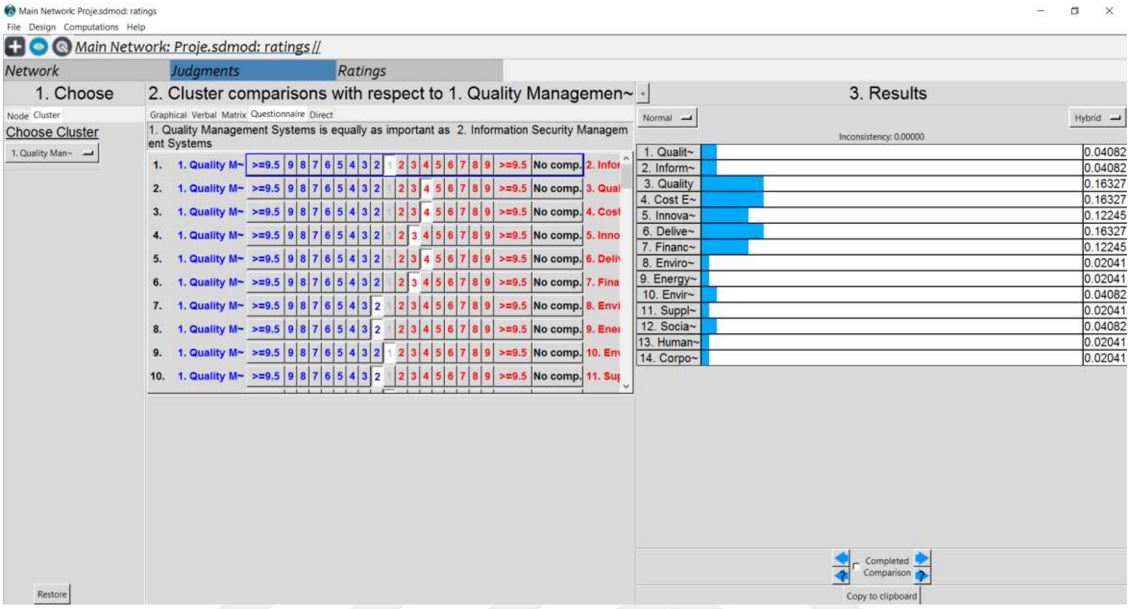
APPENDIX

Appendix 1 Cluster Comparisons with respect to

1. Quality Management



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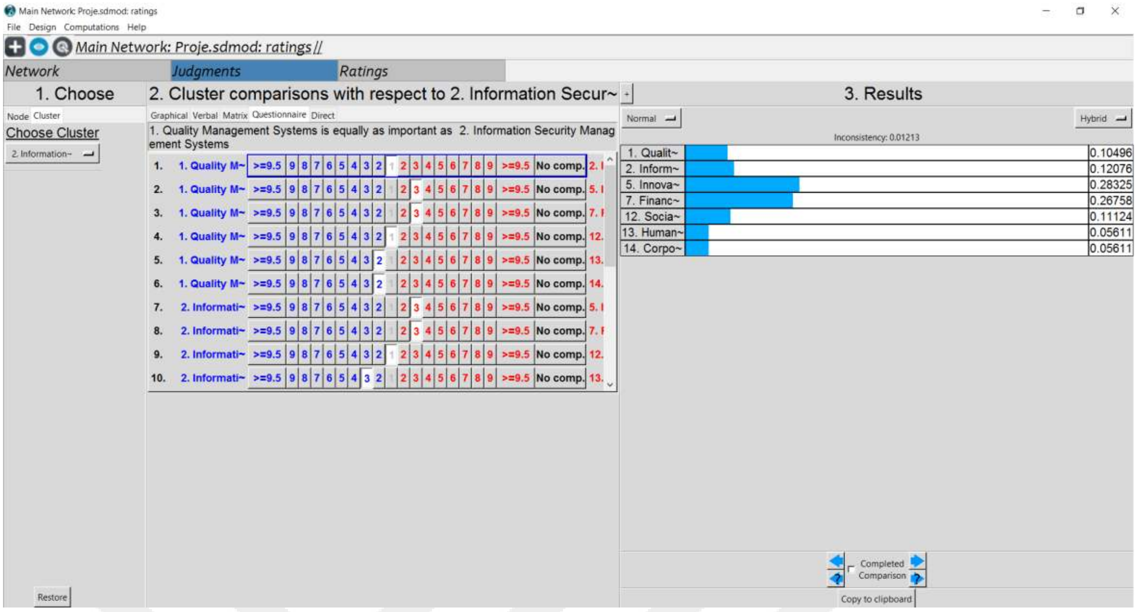
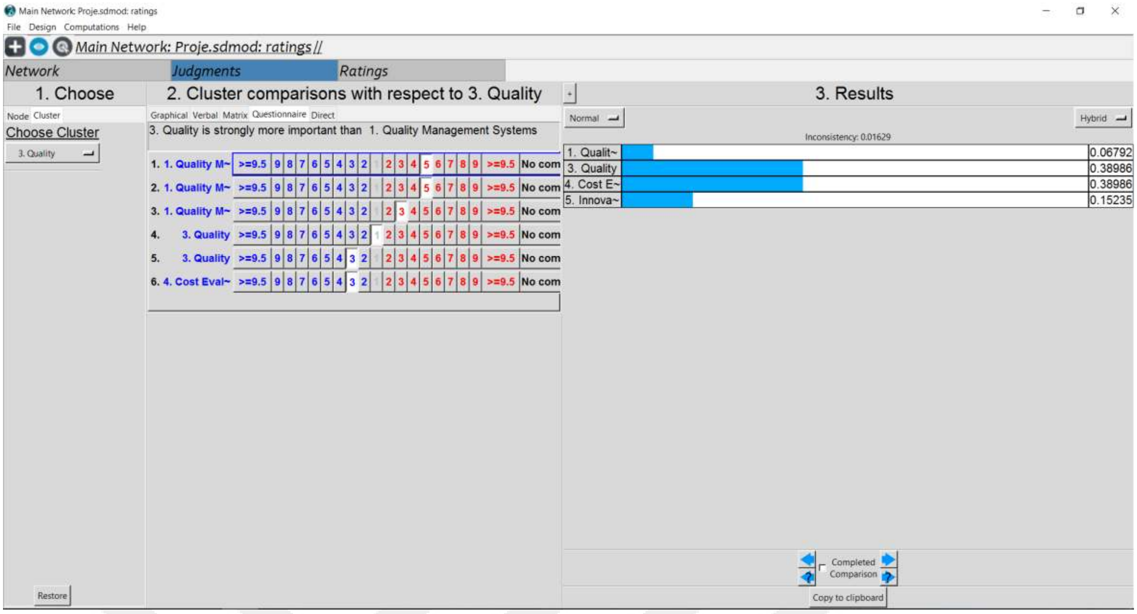
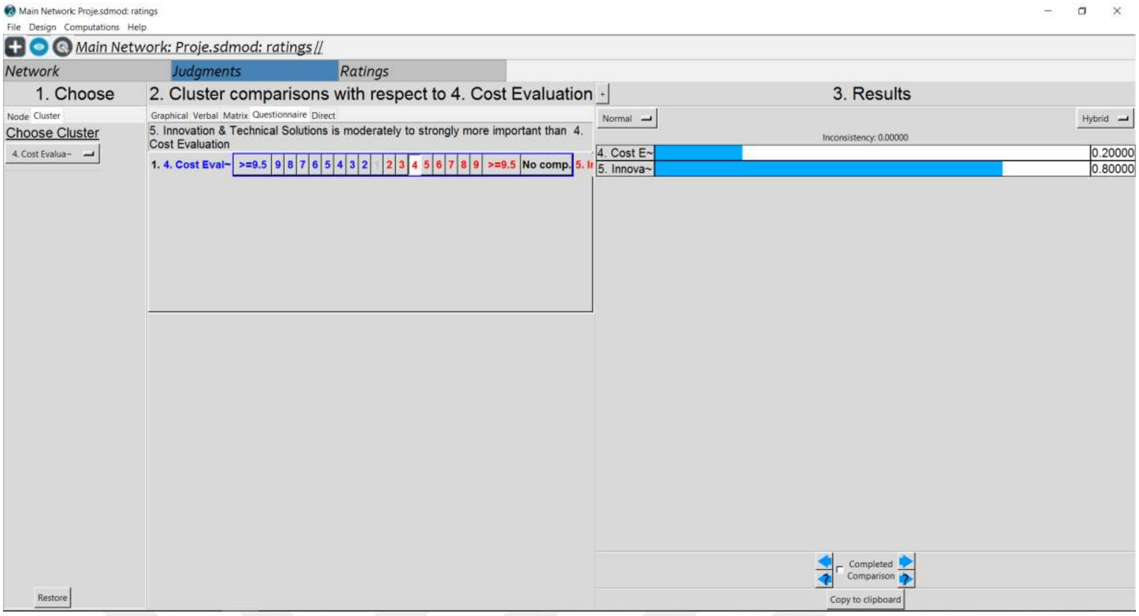


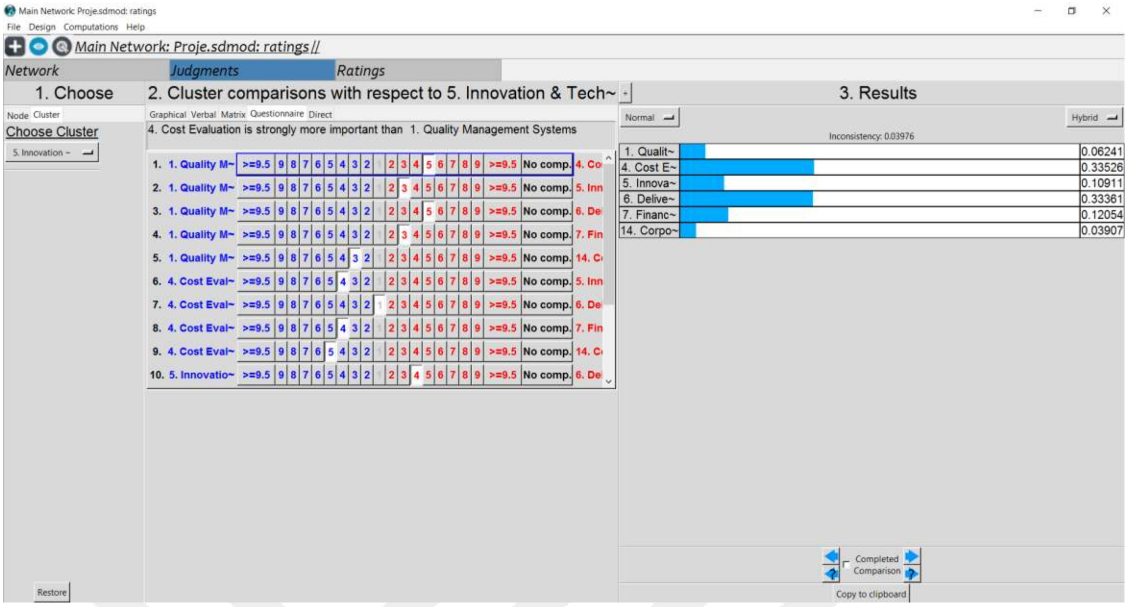
3. Quality


Main Network: Proje.sdmod: ratings
Main Network: Proje.sdmod: ratings//
Network
Judgments
Ratings
1. Choose
2. Cluster comparisons with respect to 3. Quality
3. Results
Choose Cluster
3. Quality is strongly more important than 1. Quality Management Systems
Inconsistency: 0.01629
1. Qualit~ 0.06792
3. Quality 0.38986
4. Cost E~ 0.38986
5. Innova~ 0.15235
Completed Comparison
Copy to clipboard
Restore

4. Cost Evaluation

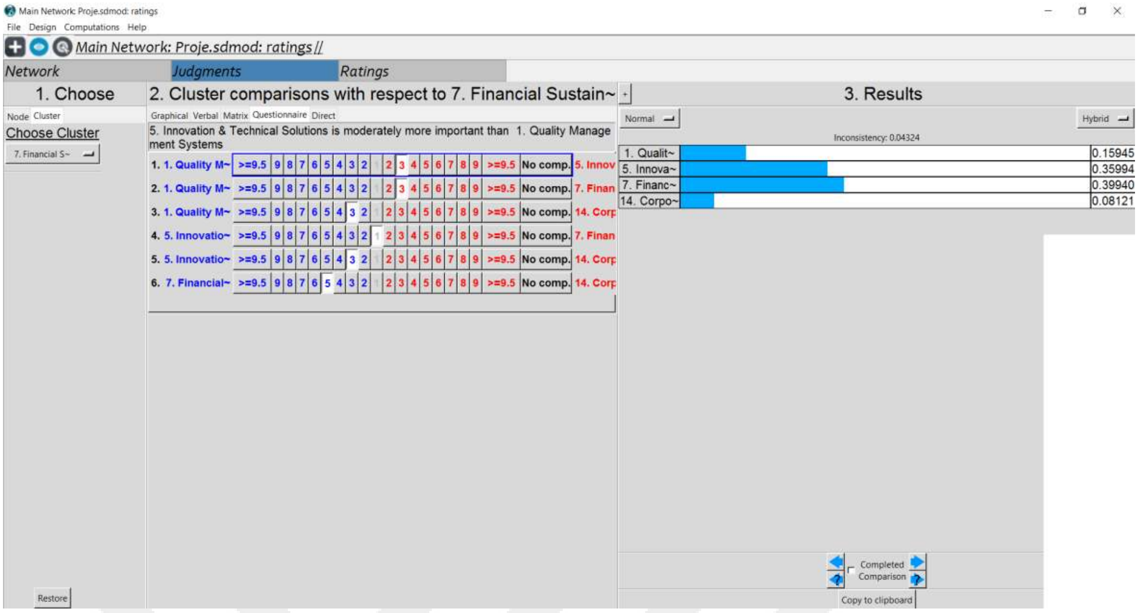


5. Innovation & Technology

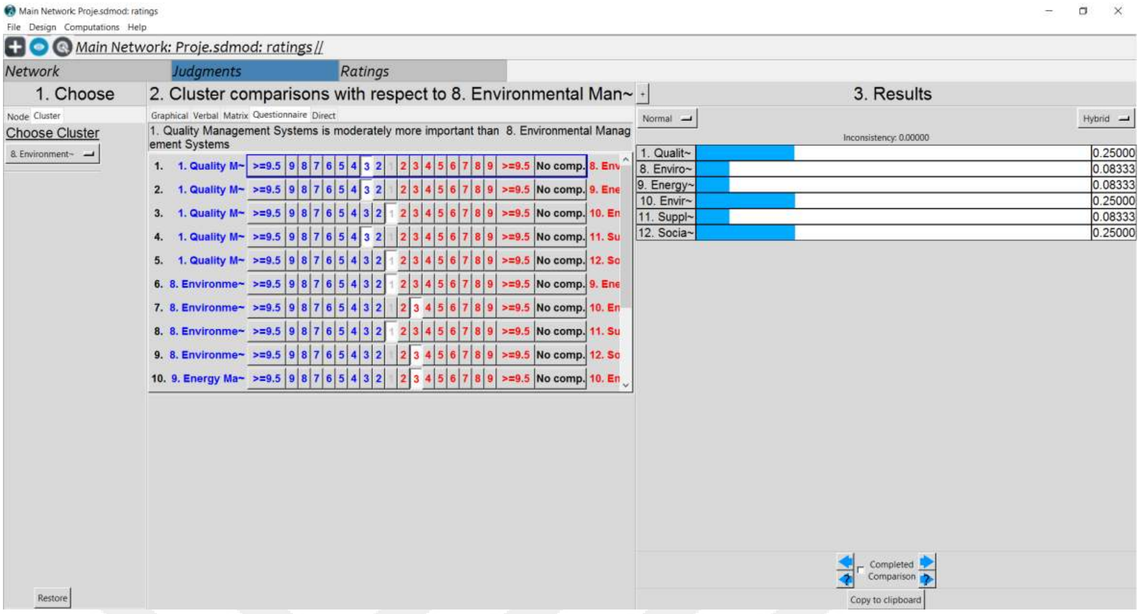


6. Delivery and Compatibility

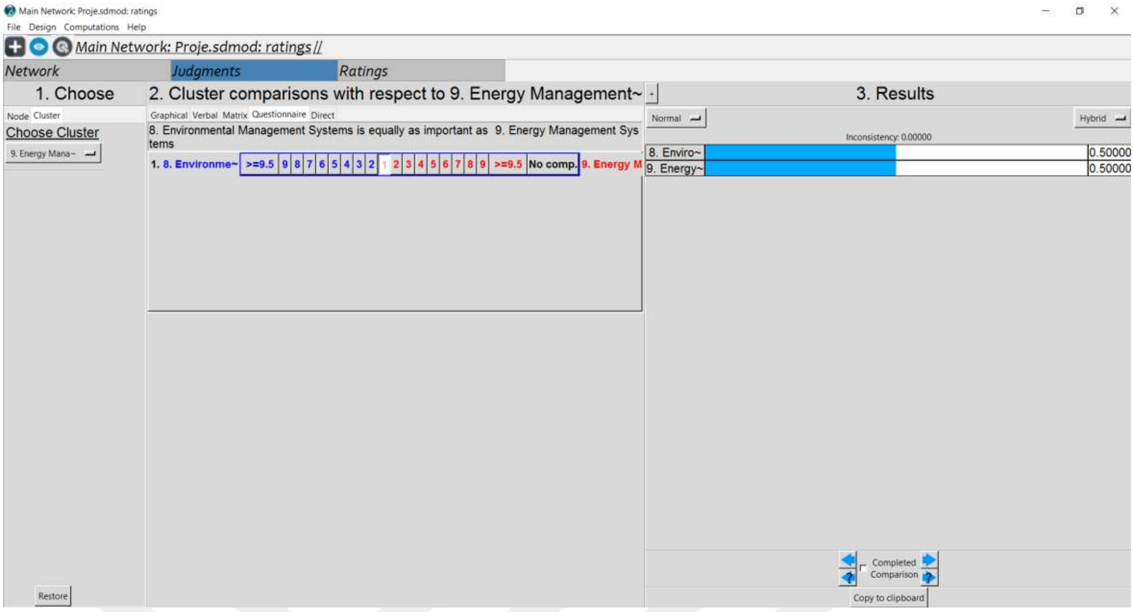
7. Financial Sustainability



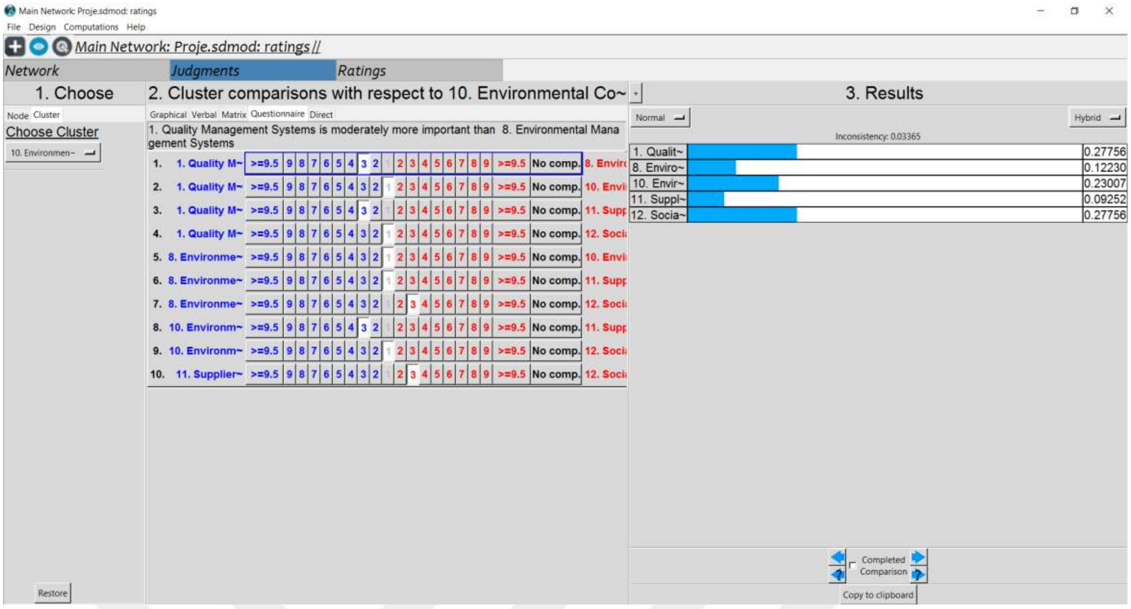
8. Environmental Management System



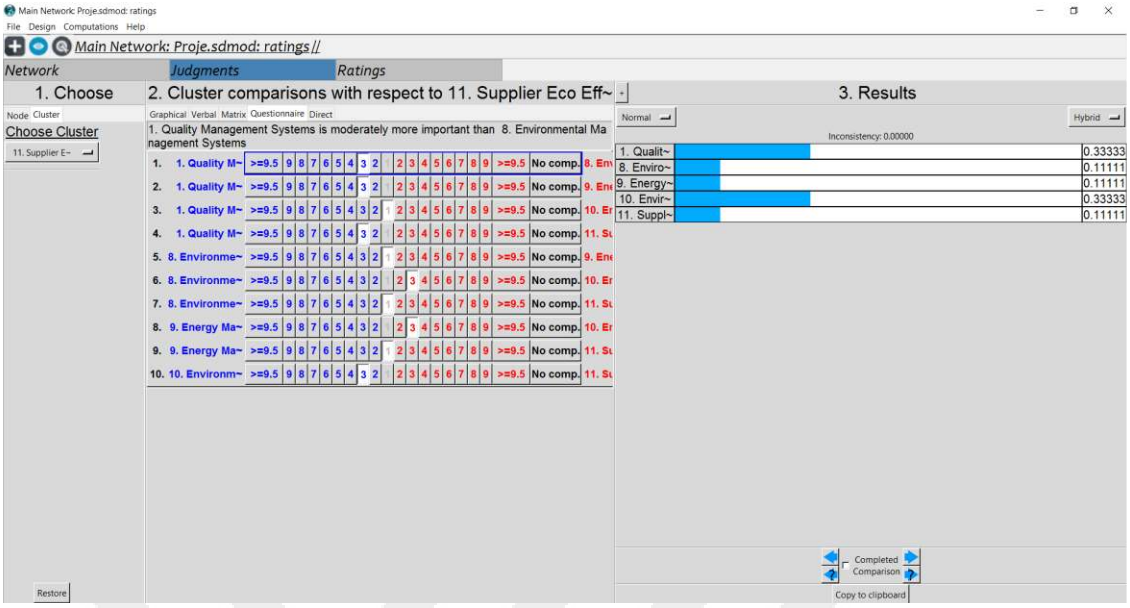
9. Energy Management System



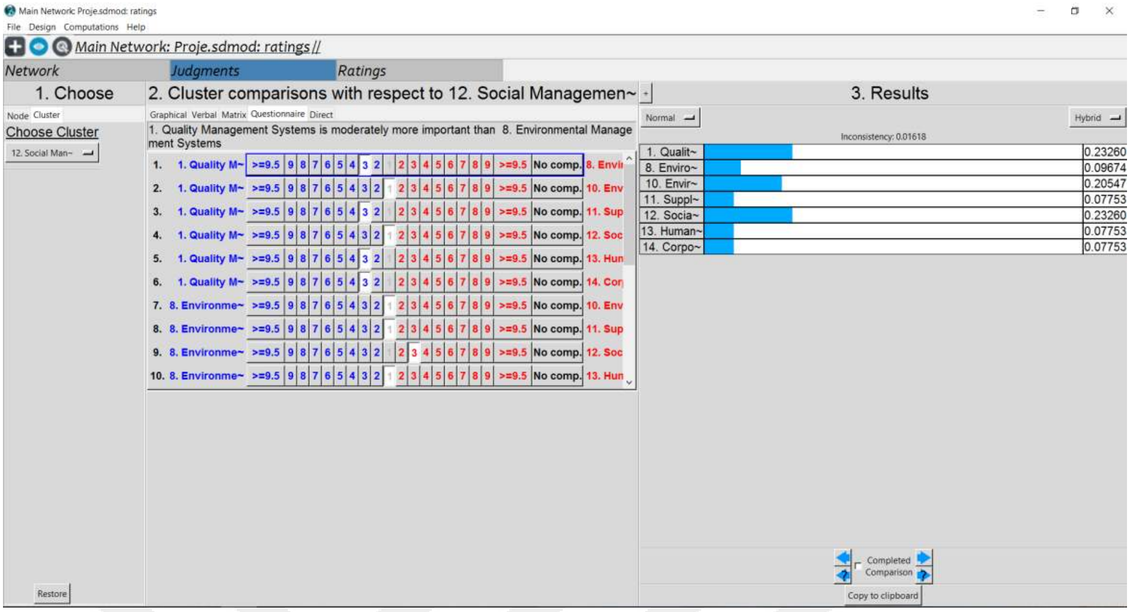
10. Environmental Compliance



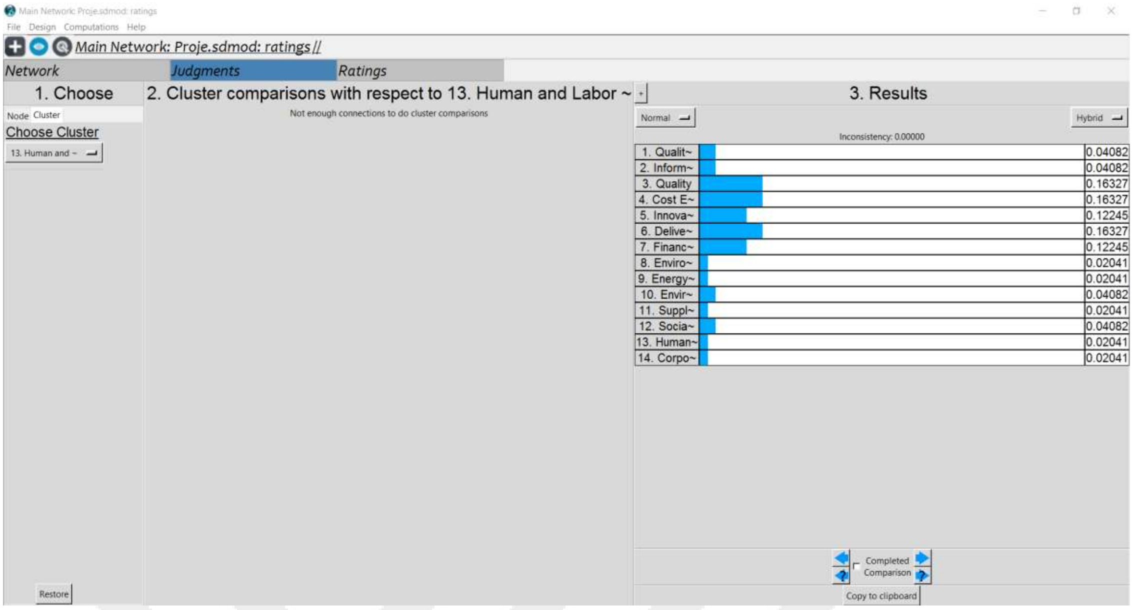
11. Supplier Eco-Efficiency



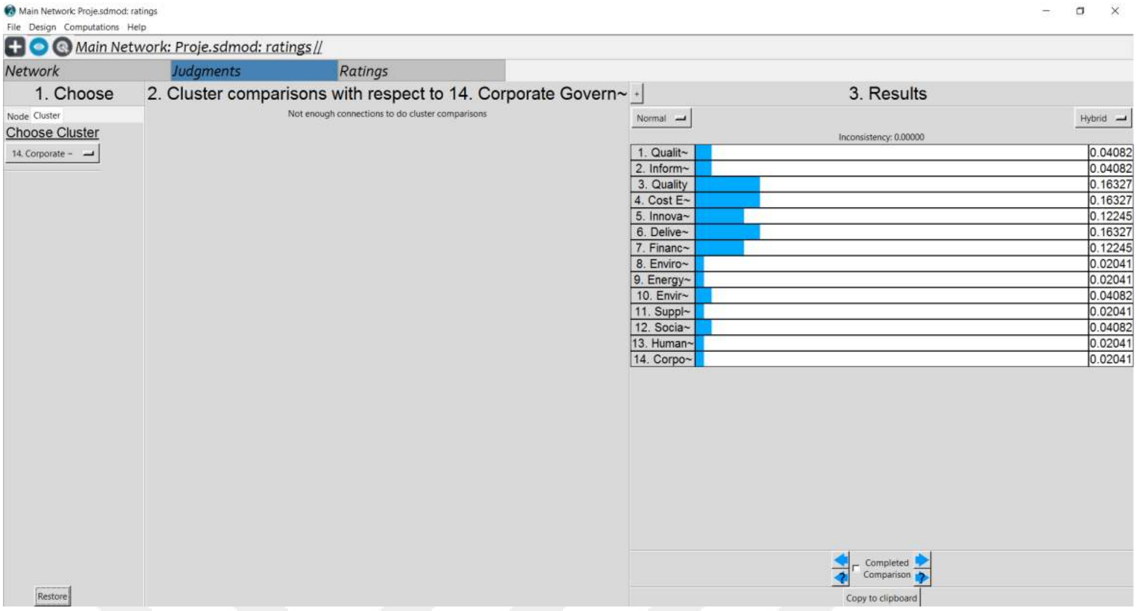
12. Social Management System



13. Human and Labor Rights



14. Corporate Governance



Appendix 2 Information on Supplier Segments

	Number of Suppliers	%
Total number of C Class Suppliers that have Certificate (Third party certificates Information Security Management System (e.g. ISO 27001))	0	0
Total number of C Class Suppliers	4	
Total number of Suppliers that have Certificate (Third party certificates Information Security Management System (e.g. ISO 27001))	4	5,80%
Total number of suppliers	69	
A Class Supplier	4	100,00%
B Class Supplier	0	0,00%
Total number of A Class Suppliers that have 100 % of Acceptance/ Rejection Rate Score (Number of recorded acceptances- given by raw material Quality Control Department)(%)	14	87,50%
Total number of A Class Suppliers	16	
Total number of B Class Suppliers that have 100 % of Acceptance/ Rejection Rate Score (Number of recorded acceptances- given by raw material Quality Control Department)(%)	35	71,43%
Total number of B Class Suppliers	49	
Total number of C Class Suppliers that have 100 % of Acceptance/ Rejection Rate Score (Number of recorded acceptances- given by raw material Quality Control Department)(%)	2	50,00%
Total number of C Class Suppliers	4	
Total number of Suppliers that have 100 % of Acceptance/ Rejection Rate Score (Number of recorded acceptances- given by raw material Quality Control Department)(%)	51	73,91%
A Class Supplier	14	27,45%
B Class Supplier	35	68,63%
C Class Supplier	2	3,92%
Total number of Suppliers that have 100 % of Acceptance/ Rejection Rate Score (Number of recorded acceptances- given by raw material Quality Control Department)(%)	51	100,00%
Total number of A Class Suppliers that have 0% of Scrap Rate(%)	15	93,75%
Total number of A Class Suppliers	16	
Total number of B Class Suppliers that have 0% of Scrap Rate(%)	36	73,47%

Total number of B Class Suppliers	49	
Total number of C Class Suppliers that have 0% of Scrap Rate(%)	2	50,00%
Total number of C Class Suppliers	4	
Total number of Suppliers that have Suppliers that have 0% of Scrap Rate(%)	53	76,81%
Total number of suppliers	69	
A Class Supplier	15	28,30%
B Class Supplier	36	67,92%
C Class Supplier	2	3,77%
Total number of Suppliers that have Suppliers that have 0% of Scrap Rate(%)	53	100,00%
Total number of A Class Suppliers that have 0% of Number of supplier claims / Number of Total supplier shipments (%) score	16	100,00%
Total number of A Class Suppliers	16	
Total number of B Class Suppliers that have 0% of Number of supplier claims / Number of Total supplier shipments (%) score	36	73,47%
Total number of B Class Suppliers	49	
Total number of C Class Suppliers that have 0% of Number of supplier claims / Number of Total supplier shipments (%) score	2	50,00%
Total number of C Class Suppliers	4	
Total number of Suppliers that have Suppliers that have 0% of Number of supplier claims / Number of Total supplier shipments (%)	54	78,26%
Total number of suppliers	69	
A Class Supplier	16	29,63%
B Class Supplier	36	66,67%
C Class Supplier	2	3,70%
Total number of Suppliers that have Suppliers that have 0% of Number of supplier claims / Number of Total supplier shipments (%)	54	100,00%
Total number of A Class Suppliers that have 100 % of Innovation and Technical Cooperation score (Total score given by R&D department based on yearly technical performance and innovation driven activities by supplier)(%)	8	50,00%
Total number of A Class Suppliers	16	
Total number of B Class Suppliers that have 100 % of Innovation and Technical Cooperation score (Total score given by R&D department based on yearly technical performance and innovation driven activities by supplier)(%)	0	0,00%
Total number of B Class Suppliers	49	

Total number of C Class Suppliers that have 100 % of Innovation and Technical Cooperation score (Total score given by R&D department based on yearly technical performance and innovation driven activities by supplier)(%)	0	0,00%
Total number of C Class Suppliers	4	
Total number of Suppliers that have 100 % of Innovation and Technical Cooperation score (Total score given by R&D department based on yearly technical performance and innovation driven activities by supplier)(%)	8	11,59%
Total number of suppliers	69	
A Class Supplier	8	100,00%
B Class Supplier	0	0,00%
C Class Supplier	0	0,00%
Total number of Suppliers that have 100 % of Innovation and Technical Cooperation score (Total score given by R&D department based on yearly technical performance and innovation driven activities by supplier)(%)	8	100,00%
Total number of A Class Suppliers that have 100 % of Communication and Service Level score (Easily contact with supplier and sustainability of relationship further)(%)	12	75,00%
Total number of A Class Suppliers	16	
Total number of B Class Suppliers that have 100 % of Communication and Service Level score (Easily contact with supplier and sustainability of relationship further)(%)	12	24,49%
Total number of B Class Suppliers	49	
Total number of C Class Suppliers that have 100 % of Communication and Service Level score (Easily contact with supplier and sustainability of relationship further)(%)	0	0,00%
Total number of C Class Suppliers	4	
Total number of Suppliers that have 100 % of Communication and Service Level score (Easily contact with supplier and sustainability of relationship further)(%)	24	34,78%
Total number of suppliers	69	
A Class Supplier	12	50,00%
B Class Supplier	12	50,00%
C Class Supplier	0	0,00%
Total number of Suppliers that have 100 % of Communication and Service Level score (Easily contact with supplier and sustainability of relationship further)(%)	24	100,00%

Total number of A Class Suppliers that have 100 % of Production Technology and Capacity score (%)	7	43,75%
Total number of A Class Suppliers	16	
Total number of B Class Suppliers that have 100 % of Production Technology and Capacity score (%)	2	4,08%
Total number of B Class Suppliers	49	
Total number of C Class Suppliers that have 100 % of Production Technology and Capacity score (%)	0	0,00%
Total number of C Class Suppliers	4	
Total number of Suppliers that have 100 % of Production Technology and Capacity score (%)	9	13,04%
Total number of suppliers	69	
A Class Supplier	7	77,78%
B Class Supplier	2	22,22%
C Class Supplier	0	0,00%
Total number of Suppliers that have 100 % of Production Technology and Capacity score (%)	9	100,00%
Total number of A Class Suppliers that have 100 % of On time delivery score (Total score of yearly supplier delivery performance evaluated by purchasing department)(%)	11	68,75%
Total number of A Class Suppliers	16	
Total number of B Class Suppliers that have 100 % of On time delivery score (Total score of yearly supplier delivery performance evaluated by purchasing department)(%)	16	32,65%
Total number of B Class Suppliers	49	
Total number of C Class Suppliers that have 100 % of On time delivery score (Total score of yearly supplier delivery performance evaluated by purchasing department)(%)	1	25,00%
Total number of C Class Suppliers	4	
Total number of Suppliers that have 100 % of On time delivery score (Total score of yearly supplier delivery performance evaluated by purchasing department)(%)	28	40,58%
Total number of suppliers	69	
A Class Supplier	11	39,29%
B Class Supplier	16	57,14%
C Class Supplier	1	3,57%
Total number of A Class Suppliers that have 100 % of Quantity Compatibility score (Difference between ordered and delivered quantity)(%)	14	87,50%
Total number of A Class Suppliers	16	
Total number of B Class Suppliers that have 100 % of Quantity Compatibility score (Difference between ordered and delivered quantity)(%)	25	51,02%
Total number of B Class Suppliers	49	

Total number of C Class Suppliers that have 100 % of Quantity Compatibility score (Difference between ordered and delivered quantity)(%)	1	25,00%
Total number of C Class Suppliers	4	
Total number of Suppliers that have 100 % of Quantity Compatibility score (Difference between ordered and delivered quantity)(%)	40	57,97%
Total number of suppliers	69	
A Class Supplier	14	35,00%
B Class Supplier	25	62,50%
C Class Supplier	1	2,50%
Total number of Suppliers that have 100 % of Quantity Compatibility score (Difference between ordered and delivered quantity)(%)	40	100,00%
Loyalty (Duration (in years) of A Class suppliers - cooperation with the supplier more than 10 years)	9	56,25%
Total number of A Class Suppliers	16	
Loyalty (Duration (in years) of B Class suppliers - cooperation with the supplier more than 10 years)	14	28,57%
Total number of B Class Suppliers	49	
Loyalty (Duration (in years) of C Class suppliers - cooperation with the supplier more than 10 years)	3	75,00%
Total number of C Class Suppliers	4	
Loyalty (Duration (in years) of cooperation with the supplier more than 10 years)	26	37,68%
Total number of suppliers	69	
A Class Supplier	9	34,62%
B Class Supplier	14	53,85%
C Class Supplier	3	11,54%
Loyalty (Duration (in years) of cooperation with the supplier more than 10 years)	26	100,00%
Total number of A Class Suppliers that have Environmental Management System Certificate (A certified Environmental Management System)	14	87,50%
Total number of A Class Suppliers	16	
Total number of B Class Suppliers that have Environmental Management System Certificate (A certified Environmental Management System)	26	53,06%
Total number of B Class Suppliers	49	
Total number of C Class Suppliers that have Environmental Management System Certificate (A certified Environmental Management System)	0	0
Total number of C Class Suppliers	4	
Total number of Suppliers that have Environmental Management System Certificate (A certified Environmental Management System)	40	57,97%
Total number of suppliers	69	

A Class Supplier	14	35,00%
B Class Supplier	26	65,00%
C Class Supplier	0	0,00%
Total number of Suppliers that have Environmental Management System Certificate (A certified Environmental Management System)	40	100,00%
Total number of A Class Suppliers that have Energy Management System Certificate (A certified Energy Management System)	9	56,25%
Total number of A Class Suppliers	16	
Total number of B Class Suppliers that have Energy Management System Certificate (A certified Energy Management System)	6	12,24%
Total number of B Class Suppliers	49	
Total number of C Class Suppliers that have Energy Management System Certificate (A certified Energy Management System)	0	0
Total number of C Class Suppliers	4	
Total number of Suppliers that have Energy Management System Certificate (A certified Energy Management System)	15	21,74%
Total number of suppliers	69	
A Class Supplier	9	60,00%
B Class Supplier	6	40,00%
C Class Supplier	0	0,00%
Total number of Suppliers that have Energy Management System Certificate (A certified Energy Management System)	15	100,00%
Total number of A Class Suppliers that Recycle (Recyclable packaging materials, any contract with external waste recyclable company)	13	81,25%
Total number of A Class Suppliers	16	
Total number of B Class Suppliers that Recycle (Recyclable packaging materials, any contract with external waste recyclable company)	30	61,22%
Total number of B Class Suppliers	49	
Total number of C Class Suppliers that Recycle (Recyclable packaging materials, any contract with external waste recyclable company)	1	25,00%
Total number of C Class Suppliers	4	
Total number of Suppliers that Recycle (Recyclable packaging materials, any contract with external waste recyclable company)	44	63,77%
Total number of suppliers	69	
A Class Supplier	13	29,55%
B Class Supplier	30	68,18%
C Class Supplier	1	2,27%

Total number of Suppliers that Recycle (Recyclable packaging materials, any contract with external waste recyclable company)	44	100,00%
Total number of A Class Suppliers that have Labor Standarts (Third party certificates Labor Standarts (e.g. SA 8000))	5	31,25%
Total number of A Class Suppliers	16	
Total number of B Class Suppliers that have Labor Standarts (Third party certificates Labor Standarts (e.g. SA 8000))	5	10,20%
Total number of B Class Suppliers	49	
Total number of C Class Suppliers that have Labor Standarts (Third party certificates Labor Standarts (e.g. SA 8000))	0	0
Total number of C Class Suppliers	4	
Total number of Suppliers that have Labor Standarts (Third party certificates Labor Standarts (e.g. SA 8000))	10	14,49%
Total number of suppliers	69	
A Class Supplier	5	50,00%
B Class Supplier	5	50,00%
C Class Supplier	0	0,00%
Total number of Suppliers that have Labor Standarts (Third party certificates Labor Standarts (e.g. SA 8000))	10	100,00%
Total number of A Class Suppliers that have Occupational Health and Safety Management System Certificate	13	81,25%
Total number of A Class Suppliers	16	
Total number of B Class Suppliers that have Occupational Health and Safety Management System Certificate	20	40,82%
Total number of B Class Suppliers	49	
Total number of Suppliers that have Occupational Health and Safety Management System Certificate	33	47,83%
Total number of suppliers	69	
A Class Supplier	20	60,61%
B Class Supplier	13	39,39%
C Class Supplier	0	0,00%
Total number of Suppliers that have Occupational Health and Safety Management System Certificate	33	100,00%

BIOGRAPHY

Natali Maya Kan was born in 1983 in İstanbul, Turkey. With a bachelor's degree in Industrial Engineering and Computer Engineering (double major) from Dogus University in 2002-2007, she has completed Turquality Program Executive Business Administration and Management (MBA) in Koç University in 2006-2007. Between 2010 and 2020, she has professional experience as Human Resources Manager in Organik Kimya. She is currently working in Arkem Kimya as Human Resources and Communication Group Manager.