T.C.

İSTANBUL KÜLTÜR UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

OPTIMIZATION OF THE SUPPLY CHAIN IN THE OIL AND GAS SECTOR IN TÜRKIYE

Master of Science Thesis

Bassel Mneimneh

Department: Industrial Engineering

Program: Engineering Management

Supervisor: Prof. Dr. Murat Ermiş

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June 2023

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June 2023 Bassel Mneimneh

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ABBREVIATIONS

Bcf	**:** Billion Cubic Feet
BP	**:** British Petroleum
BTC	: Baku-Tbilisi-Ceyhan
CEO	: Chief Executive Officer
EFP	: Ecological FootPrint
EIA	**:** Energy Information Administration
ESI	**:** Environmental Sustainability Index
FSRU	**:** Floating Storage Regasification Unit
HDI	**:** Human Development Index
IT	**:** Information Technology
GFA	**:** Green Field Analysis
GIS	**:** Geographic Information System
KRG	**:** Kurdish Regional Government
LNG	**:** Liquified Natural Gas
OGJ	**:** Oil & Gas Journal
OPEC	**:** Organization of the Petroleum Exporting Countries
OPI	**:** Operational Performance Index
SEM	**:** Structural Equation Modeling
Tcf	**:** Trillion Cubic Feet
TP	**:** Turkish Petroleum
TPAO	: Türkiye Petrolleri Anonim Ortaklığı
WCED	**:** World Council of Environment and Development

LIST OF SYMBOLS

$\boldsymbol{C_j}$: Capacity of distribution

$\boldsymbol{D_k}$: Average annual demand of node *k*

$\boldsymbol{F_j}$: Fixed cost of opening a distribution center *j*

$\boldsymbol{I}$: Refinery

$\boldsymbol{i}$: Index of refinery

$\boldsymbol{J}$: Distribution Center

$\boldsymbol{j}$: Index of distribution center

$\boldsymbol{K}$: Demanding Node

$\boldsymbol{k}$: Index of demanding nodes

$\boldsymbol{m}$: Index of transportation modes

$\boldsymbol{M_1}$: Pipeline

$\boldsymbol{M_2}$: Barge

$\boldsymbol{M_3}$: Rail

$\boldsymbol{M_4}$: Truck

$\boldsymbol{S_i}$: Total capacity of refinery *i* per year

$\boldsymbol{T_{jkm}}$: Transportaion cost from distribution center *j* to node of demand *k* via mode of transportation *m*.

$\boldsymbol{V_{ijm}}$: Variable cost of transportation from refinery *i* to distribution center *j* via mode of transportation *m*

$\boldsymbol{Y_{ijm}}$: Volume of products shipped from refinery *i* to distribution center *j* via mode of transportation *m*.

$\boldsymbol{Z_{jkm}}$: Volume of products shipped from distribution center *j* to node of demand *k* via mode of transportation *m*.

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ÖZET

TÜRKİYE PETROL VE GAZ SEKTÖRÜ TEDARİK ZİNCİRİNİN OPTİMİZASYONU

Bassel Mneimneh

Artan enerji talebiyle birlikte, önümüzdeki yıllarda enerji arzının verimliliğini ve uzun vadeli ekonomik fizibiliteyi en üst düzeye çıkarmayı hedefleyen saha geliştirme stratejilerinde tedarik zincirinin optimizasyonu önemli bir faktör haline gelmiştir. Tedarik zinciri optimizasyonu, kaynakları analiz ederek ve stratejik kararların rekabetçi pazarda uygulanmasıyla istenen üretimi yönetmek, tedarik süresini azaltmak, maliyetleri düşürmek ve müşteri ihtiyaçlarını karşılamak için verimli bir çözüm sistemi olarak kabul edilir. Kalite yönetimi yoluyla etkin teslimat hizmeti, tedarik zincirinde sürdürülebilirlik ve endüstride uygulanan yenilikçi stratejiler, petrol ve gaz sektöründe tedarik zincirinin geliştirilmesine de katkıda bulunan ana unsurlardır. Bu çalışmada, piyasada literatür taraması ve nicel yöntemler kullanılarak ölçüm, analiz, modelleme, önceliklendirme ve aksiyonların uygulanması gibi çeşitli faaliyetlerden oluşan bir optimizasyon modeli uyuglanmıştır.

Anahtar Kelimeler: Tedarik zinciri optimizasyonu, stratejik karar, etkili teslimat, kalite yönetimi, sürdürülebilirlik, yenilikçi stratejiler...

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Institute	**: Institute of Graduate Studies**
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ABSTRACT

OPTIMIZATION OF THE SUPPLY CHAIN IN THE OIL AND GAS SECTOR IN TÜRKIYE

Bassel Mneimneh

With the increasing demand for energy, optimization of the supply chain become an important factor in field development strategies targeted to maximize efficiency of energy supply and long-term economic feasibility for the next upcoming years. Supply chain optimization is considered an efficient solution system to manage the desired production, reduced lead time, lower costs and satisfy customer needs by analyzing the resources and implementing of strategic decision into the competitive market. Effective delivery service through quality management, sustainability in the supply chain and innovative strategies applied in the industry are also main contributors in enhancing the supply chain in the oil & gas sector. In this study, the optimization model consists of various activities like measuring, analyzing, modelling, prioritizing, and implementing actions using the literature review and quantitative application studies including spatial simulation and survey questionannaire tackeling the market.

Keywords: Supply chain optimization, strategic decision, effective delivery, quality management, sustainability, innovative strategies…

1. INTRODUCTION

During the last couple of years, the petroleum industry has played a major role in the global economy and modern society. Being the world's leading energy source, oil and gas are used as main fuel for the automotive industry, electricity, and a variety of manufacturing plants. Thus, it becomes a fundamental market for current world trading operations and future developments along with involving a significant number of financial transactions. However, these resources are distributed unevenly around the world. According to the Organization of the Petroleum Exporting Countries (OPEC) annual statistical bulletin in 2019, around 53% of the world's proven reserves are in the Middle East region led by the Arabian Gulf countries and Saudi Arabia which possesses the largest oil filed, followed by Canada, countries of South America, Russia, and many countries in Pacific Asia.

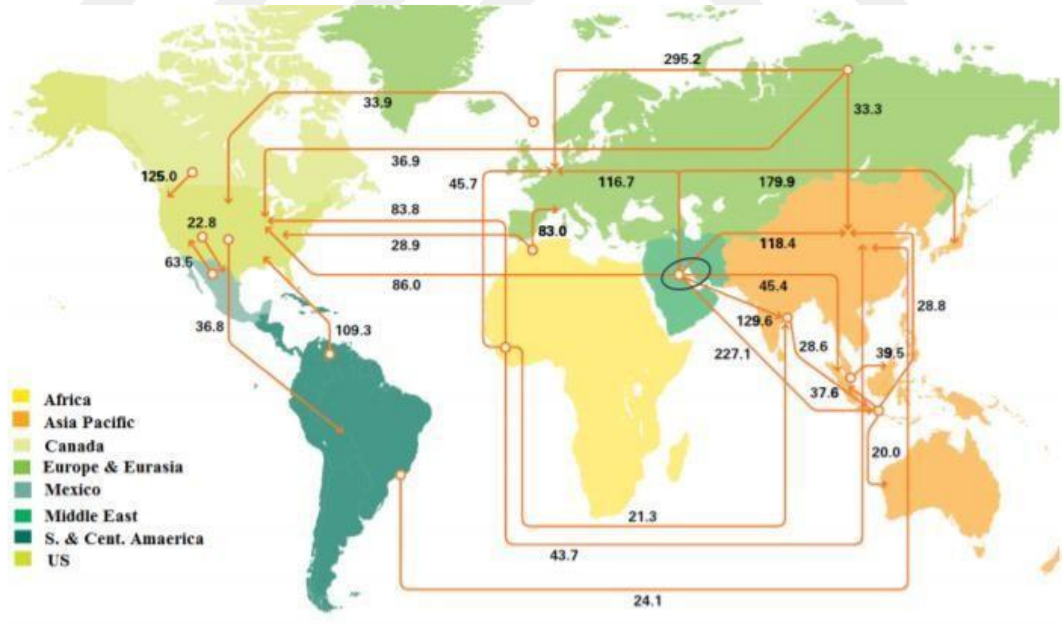

Figure 1.1: Crude oil flows (BP, 2011).

Revealing this geographical mismatch between the oil distribution and the increase of demand as shown in Figure 1.1, the role of supply chain in the petroleum sector rises.

And because of these strategic issues and the rapid technological development, managing the supply chain of oil and gas has become crucial in the geopolitical scale and the economic outlook between countries.

1.1. Background information

With a population of over 80 million, and while petroleum production meets only around 7% of the total energy demand, Türkiye is considered as a net importer of oil and gas as it spends over 40 billion dollars every year for the imports of the energy supplies such as natural gas, oil and coal (Ministry of Energy and Natural Resources, 2019). Considered as a complex vertical integrated network, the petroleum supply chain in Türkiye is mainly composed of import and transit activities as well as advanced infrastructures. Operating with two Liquefied Natural Gas (LNG) terminals, five refineries and two Floating Storage Regasification Unit (FSRU), the main gas suppliers are Algeria, Qatar, the United States and Nigeria. According to Lemieux in 2014, around 52% of the petroleum imported by pipelines is crude oil transported to refineries for chemical processing while 48% is in the form of refined petroleum products. Thus, after converting crude oil into mostly gasoline, diesel fuel and jet fuel, all these products are sent to distribution centers primarily via a network of underground pipelines. Pipelines are the primary mode of transport of crude oil and refined products since it is the safe, economical, and reliable courier of energy. Finally, the distribution units have two unique customers: i) wholesalers such as power plants, some manufacturing plants, airlines, shipping companies. ii) retail customers who represent fuels distributors for heating and transportation.

On the other hand, national oil and gas exploration and production company Turkish Petroleum (TP) is considered a top upstream developer for both onshore and offshore explorations in Türkiye and abroad in joint ventures with international petroleum companies. In addition to that, Türkiye is a main energy mediator between many petroleum producers in the region and other consumers in Europe.

After the discovery of the natural gas reserves offshore the Black Sea in August 2020, Türkiye started to develop new strategies for energy security and supply chain management of the petroleum sector (Figure 1.2).

1.2. Aim of the research

One of the key objectives of the petroleum supply chain is to ensure an optimized and safe delivery of crude oil and refined products to consumers. With increasing demand, uncertainties and freight costs, the petroleum supply chain is subjected to major challenges.

Figure 1.2: Türkiye's major oil and natural gas transit pipelines (Lieber, 2015)

Therefore, fostering a wholesome approach and efficient supply networks has become critical to satisfying the varied demands while keeping up desirable profit margins. From here, the main goal of this study is to develop an optimization model for the petroleum downstream petroleum supply chain including the network design. This model tackles the effective delivery service through quality management, sustainability in the supply chain and the innovative strategies applied.

Therefore, the optimized supply chain model is associated with the following strategic decisions:

- Optimization of distribution center's locations and capacities.
- Planning and scheduling of transfer volumes.
- Selection of transportation mode.

As a result, the petroleum supply chain responds to various disruptions more effectively by considering a different model based on minimizing the total fixed cost and distribution cost. The first stage decisions are correlated to locations and proactive mitigation strategies set in the planning phase while the second stage decisions are reactive mitigation strategies taken in the implementation phase.

1.3. Thesis Questions/Hypothesis

Nowadays, with the increasing demand for energy, research on methods to improve the supply chain management of petroleum products is more necessary now than ever. To serve all the demanding nodes across Türkiye efficiently, it is essential to manage the flow of materials along the supply chain with the allocation of the distribution centers based on the relevant logistics aspects. Therefore, this brings us to question the new development of an optimized supply chain strategy in the oil and gas industry across Türkiye for the next upcoming years. In this study, we investigate several concepts of this strategy to answer the following three questions:

- What are the challenges and opportunities facing the Turkish petroleum supply chain management?
- What aspects does the oil and gas industry have for optimizing the supply chain?
- What are the economic benefits and environmental implications considered in our model?

The first question deals with the integrated distribution network design and product allocation arising in the context of transportation planning of petroleum products distribution centers over Türkiye. The second question tackles the effective delivery service through quality management, the sustainability in the supply chain and the innovative strategies applied. The third question focuses on the financial and environmental impacts of the applied strategies of our model.

1.4. Research Significance and Contributions

Considering the importance of the petroleum industry and the necessity for the expansion of the supply chain, this research draws attention to being able to make robust decisions based on quantitative methods. This study contributes to petroleum supply chain management, strategic and operations management within the oil industry literature in several extents including the following:

- Design a potential oil and gas supply chain system along with incorporating the inputs of the discovered petroleum field.
- Design multiple modes of transportation strategically in the supply chain.
- Deal with optimization while considering various aspects of management including the environmental impact.
- Integrate the geographic information system in a proposed mathematical framework to locate refineries, potential distribution centers, and demand nodes.

1.5. Scope and Structure of Thesis

Optimization of the supply chain becomes an important factor in field development strategies targeted to maximize the efficiency of energy supply and long-term economic feasibility of the country. Hence, this study includes an integrated distribution network design evolving of a comprehensive strategy and transportation planning of petroleum products distribution in Türkiye. In this study, the optimization model consists of various activities like measuring, analyzing, modeling, prioritizing, and implementing actions. First, several aspects and contributions from the literature are presented to combine all the past studies exploited in the supply chain of the petroleum industry. Second, a well-developed quantitative methodology is conducted to evaluate the application of optimization on different oil and gas companies in Türkiye. Finally, the results are collected and analyzed to test and conclude.

2. LITERATURE REVIEW

Accounting for a large amount of the world's energy consumption, crude oil is considered one of the most valuable raw materials in many countries. Petroleum or rock oil is the result of a series of organized underground geological events in the sky thousands of million years ago. Originated from organic matter, it consists of a mixture of gas and liquid hydrocarbons which are processed and refined by fractional distillation to get various products. In fact, the petroleum industry plays a vital role in the global economy as well as in our daily life. Being the main source for car fuel, home electricity, modern medicine, and agriculture and much more domains, the petroleum sector moves a massive quantity of products and turns into backbone to almost all economic activity. As a result, the global demand for oil has increased significantly to reach more customers.

Due to this globalization, along with the technological growth in the industry, the oil and gas sector involves a large-scale supply chain consisting of international and domestic transportation, production control, logistics and information technology (Matveeva, 2015). However, unlike other industries, Chen et al. (2017) reveals the complex structure of the supply chain of the petroleum industry starting from the exploration phase to the distribution process of the end product. Thus, the complexity of this system implies a significant risk on the level of the national economy. Moreover, Muhindo et al. (2014) describes the employed logistics as a highly inflexible network since it directly depends on the activities of the production of oil and the long transportation lead time associated. According to Hilmola in 2011, these factors led the petroleum corporations to develop a tactical strategy and a strong supply chain management in order to reduce costs as well as creating their competitive value advantages in the market. Hence, several studies tackle the petroleum supply chain design and planning while other research shifts towards tactical and strategic activities implemented to ensure excellence service and delivery. By developing and applying both models, companies manage to achieve a remarkable saving in cost reaching up to 15% (Goetschalckx, Vidal, & Dogan, 2002).

Therefore, many academics have discussed the key factors for the optimization of the supply chain such as demand management, warehousing and transportation scheduling. On the other hand, recent studies and research have dealt with integrating sustainability, quality assurance and innovation in the supply chain of the petroleum sector to link further empirical theories to practices and improvements in the field.

2.1. Petroleum Industry Supply Chain Management

Supply chain management is defined as a set of organized activities integrating the responsibility of all various partners to deliver a certain product or service. This process is achieved by customer satisfaction, profitability and competitiveness of the entire supply chain. Moreover, it involves many tasks like coordinating the flows of materials, information and finance from manufacturer to final customers.

The modern petroleum industry dates to the middle of the19th century with the discovery of the Drake Well producing about 20 barrels per day in the state of Pennsylvania (Fernandes et al., 2013). Today, oil evolved to become one of the most valuable commodities traded around the world through an advanced supply chain. Hoffman (2004) defined the supply chain management as coordination and configuration while applying continuous improvements on the set of operations linking between the supplier and the customer. According to Miller in 2016, the main goal of the supply chain management in any industry is to maximize the customer service level at the lowest cost possible. Therefore, the supply chain management in the petroleum industry includes all the activities accomplished ever since the exploration, production phase, processing in refinery and product distribution along with employing capital, labor, information technology, and other resources flow. Thus, integrating operation management and optimization involves the entire supply chain as well as the large logistic network presented.

2.1.1. The Oil Supply Chain and Its Characteristics

Before discussing the different types of optimization and improvement, it is essential first to investigate the background of the oil industry as well as the production process mentioned in the literature. Coaton (2013) divided the whole supply chain of the oil and gas industry into upstream, midstream, and downstream (Figure 2.1). According to Sahebi in 2013, the upstream part refers to the exploration and production activities including seismic, geological and petrophysical operations as well as designing, drilling and well abandonment. In addition to that, Sahebi et al. (2014) underline the role of facilities engineering in the upstream segment which consists of managing the logistic network on site such as the wellhead, drilling string and production platform. Connecting the upstream and the downstream section, midstream in the petroleum industry involves the infrastructure employed in transporting the petroleum products including pipelines, tankers, ships, and rail trucks (Christopher, 2019). Beside the storage system, transportation is one of the main features in the midstream sector ensuring the delivery between the field, refinery assets and major consumers located in different regions. Li (2013) claims that refinery and petrochemical processing along with marketing strategies are the main functions of the oil and gas downstream segment. Indeed, this sector provides mainly gasoline used as fuel for vehicles, but it offers a variety of products such as diesel, lubricants and plastics depending on the quality of the crude oil and the market. Next, these finished products are delivered directly to the distribution centers and oil terminals primarily via pipelines as it is considered an economic, safe, and reliable mode of transportation (Fernandes et al., 2013). The potential customers are wholesalers such as power plants, airlines, and manufacturing companies as well as retailers like gas stations.

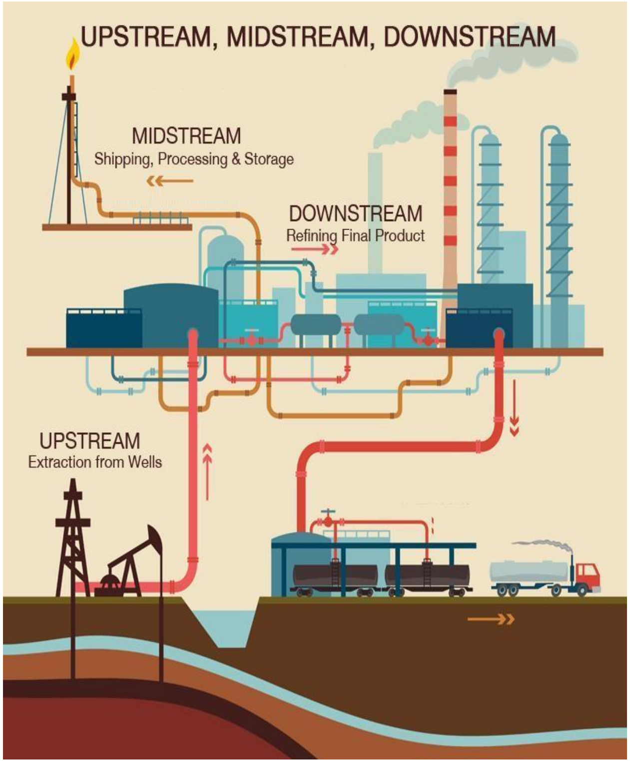

Figure 2.1: The Structure of the petroleum supply chain (Coaton, 2013)

Associated within a complex, inflexible and vertically integrated supply chain, the upstream suppliers and the downstream distributors involve strategic decisions with an efficient logistic network in order to manage increasing demand, reduce costs, improve quality and customer service.

2.1.1.1. Complex Supply Chain

In the past years, the petroleum industry has evolved to have one of the most complex and advanced supply chains around the world. Compared to other industries, crude oil passes a long journey from the first stage of production to the drop off point for the customer. Consequently, long distance attained by this fossil fuel extracted from one specific field results in a long lead time of several weeks in different players in the supply chain (Hussain et al., 2006). Moreover, Gainsborough (2006) describes the refinery process as a capital intensive and complex element which requires demand forecasting and high inventory management. Finally, the distribution activities engage logistics management to assure the delivery of goods to the right customer efficiently in time using the most convenient way of transportation such as pipeline, rail, road, or water depending on the type of petroleum products and the geographic circumstances (Hussain et al., 2006). Overall, it may be said that the petroleum supply chain is considered complex since it requires a long lead time, high inventory level and logistics management.

2.1.1.2. Inflexible Supply Chain

Another main feature assigned with the petroleum industry is the inflexibility of the supply chain. While the first distribution occurs within a fastened pipeline capability or potential coastal shipping, the secondary distribution is limited and engaged on a business oil contract as shown in Figure 2.2.

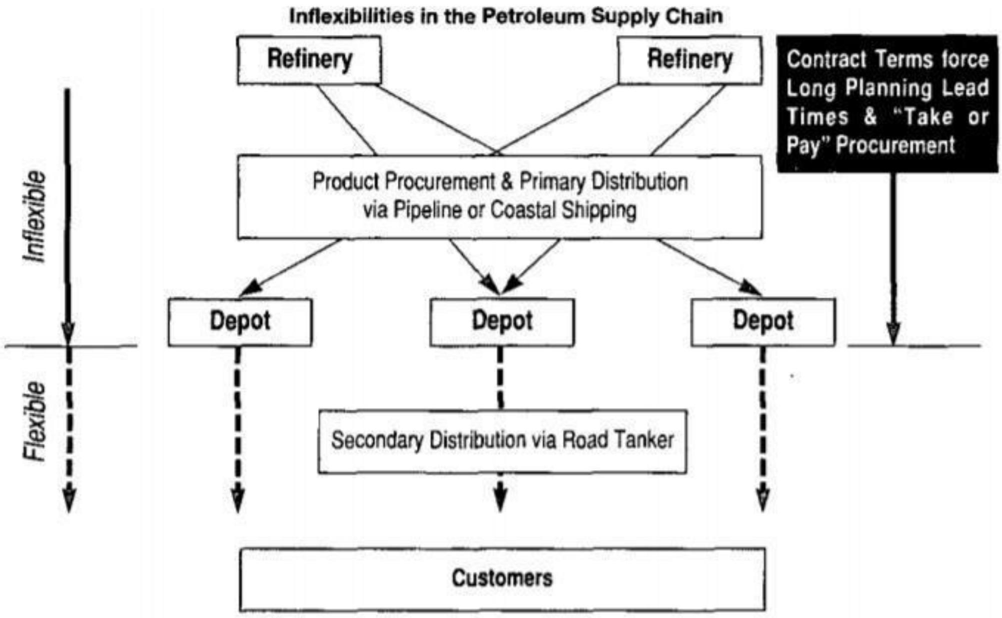

Figure 2.2: Inflexibilities in the petroleum supply chain (Gainsborough, 2006).

2.1.1.3. Vertically Integrated Supply Chain

Recent developments described the petroleum supply chain basically as a vertically integrated coupled with a push system approach. According to the prominent theory of Fisher in 1997, discussing basic concepts in supply chain strategies, demand pull affects the scheduling activities for the delivery of the product to the customers. Thus, positioning the decoupling point in the downstream sector and securing transportation reduces the bullwhip effect. Exploiting reliable transportation mode and placing inventory closer to the final consumers enhances the customer satisfaction since operational efficiency, product availability, and faster lead time are realized.

2.1.2. Management Decisions

Supply chain management is defined as a developed process starting with configuration, followed by a sequence of coordination and continuous improvement. Ashayeri and Tuzkaya (2012) examined the different aspects of configuration by involving a set of managerial decisions such as the bundle choice, sourcing, production capacity, allocation of facilities and technology adopted. Since the supply chain management involves various collaborators, coordination from the perspective of each partner is one of the most vital management decisions. Sinha et al. (2009) affirmed that coordination ensures effectiveness in cost, quality and time as it facilitates setting optimized targets for inventory, capacity and lead time. In parallel, communicating market and performance enables monitoring the supply and demand to customers as well as leading to improvement. According to Melo et al. (2009), improvement of the supply chain requires changing of the key managerial decisions taken in the configuration and coordination stage to enhance the overall system after continuous evaluation. For instance, variation of demand in the market has a direct and huge impact on cost and lead time amplifying along the whole chain. Based on the coherent information sharing between partners, improvements are managed and assessed in configuration and coordination. Other operations researchers used different analytical approaches focusing on individual improvement within the company itself. Barret (2013) tackles the economic decision taken by the firm within the supply chain to benefit from conditions and maximize profit.

2.1.2.1. Strategic Sourcing

Supply chain management also covers the decision of selecting an excellent corps of suppliers. Strategic sourcing denotes implying consistent suppliers with demonstrated performance and favorable status in the market. One of the main considerations in the petroleum supply chain management is supplying exploration platforms and production fields. For instance, supplying an offshore petroleum platform requires continuous forecasting of demand and reoccurring supplies featuring the same approach of supplying towns. Muhindo et al. (2014) illustrates an example of a petroleum company operating in 12 offshore sites and dealing with more than 400 vendors servicing on field who are effectively managed to eliminate waste and cutting cost in the project. Adding to this section one vital strategy rising in the petroleum sector, outsourcing is considered as an alternative to vertical integration. It considers the practice of contracting with third parties who are involved in supplying some aspects and features. According to Stevens in 2016, outsourcing strategy is a recent tactic which provides several benefits in the supply chain such as adding capacity without additional overhead and fixed costs. Thus, outsourcing becomes an opportunity to build core competences, market agility and corporate growth in the global supply chain management.

2.1.2.2. Strategies for Coordination and Improvement

Whether operating the upstream or downstream, petroleum companies integrate various supply chain management decisions. Frequently, coordination in the petroleum supply chain is based on negotiated contracts, long term strategic relationships and collaboration. Sole sourcing is one of the main practices of coordination between suppliers and customers in the petroleum sector where the buyer commits to be the exclusive distributor of the products covering the demand of a specific region. In exchange, the seller supports designing service bundles and quality products (Lambert, 2014). Ultimately, these agreements are built based on trust and integrity between the supply chain partners. Finally, sharing information and continuous coordination from both sides lead to improved quality, reduced costs and customer satisfaction. Once terms and conditions are agreed, improvement will always take place in the supply chain. Nowadays, oil and gas companies are optimizing their operations, looking for the ideal configuration to apply, incorporating new technology and gaining competitive advantages by integrating sustainability.

2.2. Major Issues Challenging the Petroleum Supply Chain

Paratorius, the president of the largest multinational petrochemical company BASF SE, once said that “Manufacturing efficiency alone does not ensure a competitive advantage anymore” (Whitfield, 2004). The discovery of new production sites and the opening of distribution centers in major cities facilitate the delivery of the petroleum products and tend to make it more flexible and less complex. However, the procurement of such assets in the oil and gas industry is very challenging, specifically when installing the logistics network, and it would basically consider the financial and environmental aspects of the plan (Matthew, 2019).

In addition to that, integrated process management along with the information sharing systems directly affects the performance of the supply chain partners in the petroleum industry. According to Christopher in 2019, the petroleum industry stands behind a challenging supply chain planning which requires integration of sophisticated information technology considering the security, scheduling, and collaboration. The implementation of such a system in the supply chain leads to the increase of the cost of acquiring crude oil, which will eventually affect pricing. In the study of literature, supply chain risks in the petroleum sector are categorized in various ways. For instance, Heckmann et al. (2015) classified supply chain risks as operational and disruption risks. Referring to the inherent uncertainties, operational risks include the continuous variation of customer demand, uncertain demand, and cost in function of time. On the other hand, disruption risks consist of any natural disaster (e.g., storms, earthquakes, tsunami, etc.), or socioeconomic crisis such as epidemic, currency evaluation, and military strikes.

The study of Zhao and Chen in 2014 reveals other risk classification, associated the supply chain risks based on physical, financial and information streams engaging the flow of materials and cash and services involved in the process. In addition to that, varied and numerous studies tackle the risks attempted in the logistics part. Sahebi et al. (2014) confirmed that these risks concern various sides of the supply chain management such as the strategy, customer relations, financial, and fiscal legitimate necessities. However, Kiser and Cantrell (2006) had a different point of view by highlighting two sources of risk: the internal risks in petroleum production, planning and control from one side, and external risks like the demand environment of supply in the market. In a nutshell, Figure 2.3 summurizes the main disputes facing the modern petroleum supply chain including profiltibility, performance and impact on environment.

Figure 2.3: Top challenges influencing the petroleum supply chain (Kiser & Cantrell, 2006)

2.3. Optimization of the Oil Supply Chain

Since the petroleum industry is considered as one of the highest capital intensives around the countries, supply chain optimization has become a great opportunity for oil companies to substantially decrease costs and improve performance (Sahebi et al., 2014). In fact, Morphet J. (2016) defines supply chain optimization as an efficient solution system to manage the desired production, reduced lead time, lower costs and satisfy customer needs. Although the application of these activities requires a huge analysis of resources and a good implementation of strategic decisions into the competitive market, the optimization of the supply chain leads to the right decision making in view of every member of the supply channel owing distinctive resources, opportunities, and limitations (Oliveira et al., 2014).

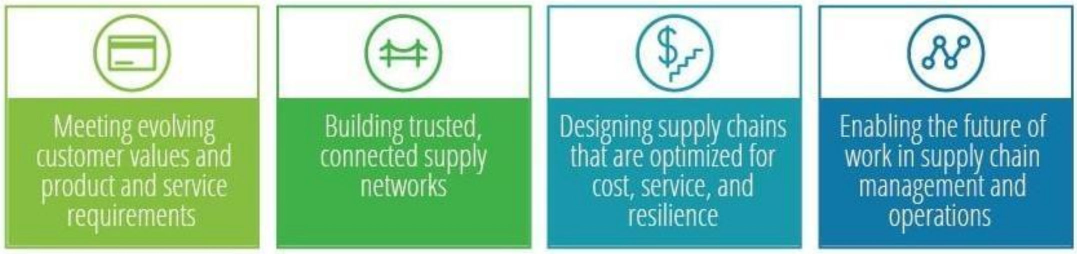

Figure 2.4: Top keys for optimization of the supply chain

To meet all these objectives shown in Figure 2.4, Bhosekar and Ierapetritou (2021) point out five main activities considered as an operational, strategic, and tactical backbone for optimization in the petroleum midstream and downstream supply chain. Applying basic procurement, refinery, distribution, and marketing, this fundamental process includes the following:

- Planning
- Scheduling
- Executing
- Tracking
- Adjusting

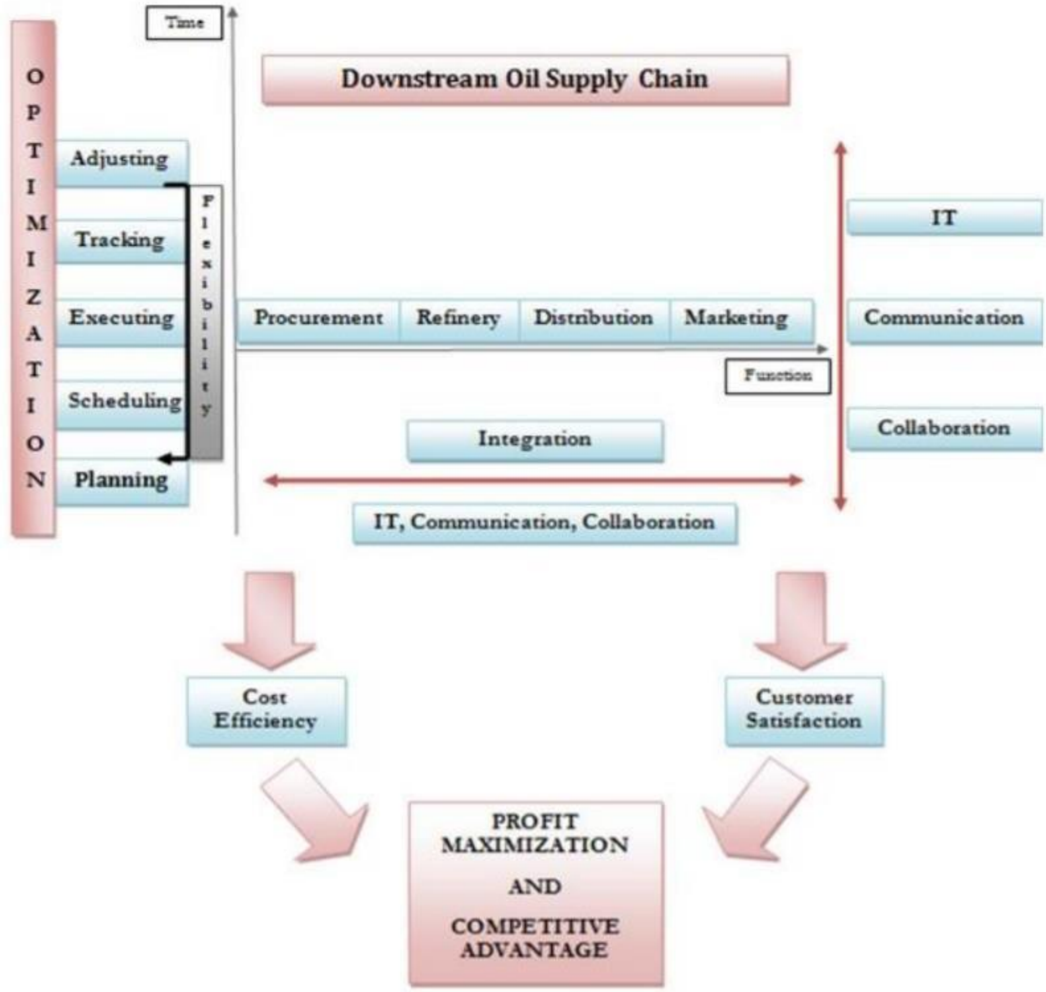

Figure 2.5: Theoretical framework for petroleum supply chain optimization (Bhosekar and Ierapetritou, 2021)

First, planning involves the act of thinking ahead and drawing the results of every decision token at each stage of operation. In other words, it is the development of a standard of performance by the company management to save time and money in the long run. Second, scheduling comes to minimize the scale of planning on a short-term basis. For example, it refers to the phase of allocation of resources, procurement, or the distribution of refined products. In today's market, high quality scheduling strategies result in optimized production of oil and rapid response to global demand. Next, execution is the implementation of both supply chain planning and scheduling to ensure a feasible operation within the designed model and constraints. Thereafter, tracking is achieved by the measure of performance, monitoring, and improving of the optimized supply chain based on the expected rate of return and benchmarking. Due to the daily variation in the market, adjusting plays a vital role in the petroleum supply chain to quickly respond to the customer needs and offer a more sustainable competitive advantage in the future.

2.4. Effective Delivery Service through Quality Management

Today, because of the high level of competition in the petroleum market, the quality management system has become one of the most efficient solution strategies to improve performance. Driven by the increase of business performance, customer satisfaction, and profitability, quality management comprises ecology safety, reliability, efficiency, and effectiveness of the whole supply chain. The need for quality management in the petroleum sector is crucial to assure customer satisfaction by delivering high quality products and services complying with client standards and governmental regulations. According to Craciu and Mihaela in 2013, it expedites trading, information sharing and technological progress by practicing the management process shown in Figure 2.6.

Revealing the market competition, Priede (2012) reveals the top keys of delivering a high-quality service in the oil and gas industry in the following activities:

- Design, formulation, and registration of petroleum products.
- Analyze operations in terms of customer needs.
- Improve quality for higher productivity.
- Reduce the cost of the delivery service.

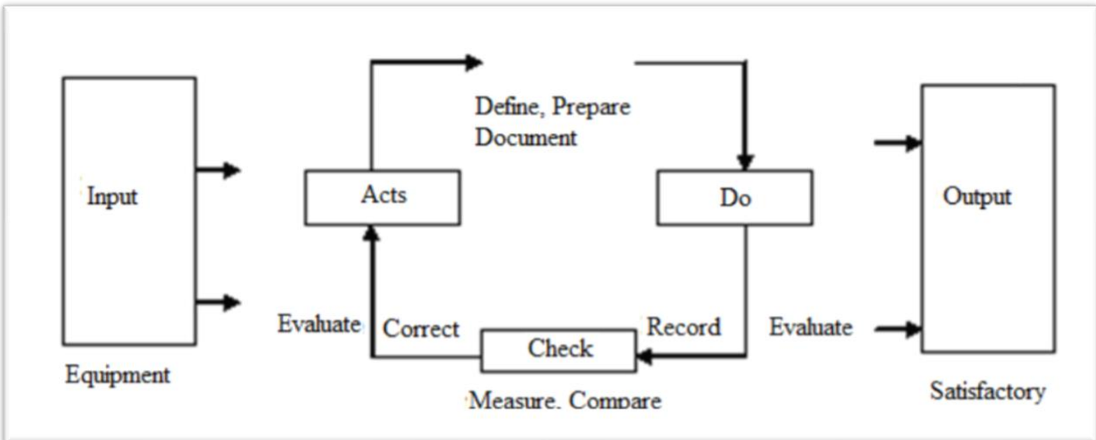

Figure 2.6: Quality management system process (Priede, 2012).

Applied in every stage of the petroleum supply chain, the total quality management ranges from the product's reliability, delivery service and finally the price. Recently, with technological advancement, new electronic devices and techniques are used to measure the accuracy and efficiency of products and services in the oil and gas sector such as six sigma and total quality assurance (Craciu & Mihaela, 2013).

2.5. Sustainability in the Supply Chain

Nowadays, sustainability is one of the most emergent topics examined in supply chain management. Since sustainability has been defined in various styles in different sources of literature review, the first internationally recognized definition of sustainability is that of the World Council of Environment and Development (Du Pisani, 2006). It claims sustainability as "*the development that meets the needs of the present generation without compromising the ability of the future generations to meet their own needs.*" (WCDE, 1987, p.8). Therefore, adopting sustainability is a modern approach that deals with environmental impact and ensures the preservation of natural resources. Nonetheless, oil and gas companies are increasingly adopting sustainable practices in their short- and long-term decisions to meet the interests of stakeholders and generate a competitive advantage in the market. First, demands came from governments by putting strict regulations forcing companies to examine sustainable strategies since concerns rise about the depletion of natural resources. Yet, recent economic studies have argued that sustainable managerial practices in the supply chain are a major factor in improving business performance as well as decreasing total cost (Kazancoglu et al., 2018). Due to the rising of this concern in emerging economies, Tseng et al. (2019) affirm that it essential to apply sustainable initiatives in the petroleum supply chain to increase efficiency and effectiveness at the economic, environmental, and social level along with identifying the key challenges in the field.

Figure 2.7: Sustainable supply chain dimensions.

According to Carter and Rogers in 2008, sustainability in the supply chain mainly tackles three components: economic, environmental, and social (Figure 2.7). While the economic dimension is only related to the members of the supply chain, the environmental and social dimension became a global concern and prosperity for future generations. For example, commercial shipping vessels used in the oil and gas transportation could menace the marine ecosystem in case of leakage. In addition to that, sustainability includes waste management since the petroleum supply chain emphasizes a long and continuous flow from the extraction of the crude oil to the distribution of the finished products (Sahebi et al., 2014). However, developing a sustainable supply chain management requires continuous collaboration, efficient planning, and viable strategies. For instance, codes of conduct are spread in the petroleum industry by information sharing networks to establish principles and ensure those standards throughout the supply chain.

2.6. Innovative Strategies Applied in the Industry

The oil and gas industry has played a vital role lately in adapting new technologies in the market. Therefore, Carter and Rogers (2008) claims that innovative strategies are applied in the field to reduce operational costs in both upstream and downstream sectors such as increasing supply chain visibility, improving compliance, and enhancing supplier collaboration. In fact, these strategies require a balance in supply inventories while having an overview of the regulations and policies in the logistics process. According to Muhindo et al. in 2014, innovative strategies in the petroleum supply chain include minimization of material procurement, maximization of manufacturing capacity, meeting demand, and maximizing throughput. Nevertheless, some external factors cannot be controlled and require challenging practices and innovative solutions. As shown in Figure 2.8, Matthew (2019) develops a conceptual framework describing innovations embedded in the petroleum supply chain.

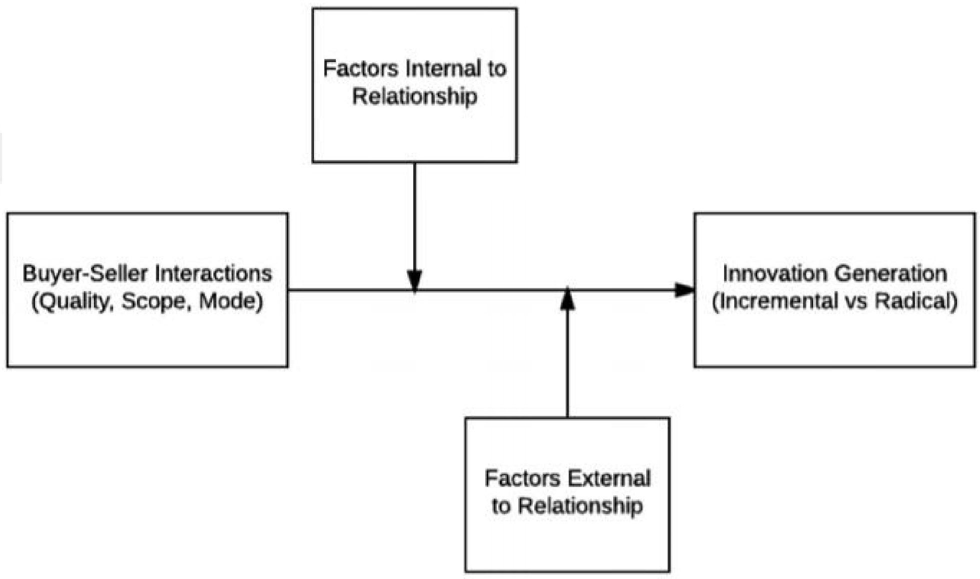

Figure 2.8: Innovation framework in supply chain generation (Matthew, 2019).

While internal factors include managerial actions such as IT adoption, commitment, and trust, external factors are hard to control and involve applications of technology, stability of demand, and network connections. Hence, applications of technology are crucial to understanding innovation, while the nature of demand illustrates the agility of the supply chain.

3. METHODOLOGY

Building and developing an optimized supply chain in the petroleum sector has been a challenging process involving the procurement, production, transportation, sales, and financial segments of the business. According to Leiras et al. in 2013, supply chain optimization in the petroleum sector tackles all types of processes leading to improved performance and efficiency. It applies to managerial tactics, both quantitative and qualitative, that results in a supply chain that is more lean, profitable and agile. Indeed, our petroleum supply chain optimization model focuses on a mathematical problem-solving method illustrating quantitative approach for finding the best combination of upstream production, refineries, terminals, the flows between them, and other elements under specific constraints. Linking quantitative approach to management-based qualitative methods divides the petroleum network optimization into three categories:

1. Strategic management relating size and location of refineries and terminals, the structure of service networks and most efficient overall supply chain design.
2. Tactical decisions addressing upstream production, modes of transportation, and inventory planning while dealing with international market supply and demand uncertainty.
3. Operational management including production scheduling and control, refineries and terminals operations.

Therefore, mixed methods research is integrated in this study where quantitative and qualitative techniques complement one another while investigating different aspects of optimization of the petroleum supply chain in Türkiye. According to Creswell in 2011, this synthesis involves multiple methods to generate and examine integrated data, so combining the overall functions associated with qualitative and quantitative research. Strategic and tactical enhancement results mostly in solving large-scale data-intensive problems while applying mixed-integer linear programming solvers and visualization using Geographic Information System (GIS). Since its first conceptualization in the 1950s, GIS has been a powerful technology used to capture, examine and manage spatially the input data. Today, the applications of this system go beyond geography and include mapping, resource planning, transportation and environmental science. In the petroleum sector, GIS is applied in both upstream and downstream segments to provide solutions such as locating the drilling wells on site, routing the pipeline system and building refineries (Yeletaysi, 2009). Moreover, models and solutions processed by the software have recently been employed by major service companies to optimize and support strategic and tactical decisions in the petroleum supply chain (Zhang et al., 2021). In addition to that, GIS is also considered as a primary source of information to enrich communication between supply chain partners.

3.1. Strategic and Tactical Development GIS Model

In this model, various approaches using GIS are modeled to foster a total dynamic framework for the petroleum supply chain in Türkiye. Retreiveeng the main data from EIA 2016, the simulated model in Anylogistix is analysed using the location and capacities of refineries, distribution centers and demanding nodes existed in literature along with the cost of transportation. Therefore, large-scale distribution network design models are visualized and adjusted through integer programming network optimization. Based on the ground and waterway networks, pipeline and rail routes, the model assesses the shortest flow path algorithm of petroleum products. The study only covers the fast-moving petroleum products: gasoline and fuel. After locating the refineries, potential distribution centers and demand nodes in the area, the optimization model assigns the flow volume and mode of transportation while considering optimal planning decisions.

As mentioned in the Oil & Gas Journal (OGJ)aren 2016, the amount of proved oil reserves in the southeast region of Türkiye is estimated around 312 million barrels. In addition to that, the estimated natural gas reserves are about 177 billion cubic feet (bcf).

3.1.1. Petroleum Sector Organization

Considered as state-owned firms, Türkiye Petrolleri Anonim Ortaklığı (TPAO) and Petroleum Pipeline Corporation (BOTAŞ) operate as the main exploration and production petroleum companies along with foreign joint ventures in upstream activities. Accounting for more than 80% of the import and export energy market, the two companies build and operate natural gas pipelines, terminals and storage facilities over the country as well as marketing and trading.

3.1.2. Exploration and Production/ Consumption and Imports

While consuming more than 860,000 barrels of liquid fuel daily (Figure 3.1), Türkiye produced about 62,000 barrels daily in Batman and Adiyaman fields which account for around 7% of Türkiye's oil consumption (EIA, 2016).

Also, natural gas consumption increased recently to reach around 1.7 trillion cubic feet (tcf) yearly while BOTAŞ imports almost 22 tcf of gas considering the variation of demand over the year. Moreover, Türkiye is an important rising transit center serving the delivery of oil and gas supplies from Russia, Central Asia and Middle East to Europe. Assuring the transport via the Turkish waterways Bosporus and Dardanelles, significant volumes of natural gas are delivered by tankers and pipelines.

Recently, offshore and shale oil reserves have become a promising source of energy in Türkiye after the discovery of potential fields in the Aegean and Black Sea (Figure 3.2).

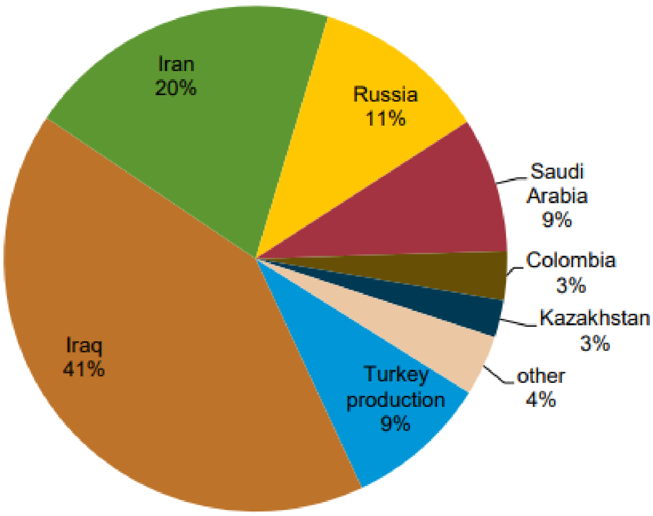

Figure 3.1: Türkiye's crude oil supply sources

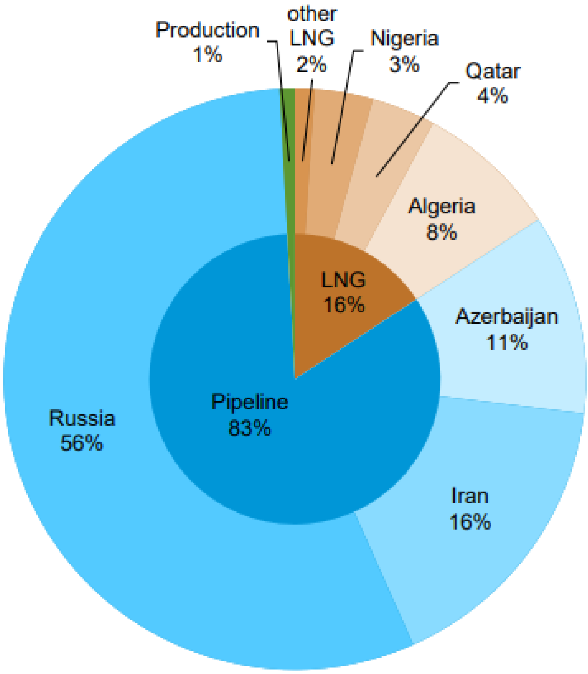

Figure 3.2: Türkiye's natural gas supply source

Gasoline is considered the most consumable product followed by fuel due to the difference in demand for each product (Ministry of Energy and Natural Resources, 2019).

3.1.3. Pipelines

The piplines from which crude oil is imported to feed Türkiye are given in the Table 3.1, and the two most important main pipelines are:

- Baku-Tbilisi-Ceyhan (BTC) from Azerbaijan.
- Kirkuk-Ceyhan from Iraq.

Table 3.1: Türkiye's crude oil pipeline

Pipeline	Status	Capacity (million b/d)	Length (km)	Supply Regions	Destination	Description
Baku-Tbilisi-Ceyhan (BTC)	Operating	1.2	1770	Azerbaijan & Kazakhstan	Ceyhan Oil Port	Started to operate in 2006
Kirkuk-Ceyhan	Not Operating	1.5	1965	Kirkuk	Fishkhabour	Started to operate in 1976 and stopped in 2014 after the attack in Iraq
	Operating	1.5	645	Fishkhabour	Ceyhan Oil Port	

Kurdish Regional Government (KRG)	Operating	0.7	400	Northern Iraq	Ceyhan Oil Port	Minor Pipeline started to operate in 2013
Samsun-Ceyhan	Canceled	1.5	550	Russia & Central Asia	Ceyhan Oil Port	Uncompleted due to economic reasons

In addition to that, BOTAŞ has natural gas pipeline interconnections to international import and export operations, and it is expanding to fulfill growing domestic natural gas consumption as well as the market in Europe (Table 3.2).

Table 3.2: Türkiye's natural gas storage facilities

Facility	Status	Capacity (bcf)	Destination	Description
Kuzey Marmara	Operating	90	TPAO	One of the oldest gas storage facilities in Türkiye consisting of 2 depleted reservoirs and the capacity could be expanded to reach 150 bcf
Marmara Ereğlisi LNG	Operating	6	BOTAŞ	LNG terminal storage
Aliağa LNG	Operating	6	EgeGaz	LNG terminal storage
Tuz Gölü	Under Construction	35	BOTAŞ	Salt dome storage
Tarsus Province	Planned	180	Bendis Energy	Planned to open in 2023 to be the largest gas storage facility in Türkiye

3.1.4. Refining Sector

According to OGJ in 2016, Türkiye had five refineries with a combined processing capacity of 663,000 b/d, Tüpraş is Türkiye’s dominant refining firm and operates four refineries that account for 85% of the total refining capacity. Tüpraş also owns more than half of the total petroleum products storage capacity in Türkiye. Tüpraş was formerly state-owned, but since 2005 it has been 51% owned by a joint venture controlled by Koç Holding.

3.1.5. Multimode Supply Chain Model

Considering an optimized model of the downstream petroleum supply chain, a comprehensive description is provided by SCM software (Anylogistix) focusing on developing numerous simulations for single mode and multimode of transportation.

Then, supply chain configuration, total cost of transportation and performance measures of each generated model are analyzed and compared to realize the ultimate potential network design of distribution. In the proposed model, various input indices, parameters and constraints are set in SCM to reach the key decision variables as shown below.

<u>Notation:</u>

i : Index of refinery; $i \in I$

j : Index of distribution center; $j \in J$

k : Index of demanding nodes; $k \in K$

m : Index of transportation modes; $m \in M$; (M_1=pipeline; M_2=barge; M_3=rail; M_4=truck)

D_k : Average annual demand of node *k*

F_j : Fixed cost of opening a distribution center *j*

V_{ijm} : Variable cost of transportation from refinery *i* to distribution center *j* via mode of transportation *m*

T_{jkm} : Transportation cost from distribution center *j* to node of demand *k* via mode of transportation *m*

S_i : Total capacity of refinery *i* per year

X_j : 1, if a distribution center *j* is opened; otherwise, 0.

Y_{ijm} : Volume of products shipped from refinery *i* to distribution center *j* via mode of transportation *m*

Z_{jkm} : Volume of products shipped from distribution center *j* to node of demand *k* via mode of transportation *m*

C_j : Capacity of distribution center *j*

#	Customer	Product	Demand Type	Parameters	Time Period	Revenue
	filter	filter	filter		filter	filter
1	Mediterranean	(All products)	Periodic demand	Order interval: 7, Qu...	(All periods)	1,534,500,000
2	Marmara	(All products)	Periodic demand	Order interval: 7, Qu...	(All periods)	3,751,000,000
3	Aegean	(All products)	Periodic demand	Order interval: 7, Qu...	(All periods)	2,387,000,000
4	Black Sea	(All products)	Periodic demand	Order interval: 7, Qu...	(All periods)	1,364,000,000
5	Central Anatolia	(All products)	Periodic demand	Order interval: 7, Qu...	(All periods)	6,308,500,000
6	Southeastern Anato	(All products)	Periodic demand	Order interval: 7, Qu...	(All periods)	1,705,000,000

Figure 3.3: Demand configuration on Anylogitix software

#	From	To	Cost Calculation	Cost Calculation Parar	CO2 Calculation Parar	Currency
	filter	filter	filter			filter
1	Tupras Izmit Locatic	TPAO Location	Product&distance-b	Distance [0, 1,000): 0...	Distance [0, 1,000): 0...	USD
2	Tupras Izmit Locatic	Botas Location	Product&distance-b	Distance [0, 1,000): 0...	Distance [0, 1,000): 0...	USD
3	Tupras Izmir Locatic	EGE Gas Location	Product&distance-b	Distance [0, 1,000): 0...	Distance [0, 1,000): 0...	USD
4	Socar Star Oil Locati	EGE Gas Location	Product&distance-b	Distance [0, 1,000): 0...	Distance [0, 1,000): 0...	USD
5	Tupras Kirikkale Loc	BOTAS Salt Dome Lc	Product&distance-b	Distance [0, 1,000): 0...	Distance [0, 1,000): 0...	USD

Figure 3.4: Product flow configuration on Anylogotix software

Source	Expand Sources	Destination	Expand Destinations	Vehicle Types	Product	Expand Products
filter	filter	filter	filter	filter	filter	filter
Sakarya Field		Tupras Kirikkale		Vehicle Type	(All products)	

Figure 3.5: Primary transportation constraints on Anylogitix software

In summary, this multimode supply chain model examines the location of distribution centers and their overall capacities as well as the flow capacity from refineries to the final nodes of demand while engaging 4 modes of transportation. Therefore, the software runs on optimizing the supply chain design by mathematical formulation to determine the decision variables considering the following objective functions:

- Minimize the total fixed cost of distribution centers.
- Minimize the total variable cost within the distribution centers.
- Minimize the total operating cost of transportation of products from refineries all the way to demand nodes.

3.2. Research Questionnaire on Sustainability Adoption in Petroleum Supply Chain

On the other hand, operational issues are also assessed with an evaluation of the company's activities involved in the supply chain through a well-designed survey. Commonly, survey research is a typical quantitative method used to collect sample data based on several types of communication (Creswell, 2011). Generalized to the oil industry, the assessment was conducted to 22 of petroleum companies in Türkiye through Google Form link sent by email attached with an introductory and a cover letter. Since the sample must be a true representative of the targeted companies (Walliman, 2011), chief executive officers (CEOs) reflect and generalize invariably the vision of their firms like optimization and sustainability adoption. Using the

LinkedIn searching and filtering engine, various types of companies were pointed in this research according to their size and activities including operators, service companies, consultancy and contractors. In designing the questionnaire, the first input section provides an overview of oil and gas companies in the Turkish petroleum industry including collective and financial information. The main objective of this survey is to determine the impact of sustainability strategy on the operational supply chain performance of petroleum companies. This questionnaire is used to collect and investigate the impact of sustainability practice in the supply chain between petroleum companies operating in Türkiye on organizational profit. Considered as a pioneer quantitative methodology to investigate, questions tackle the drivers of sustainability, level of practices, challenges and performance of operational and service companies in the oil sector. Indeed, an empirical study is implemented to test the impact of integrating a green supply chain on the operational and financial level of organizations targeted.

The survey aims to assess the impact of implementing sustainability in petroleum supply chain management. It is composed of 16 questions and will take around 10 minutes to complete. By participating in this study, all operational activities of the company will be assessed for academic purposes only and a summary of findings will be available for you.

A. Company Background Information

1. Company Name: ……………………………………………….
2. Year of Establishment: …………………………………….
3. Number of Employees:
   - Up to 50.
   - 51-200.
   - 201-500.
   - 501-2000.
   - More than 2000.

4. Industry Sector:
   - Upstream: Exploration & Production.
   - Midstream: Transportation, Logistics & Storage.
   - Engineering Consulting.
   - Engineering Services: Reservoir, Drilling, Facilities & Equipment.
   - Downstream: Refinery, Distributor & Allied Services.
5. Average Turnover per year:
   - Up to 100K $.
   - 101K $ - 500K $.
   - 501K $ - 1M $.
   - 2M $ - 10M $.
   - More than 10M $.

B. Level of Sustainability Practices

6. Sustainability Duration Status:
   - None.
   - 1 – 2 years.
   - 3 – 5 years.
   - 6 – 10 years.
   - More than 10 years.
7. Initial Sustainability Investment Amount:
   - Up to 5K $.
   - 6K $ - 50K $.
   - 51K $ - 200K $.

- 201K $ - 500K $.
- More than 500K $.

8. Indicators of Sustainability:
   - Economic.
   - Environmental.
   - Equity.
   - Legal.
   - Other …………………….
9. System of Performance Assessment:
   - Environmental Sustainability Index (ESI).
   - Ecological Footprint (EFP).
   - Operational Performance Index (OPI).
   - Human Development Index (HDI).
   - Other ……………………….
10. Sustainability Indicators Functions:
    - Anticipate Information.
    - Compare Situations & Organizations.
    - Scaling Larger Systems.
    - Other …………………...

C. <u>Drivers of Sustainability</u>

11. To which extent do you believe the following measures and strategies affect the operational performance of the company?

Environmentally friendly processes *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Reducing waste *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Engaging free emission processes *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Using renewable energy *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Using outsourcing ecological guidelines & Reprocessing *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Engaging into environmental research programs *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

D. <u>Sustainability Strategies Implemented</u>

12. What are the sustainability market driven strategies adopted in your company?
    - Introducing new environmentally sensitive products.
    - Redesigning existing products to make it environmentally sensitive.
    - Advertising environmental benefits of products.
    - Dealing with material recycling & selling wastes.
    - Other…………………

13. What are the sustainability process driven strategies adopted in your company?
    - Environmentally friendly production.
    - Reducing & Treatment of wastes.
    - Using renewable resources.
    - Designing free emission process.

- Other…………………

14. What are the difficulties confronting the implementation of sustainability strategy?
    - Higher operational cost.
    - Shortage in competence.
    - Lack of expertise & information.
    - Inappropriate infrastructure.
    - Other…………………
15. What is the time expected to return your investment after the sustainability strategy is adopted?
    - Up to 2 years.
    - 3-5 years.
    - 6-8 years.
    - More than 8 years.

E. Competitive Advantages

16. To which extent the following competitive objectives are priorities in your operation?

Speed *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High

Cost *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High

Delivery *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High

Quality *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High

Innovation *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High

Customer Loyalty *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High

Relative Performance to Competitors *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High

Dividing the survey into 5 parts, section A represents 5 questions about background information and demographic description of responding companies including the size and main workflow process in the petroleum industry. Then, section B covers 5 multiple choice questions targeting the level of sustainability practices such as investments and reporting applied in the company. Thus, this part evaluates the importance of long-term investments on sustainability by petroleum companies as well as often measuring the effect of the sustainability strategies on operational performance mentioned in the next section (Yusuf et al., 2012). Hence, section C represents a linear scale question which assesses 6 different measures and strategies affecting the operational performance of the company. Section D attempts to discover the aspects of sustainability strategy and environmental concerns. Nowadays, literature intensively expresses the drivers of sustainability in firms to preserve and protect the environment as Shrivastava (2010) cited social and ecological sustainability variables like transparency and provision of safety and health facilities. Several inhibitors of sustainability are also pointed out in question 14 to spot the light on the barriers facing the responding companies from adopting sustainability in the petroleum industry. Revealing the competitive advantages of implemented strategy, section G of the survey represents a linear scale question consisting of 7 different priorities taken into consideration by the responding firms and examines the optimization factors in the organizational strategy and operations. According to Kleiner in 1991, sustainability asserts a strong correlation on both markets driven and process driven strategies.

4. IMPLEMENTATION AND RESULTS

First, the distribution center's locations are defined in the model along with the corresponding inclusion type for the supply chain. Then, these implications are recognized per servicing area, source of the products flow and storage policies. In addition to that, asset constraints are defined as well as the cost calculation policy parameters to finally meet the simulation's optimization objective.

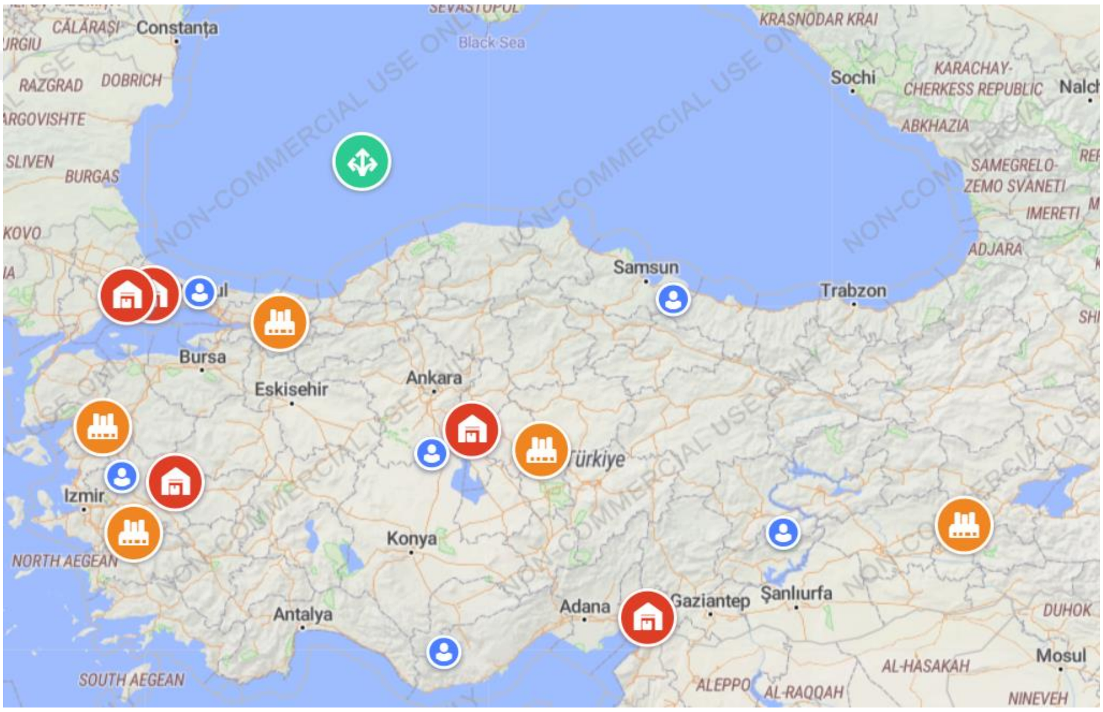

Figure 4.1: Spatial Configuration

Figure 4.1 presents the main locations and capacities of the distribution centers where pipeline is the only mode of transportation. Distribution centers are presented with proportional symbols to the optimal capacities allocated for a more realistic visualization.

4.1. Execution of the model

According to Tsao (2012), the transportation cost varies linearly with the freight distance and has an average of 0.8 cents per ton-kilometer by pipeline, 0.15 cents by barge, 9 cents by rail and 27 cents by truck. Thus, the transportation network is simulated for each mode in software by visualizing the real distance of truck routes, waterway and railway network to obtain the total cost from refineries passing by distribution centers to final customers.

Next, Greenfield Analysis (GFA) executes the simulation to calculate the distribution center's locations considering roads, nodes of demand and existing infrastructure in the area. Since the transportation map of Türkiye is not included in this softaware, this supply chain network design offers optimal mathemathical solution to determine the best location of opening of a warehousing facility if needed based on the locations of the customers, the demand of the product, and the direct distance between customers and existing distribution centers.

4.2. Variation and Comparison Experiment

The third step is also executed by the simulation distribution network analysis to engage variation and comparison between the single mode and multimode transportation scenarios (Figure 4.2). As expected, a new gas pipeline parallel to the BTC is established to connect Sakarya field with the nearest refinery in Kırıkkale operating at an optimal capacity of around 32 billion cubic feet per annum. In addition to that, 3 new distribution centers were opened to receive mainly liquified natural gas via pipeline and deliver to demanding nodes all over Türkiye. Therefore, mode of transport is a critical component particularly when considering a multimode design. While single mode of transportation is not considered efficient in terms of costs, multimode scheduling is compared, validated and analyzed at the tactical level. For example, engaging several modes of transportation here chooses optimal distribution centers locations regarding the accessibility of different refined products. As a result, all parameters such as geographical location, number and capacity of the new distribution centers alter in the multimode simulation which employs offshore pipelines towards the refinery. Moving from refinery to storage, pipeline and rail allows delivery while all modes are used in the secondary transportation to carry the transfer of refined products to demand nodes.

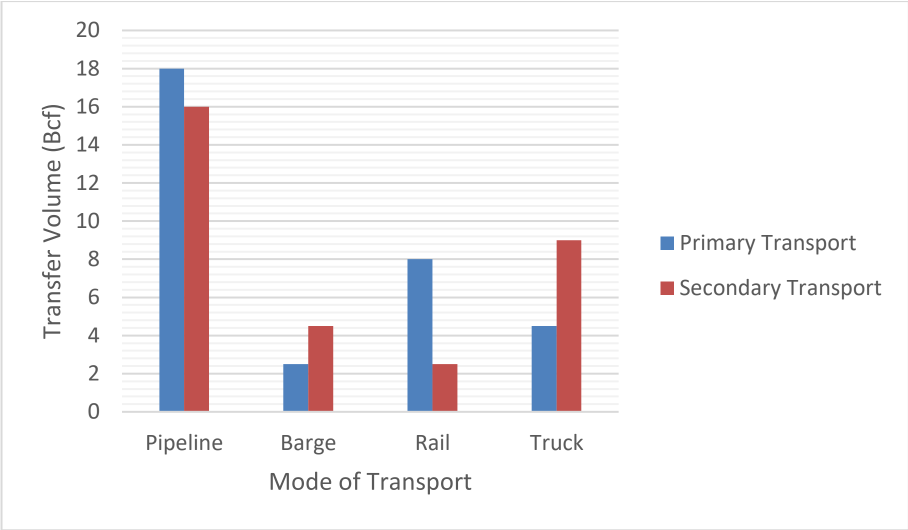

Figure 4.2: Transfer volumes in the primary and secondary transportation

Through strategic planning of the supply chain, different petroleum storage facilities are using multiple modes of transportation to demand points. This process accounts mainly to use pipeline and rail in the primary transport of gasoline and fuel. On the other hand, secondary transport combines mostly pipeline, truck and barge. Considering the constant handling cost of both fuel and gasoline across all the distribution centers, the mode of transport preferred of all products depends only on the accessibility and the distance of the transportation network to the demanding nodes. After fixing all distribution centers location derived from the model simulation, a multimode option is assigned while keeping all constraints selected in Table 4.1- 4.2 to investigate the efficiency of implementing the multimode route instead of the single mode model.

Table 4.1: Cost comparison (in Million $) between single mode and multimode model

	Single Mode Model	Multimode Model
Primary Transportation Cost	34.2	34.2
Secondary Transportation Cost	36.3	41.4
Total Supply Chain Cost	70.5	75.6

Table 4.2: Statistics measures for DC capacity in single and multimode models

	Single Mode Model	Multimode Model
Mean	17,888,112	11,171,631
Median	15,864,587	9,264,498
Standard Deviation	14,689,686	10,686,575

As a result, the selection of multimode transport optimizes the model since the total cost decreased for the supply chain as shown in Figure 4.3.

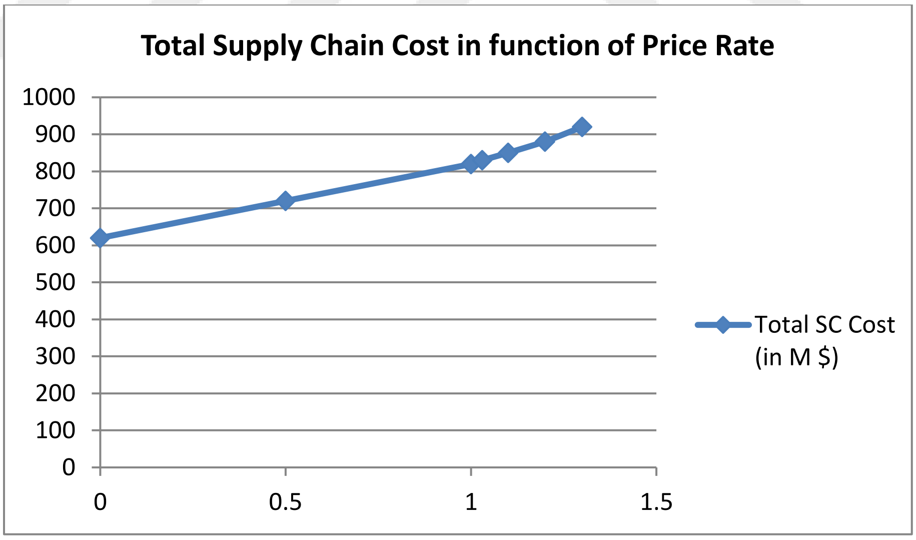

Figure 4.3: Sensitivity analysis on the total cost of the supply chain

This is often primarily due to the key plan of the multimode model distribution centers which allows the supply chain players to select the efficient mode of transportation in each echelon. Therefore, the optimized model decreased the total supply chain cost by around 2.5% which is considered relatively significant in margin profit of the petroleum supply chain (Kazemi and Szmerekovsky, 2016). On the other hand, this multimode model yields a more efficient supply chain design by selecting the right approach in both primary and secondary transportation. For example, using the barge minimizes the overall shipment costs as well as total supply chain cost.

In summary, our multimode model optimizes the location of the distribution centers by considering the allocation of transfer volumes to the selected transportation modes to satisfy the demand and minimize the total supply chain cost. Thus, it is crucial to integrate multimodal transportation decisions in the strategic design of the supply chain to operate with cutting costs and improve supply chain efficiency.

In order to have a better understanding of incorporating multimodal transportation in strategic planning, further statistical analysis is computed on the capacity of each distribution center. These calculations include mean, standard deviation, and median of distribution centers capacities as reported in Table 4.2. Ultimately, the simulation approach using Anylogistix and numerical results of the GFA, and the transportation models are discussed in this chapter. After comparing the multimode and single model, numbers show that using multimode transportation in the petroleum supply chain is more beneficial at the strategic planning level since it results in better performance and cost-efficiency on the total supply chain.

4.3. Sensitivity Analysis

Since supply chain nowadays is widely complex and incorporates various processes, studying and understanding cost drivers become crucial to reduce the entire supply chain expenses between the interconnected features.

This section examines the effect of variation of key model parameters defined in the software on the petroleum supply chain design. The main objective of sensitivity analysis is to visualize the model with several input factors to run interference for decision makers in strategic and tactical processes within the petroleum supply chain. In addition to that, sensitivity analysis implicates calibration of the model as well as solving the large-scale problem by enrolling in historical data analysis, literature reviews and future assumptions. The output data of this method is related directly to the key decision associated with the infrastructure, logistics operations and economic structure of the supply chain.

First, the oil price parameter was interpreted by defining an interval of variation between 1 and 30% considering the total demand in the region as well as the current economic and political situation.

As expected, the total petroleum supply chain cost increases proportionally with the rise of the unit price. However, the simulated model design remains the same with a slight change in distribution centers capacities. Therefore, the base model remains almost consistent across all the values of the input price parameter.

Second, the demand nodes were also assessed in this section according to EIA online resources in 2016 to predict the impact of variation of demand in the future supply chain decisions. The sensitivity analysis was performed to study the total consumption values of fuel and gasoline in Türkiye for the next 10 years with a range of increase by 10% and 18% respectively as shown in Figure 4.3 (EIA, 2016).

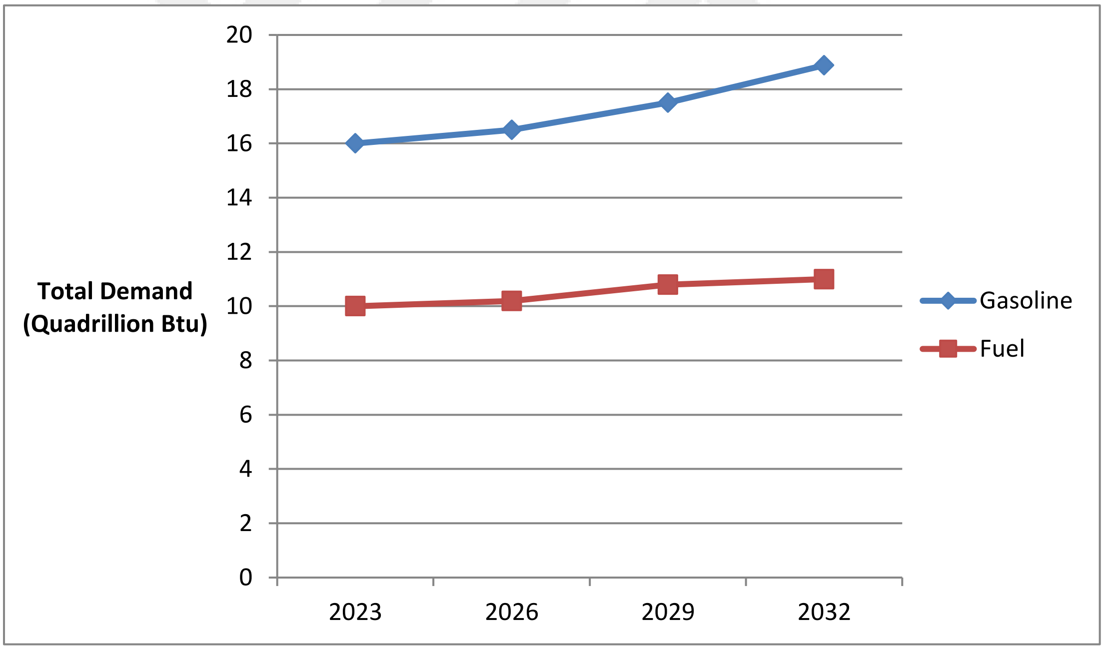

Figure 4.3: Total demand forecast during 2022-2032

Investigating the effects of this parameter, the results confirm that the variation in demand has a direct and significant impact on the supply chain configuration. In fact, two scenarios were executed by Anylogistix with respect to the rate of change in demand values as follow:

a) Reforming the supply chain model completely by optimizing the location of distribution centers, their capacities and allocation of products.
b) Keeping the base model fixed while optimizing the capacities of the distribution centers and allocation of products according to the change in demand,

These two scenarios are optimized and compared to the base model to assess the effect of the change of demand on the supply chain design and configuration.

Before embarking on analyzing the simulated data, it is vital to generalize the main significant supply chain cost drivers in the model to include investment of all supply chain partners on facilities and resources, transportation costs like routing and deployment of resources, procurement, production and inventory costs (Figure 4.4). Managing strategic decisions concerning the combination of all costs mainly leads to reducing the total supply chain costs as well as improving delivery performance.

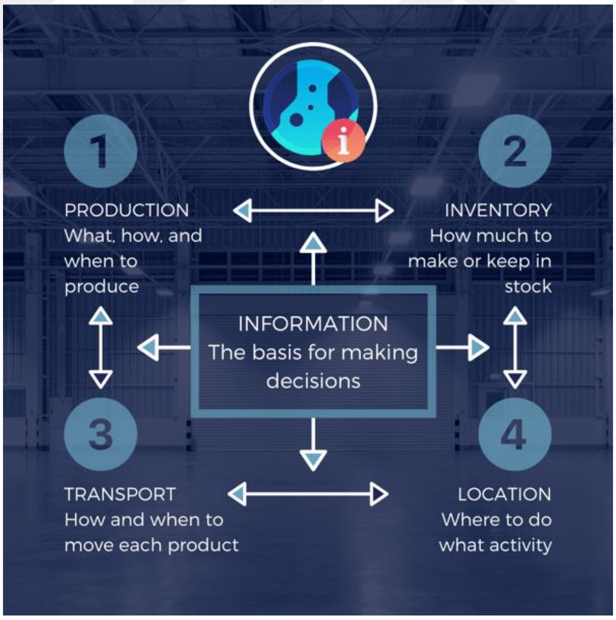

Figure 4.4: Supply chain cost drivers

The outcomes of the sensitivity analysis are presented in Table 4.3 which shows that the total supply chain cost is raised up in both scenarios. This increase in rate is affected evidently by the increase in demand, especially of gasoline which has the most significant impact on the performance of the whole petroleum supply chain. Scenario (b) has a lower total supply chain cost since the whole system was redesigned leading to an opening for 3 new distribution centers with different capacities to satisfy the increase in demand with time.

Despite keeping the same number of distribution centers in scenario, the overall cost of the supply chain in scenario (a) exceeds the value in scenario (b) by around 10 million dollars. This implies that increasing demand for the upcoming years has an outstandingly expanding supply chain configuration with higher annual total capacities to perform well and optimize the aggregate expenses.

It is important here to highlight that the goal is to reduce excess inventory as well as maintain the right quantity of fuel and gasoline in the convenient distribution center at the accurate times across the multi-echelon distribution network.

Table 4.3: Impact of forecast demand on supply chain model

	Base Model	**Scenario (a)**	**Scenario (b)**
Total Supply Chain Cost (million $)	85.6	80.5	76.8
Number of Distribution Center	5	5	7
Total Annual Capacity (million ton)	57	57	63
Primary Transportation Cost (million $)	34.2	34.2	44.6
Secondary Transportation Cost (million $)	41.4	36.3	15.7

In summary, the sensitivity analysis entails the impact of the increase in demand on the strategic decisions of the supply chain base model. Over the forecasted period, transportation costs increase due to high-capacity utilization; however, the opening of 3 additional distribution centers optimizes the overhead. This also shows that the multimode supply chain configuration tends to perform robustly by considering alterations in key parameters in the upcoming years. Finally, optimizing the supply chain leads to the lowest costs and the efficient configuration to deal with the variation of demand. Thus, a tradeoff is considered to minimize the overall impact of demand on supply chain design and budgets by setting constraints for capacity expansion as well as re-optimization.

4.4. Survey Responses Analysis

A total of 40 questionnaires were sent to online addresses of respondents imported from the LinkedIn database by applying the corresponding search filters of industry and region. 14 companies replied to the message and filled the survey giving a response rate of 35% which is considered reliable for the study on the petroleum supply chain in Türkiye.

4.4.1. Profile Characteristics of Respondents

Identifying core demographic features of survey respondents which refer to the size of organizations measured by number of employees and by annual turnover submitted by 14 respondents, Figure 4.5 shows that half of the sampled organizations have more than 2000 employees and about 30% represents companies operating with less than 50 workers.

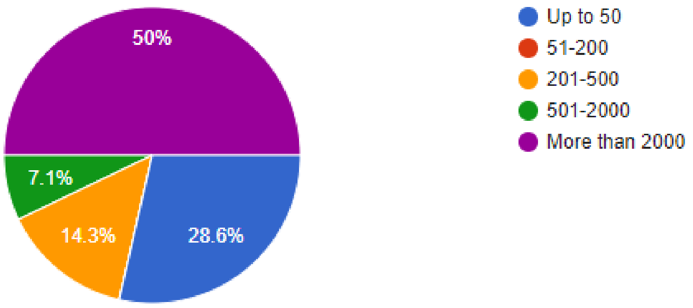

Figure 4.5: Company size results

The result of the company's annual turnover in Figure 4.6 shows that around 60% of participants have an income between 500 thousand and 10 million dollars per year while more than 35% marks a higher rate.

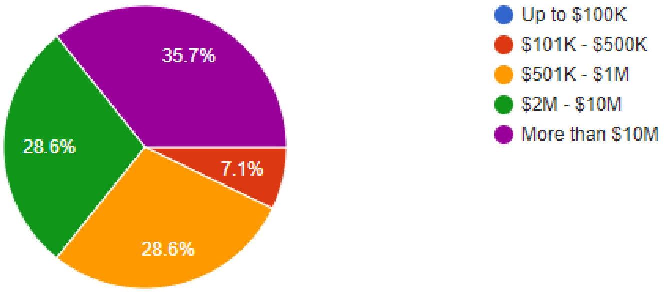

Figure 4.6: Company turnover results

This result shows that the majority of the reacting parties are large scale companies with a range of other medium and small size enterprises based on the European Union classification in 2003.

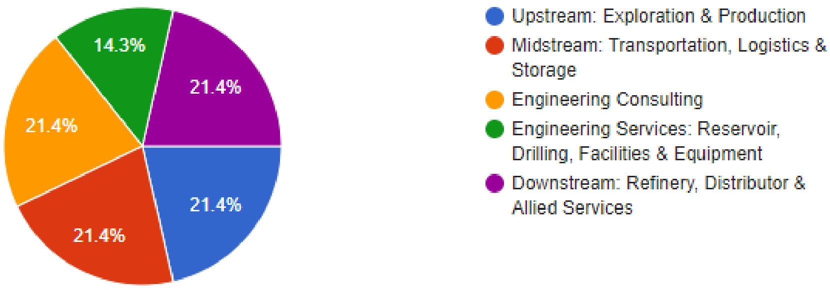

Figure 4.7: Industry sector results

Figure 4.7 displays that petroleum companies are almost equally distributed in each business sector including exploration and production, midstream, consulting and downstream sector. Therefore, the principal industry types of companies here imply the diversity of the petroleum segment which is analyzed by a group of organizations with different cultures and backgrounds.

4.4.2. Level of Sustainability Practices

This section aims to evaluate the level of sustainability practices in the oil and gas sector in Türkiye to recount the impact on the optimization of the supply chain. Hence, the scope of sustainability application in the companies was assessed to tackle the duration, investment and measures taken into consideration for sustainability adoption.

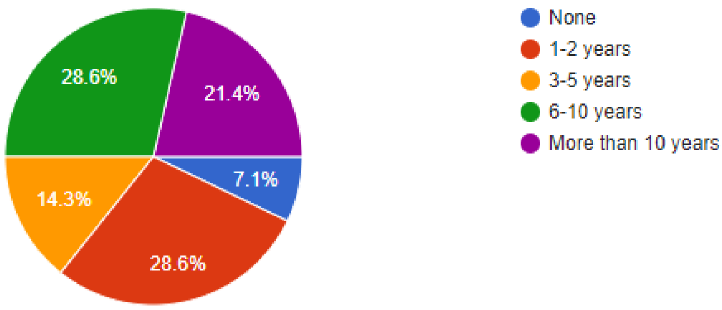

Figure 4.8: Sustainability duration status results

Figure 4.8 shows that around 20% of the oil firms spent more than ten years on sustainability practices, about 30% of companies adopt sustainability within six to ten years, whilst another 30% examine sustainability between one to two years. One company out of 14 is not performing any sustainability activity. These statistics indicate that most of the oil firms are spending at least five years on sustainability implementation and practices within their framework.

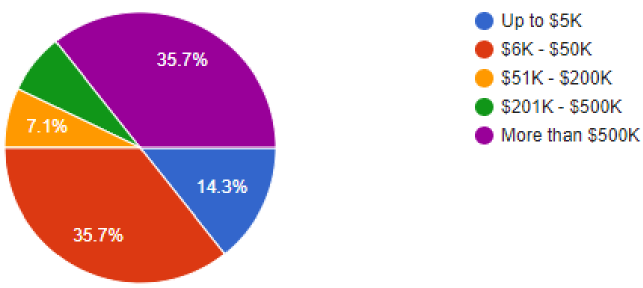

Figure 4.9: Sustainability budget results

Figure 4.9 presents the capital and the overhead costs enquired by companies while implementing and operating sustainable strategies in their business model. Bearing in mind the diversity in the data collected, one third of the respondents invested a considerable sum of money exceeding five hundred thousand dollars while another third of companies spent between six to fifty thousand dollars. According to Nidumola et al in 2015, these funds are disbursed over sustainability market driven strategies which are discussed further in the following section of the survey.

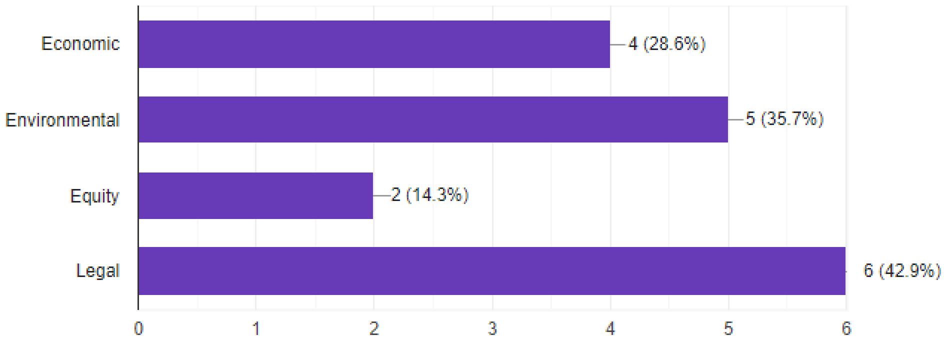

Figure 4.10: Indicators of sustainability results

Sustainability strategies adopted in petroleum companies develop and improve economic, environmental and social aspects. As shown in Figure 4.10, indicators of sustainability in oil and gas companies are a combination of legal, environmental, economic and legal development. The results approve that firms tackle various process driven sustainability strategies counting 17 recorded indicators.

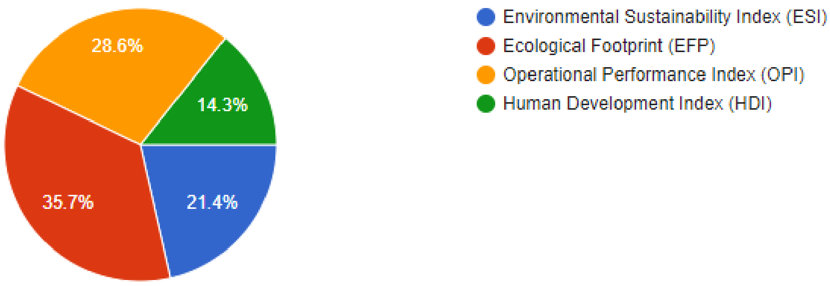

Figure 4.11: System of performance assessment results

To assess the performance of the sustainability system adopted, the results claim that more than 35% of the companies use Ecological Footprint index (EFP) and around 30% of the respondents consider the Operational Performance Index (OPI). Environmental Sustainability Index (ESI) comes in third place to account for around 20% while only 2 companies out of 14 employ the Human Development Index (HDI) as evaluation method (Figure 4.11). In fact, this reporting system reflects the widespread orientation of the petroleum operators and service companies in Türkiye.

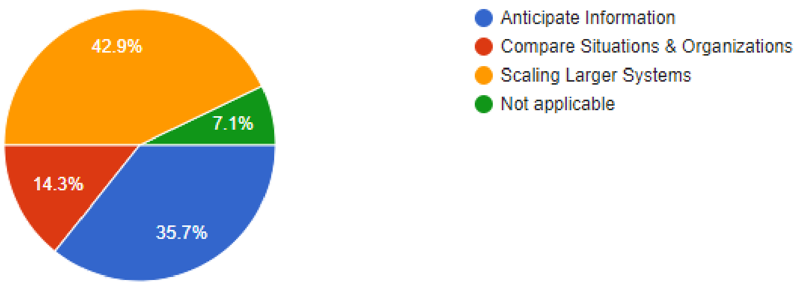

Figure 4.12: Sustainability indicators functions results

Generally, sustainability indicators exploit quantifying and reporting the progress of sustainability performance in organizations (Delai and Takahashi, 2011). As presented in Figure 4.12, the majority of the participant firms examine and report through scaling larger systems as well as anticipating information combining economics, environmental and social indicators.

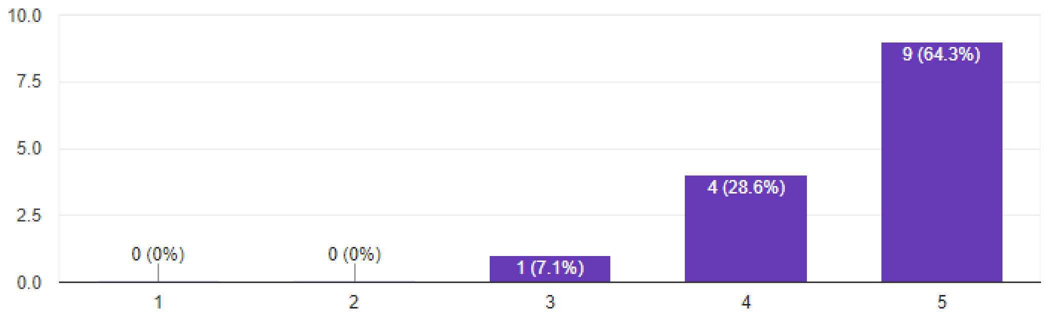

Figure 4.13: Results of the impact of environmentally friendly processes on the operational performance

As expected, Figure 4.13 indicates that most of the companies believe that the sustainability strategies adopted have positive impacts on the environment. By building an environmentally friendly process, these companies which are considered partners in the petroleum supply chain developed new consumer friendly products decreasing the harm and distortion of the environment during the whole cycle.

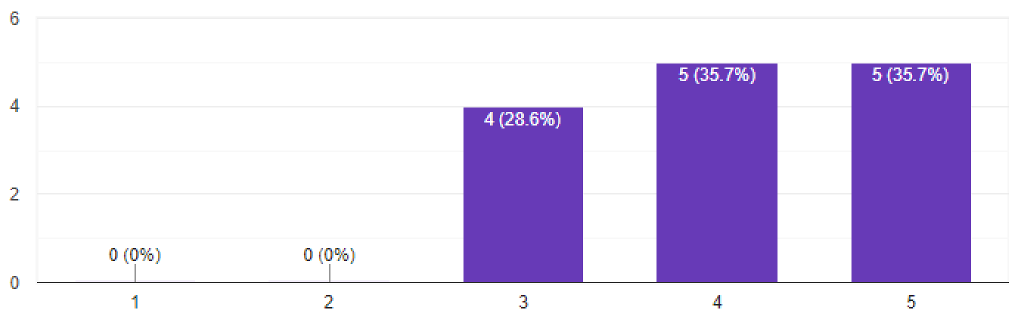

Figure 4.14: Results of the impact of reducing waste on the operational performance

Waste management is a sustainability initiative used to protect land field from deterioration caused by waste deposits (A. Piva, 2022).

Figure 4.14 shows that around 70% of the respondents are considering ways to reduce waste, including 35% who strongly agree that reducing waste has a direct impact on the operational performance of the firm. However, about 30% of the respondents' companies have neutral beliefs. These companies drive engineering services for reservoirs, facilities and equipment without producing any waste while operating.

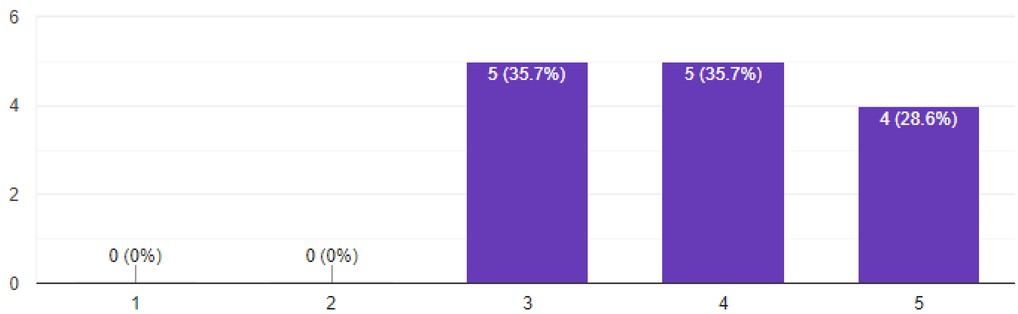

Figure 4.15: Results of the impact of engaging free emission processes on the operational performance

Over the last decades, greenhouse emissions have been considered one of the main contributors of the atmosphere contamination leading to global warming. Hence, about 65% of the respondents relate the impact of free production system on the operational performance, while 35% were neutral (Figure 4.15). This reveals the initiative of reducing future environmental destruction since the majority agrees that engaging free emission processes affects the operational performance of the companies.

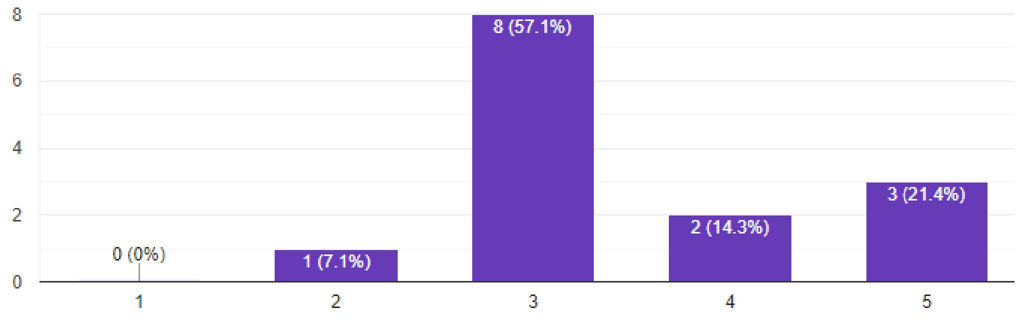

Figure 4.16: Results of the impact of using renewable energy on the operational performance

Although exploring and producing hydrocarbon resources has greatly contributed to the environment, about 35% of the respondents agree that renewable resources affect their operational performance, more than 50% were neutral and 7% disagree with the relevance of renewable energy in their operations (Figure 4.16). These results affirm that numerous petroleum companies in Türkiye started to introduce renewable resources as raw materials in their tactical strategies taking into concern the preservation of natural resources in the environment.

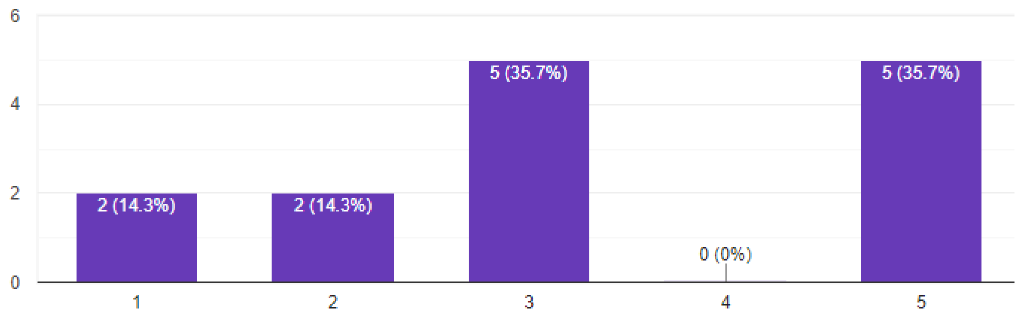

Figure 4.17: Results of the impact of using outsourcing ecological guidelines & reprocessing on the operational performance

Relating sustainable performance to the use of outsourcing ecological guidelines and reprocessing, organizations show a balance in the inherent tension between following different initiatives of cost efficiency and developing innovative practices. Figure 4.17

spectacles this contrast of introducing this concept into the operational tactics of the responding companies.

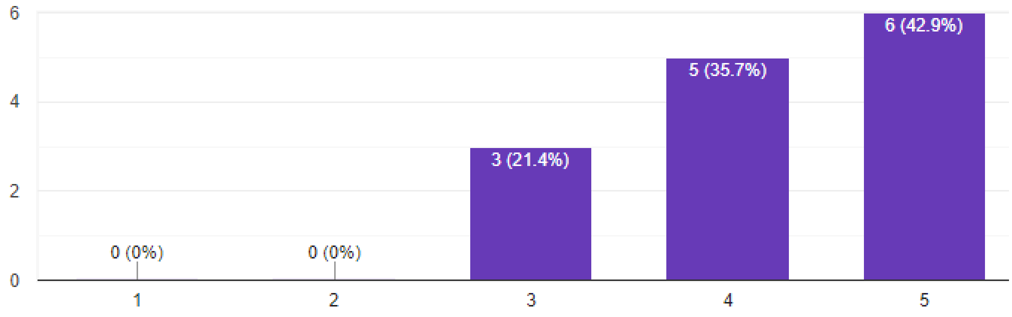

Figure 4.18: Results of the impact of engaging into environmental research programs on the operational performance

More than 75% of the responding companies support the idea of engaging environmental research programs into their different fields of operation, although around 20% were neutral towards this instructive practice (Figure 4.18). It is thus concluded that environmental proactivity has direct effects on business performance of most of the petroleum companies in Türkiye.

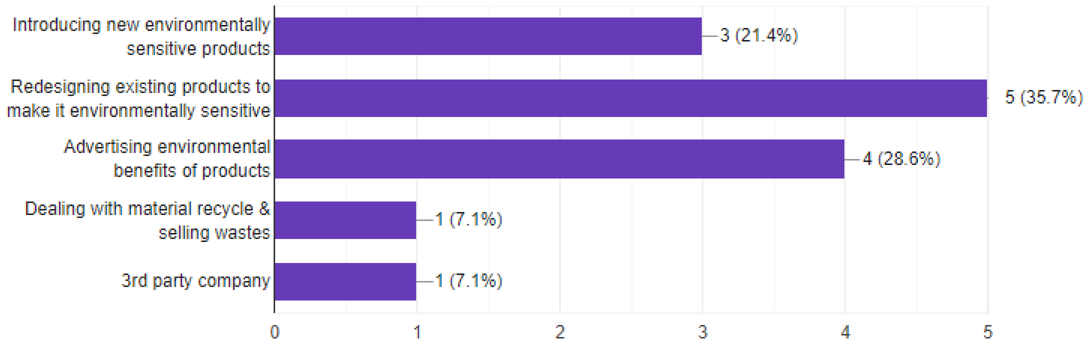

Figure 4.19: Sustainability market driven strategies results

Figure 4.19 demonstrates the drivers of sustainability including advertisement of environmental benefits of products and the development of existing products to make it environmentally sensitive to share around 35% and 30% of the sustainability market driven strategies each respectively. Then, the results mark about 20% of companies introducing new products and minor market share deals with recycling and subcontracting.

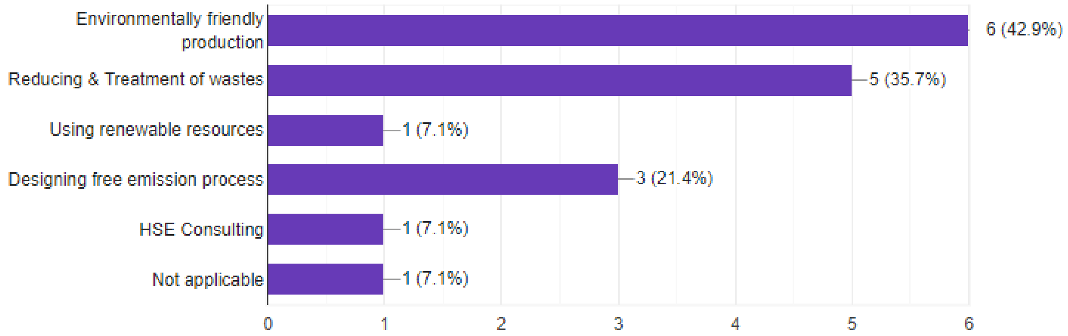

Figure 4.20: Sustainability process driven strategies results

In terms of sustainability process driven strategies, the most preferential route by the responding companies was environmentally friendly production contributing to 43% followed by reducing and treatment of wastes (35%) (Figure 4.20). This outcome validates the finding of the previous question to combine the drivers of sustainability in oil and gas companies and sustainability performance assessment.

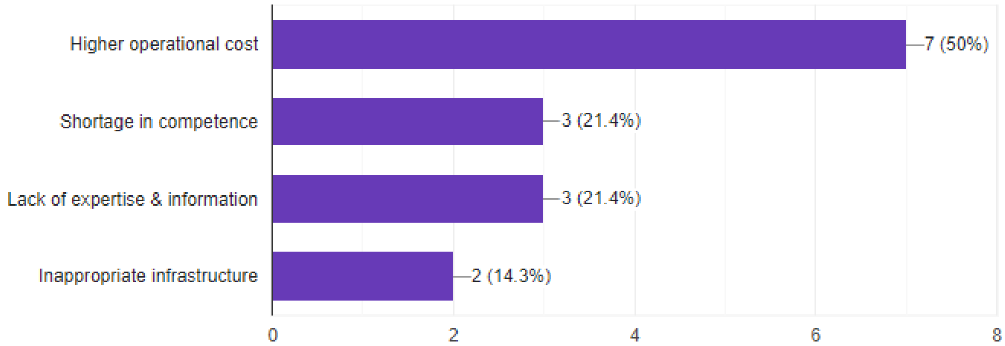

Figure 4.21: Difficulties confronting the implementation of sustainability strategy results.

If sustainability implementation has often been noticed to be challenging to undertake in many companies, cost of adopting sustainability is one of the main reasons advanced by half of the responding firms who claimed that investments on sustainability practices realize a negligible return from required capital. Additionally, shortage in competence certainly weakens the ability of implementing sustainability strategies according to more than 20% of the survey participants. Another obstacle facing the companies moving towards sustainability implementation is lack of necessary information and expertise. As shown in Figure 4.21, around 20% of organizations miss a large amount of environmental information needed while employing sustainability practices in their business. Furthermore, about 15% of companies confront inappropriate infrastructure while installing new types of technologies that are less harmful to the environment.

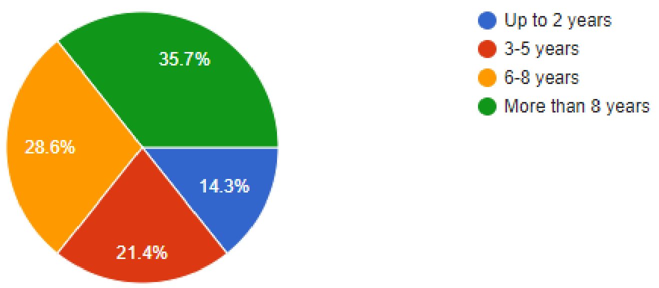

Figure 4.22: Time expected to return investment after implementation of sustainability strategy results.

The projected time for recovering the initial investment on a sustainability plan is not universally acknowledged but it is usually a long-term driven return strategy (Gopalakrishnan et al, 2012). Hence, Figure 4.22 indicates that around 35% of the responding companies took more than eight years to recuperate their initial capital investments. It also took six to eight years for about 30% of the participating firms to recover while about 15% took less than two years to recoup their sustainability investments.

4.4.3. Competitive Advantage Objectives

In the petroleum supply chain, there are several competitive objectives taken on board by companies to develop and enhance their operational performance. This signifies that these measurable practices influence the petroleum supply chain at different levels depending on the type of business in Türkiye. All objectives are collected and integrated in the last section of the survey analysis.

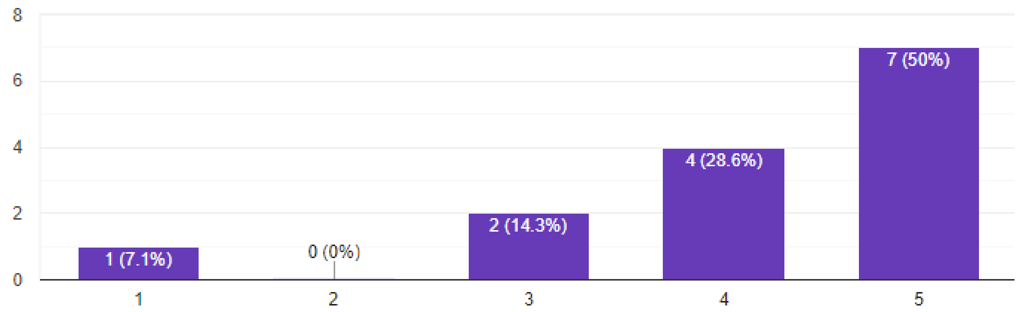

Figure 4.23: Time priority of speed within the company operation results

Figure 4.23 demonstrates that 50% of the respondents agree that speed has very high impact and around 30% also claim that speed has high impact within the company operations, while 2 companies assert that speed is moderate in function of their business operations and one company believes that the relation is irrelevant.

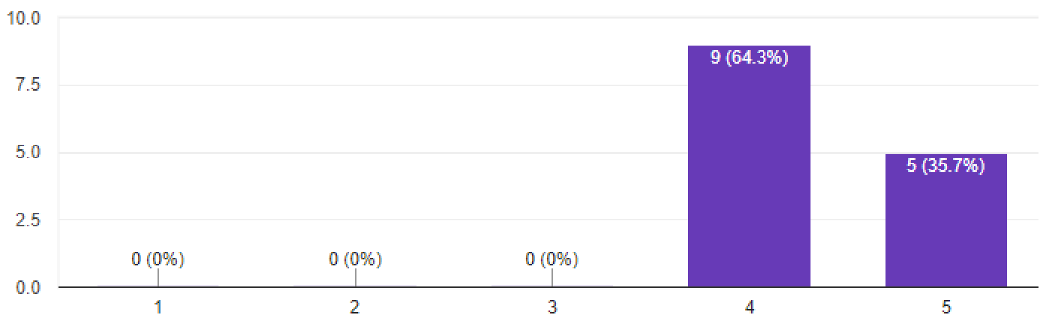

Figure 4.24: Priority of cost within the company operation results.

In terms of cost, all respondents believe cost has a very high and high impact on their operational performance (Figure 4.24).

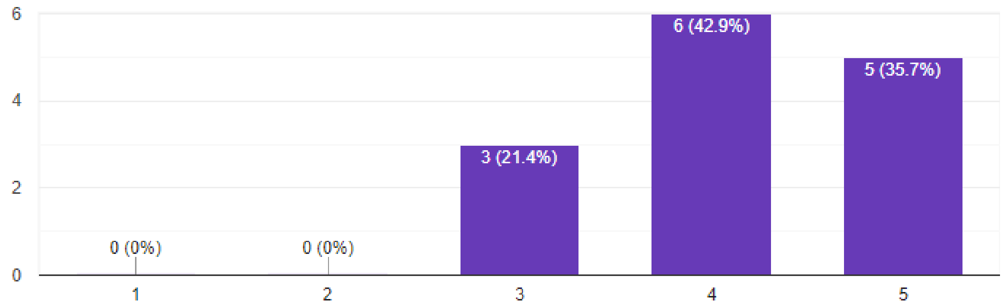

Figure 4.25: Priority of delivery within the company operation results

Figure 4.25 indicates that more than 75% of the respondents believe that there is high and very high importance in delivery in their operations while about 20% consider it moderate priority in their work.

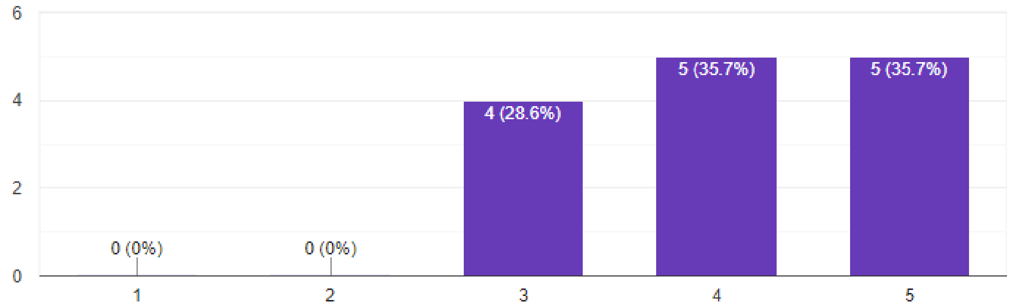

Figure 4.26: Priority of quality within the company operation results

Figure 4.26 denotes that 70% of the respondents confirmed that quality also has high and very high precedence in the operation of the company while about 30% are slightly oriented towards quality.

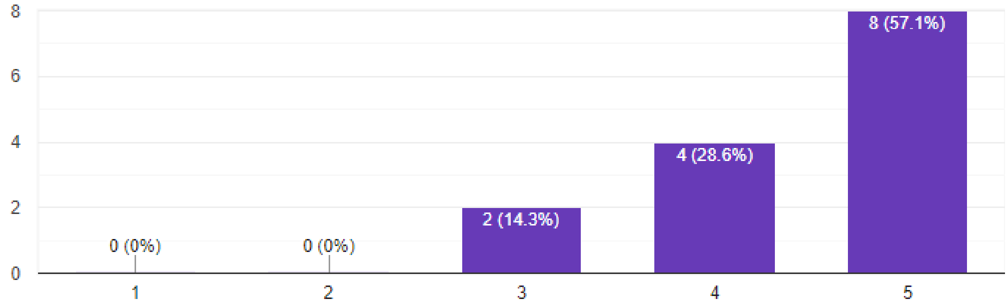

Figure 4.27: Priority of innovation within the company operation results.

Figure 4.27 displays that 85% of respondents are of the view that innovation derives a very high and high impact on the operations within the firm while 15% are neutral.

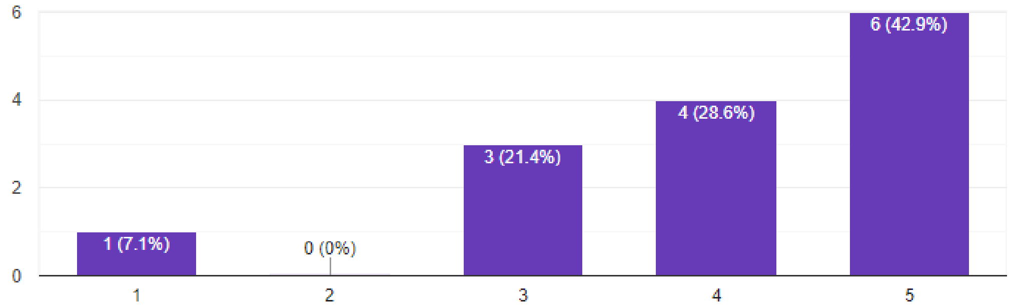

Figure 4.28: Priority of customer loyalty within the company operation results

Customer loyalty highly accounts for around 70% of the respondent's priority as stated in Figure 4.28 while about 20% indicate moderate necessity. Only one company out of 14 strongly disagrees with keeping customer loyalty as a priority in their operation and this is most likely a direct reflection of their market share.

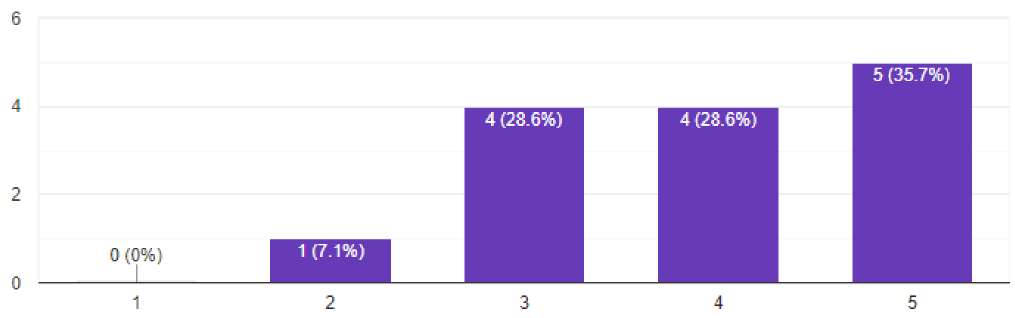

Figure 4.29: Priority of relative performance to competitors within the company operation results.

On the measure of performance relative to competitors, two third of the respondents pronounced high and very high impact on their operational performance, 30% are neutral while one firm disagrees to highlight this competitive advantage at the operational level (Figure 4.29).

This section mainly reported the results of the survey by questionnaire filled by several companies contributing in the petroleum supply chain in Türkiye to assess the impact of sustainability practice and the operational activities in supply chain between petroleum companies. Based on the data collected, the implementation of sustainability is a competitive advantage creating significant effect at the operational level of organizations. This is consistent with the extensive literature review and the expert opinion of academic professionals considering the drivers, inhibitors and the dimensions of sustainability. Moduli et al (2012) stated that drivers of sustainability are a combination of environmental, economic and ecological motives for companies. Yet, implementing green supply chain management counters various managerial problems including the deficiency in funds, lack of information and experience as well as lack of government initiatives in ensuring suitable infrastructure and regulations to adopt sustainability (Dashore and Sohani, 2013). Accordingly, companies decide to implement their tactical plans and operational schemes considering the market driven strategies and the required capital investments.

4.5. Correlation Analysis

Standardized estimates and squared multiple correlations of the survey structures (environmental processes, sustainability market-driven strategies and process-driven strategies) were assessed through Structural Equation Modeling (SEM) to test the conceptual model. The previous data collected from the survey were entered into SPSS® version 26 for Windows to run statistical analysis. According to Malkanthie in 2015, the SPSS software tool enables computation of detailed statistical analysis such as correlation analysis of the data between different variables described in the questionannaire with a correlation coefficient representing the strength and the direction of the relationship of each pair of variables. The regression strength ranges from -1 and +1 which indicates the perfect relationship whether being negative or positive. The direction of the regression is associated with an inverse relationship for negative values and matching relationship for positive values. In this section, correlation between the three independent variables under study was conducted to check the implication of adopting sustainability practices in the petroleum supply chain organisations.

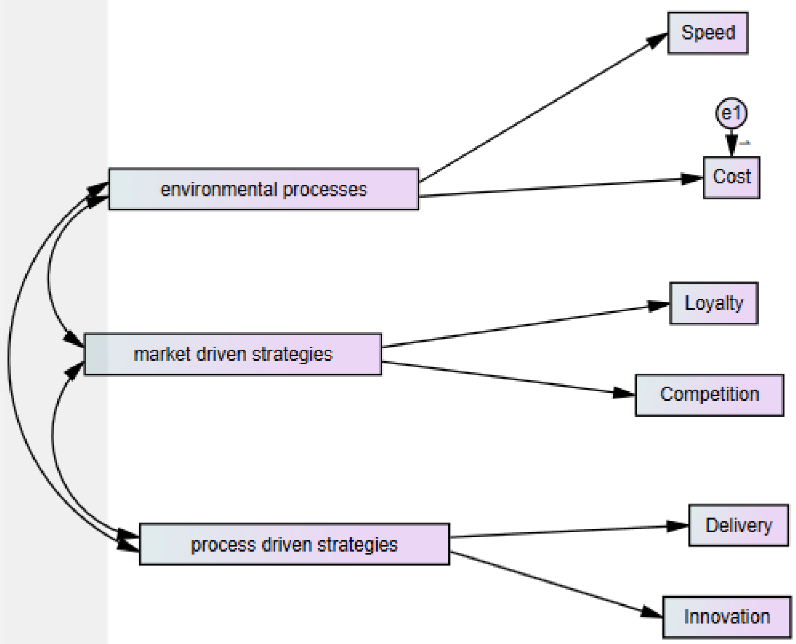

Figure 4.30: Data set diagram input in SPSS AMOS

In this assumed conceptual model, environmental process is connected directly with two regression lines linking the speed and cost priorities, the market driven strategy influences loyalty and competive objectives while the process driven strategy affects the delivery and innovation practices. Moreover, these three groups relate to covariation lines as represented in Figure 4.30.

Table 4.4: Correlation of the environematal processes with the operational speed performance

Variables	Increasing operational speed performance				
Environmental Processes	Very poorely	Poorely	Neutrally	Strongly	Very strongly
Outsourcing ecological guidlines	0.072	0.281	0.465	-0.331	-0.243
Engaging environmental research program	0.201	0.247	0.277	0.243	-0.172
Reprocessing	0.016	0.192	0.208	0.124	0.031

Table 4.4 shows correlation between the operational speed performance and the implementation of environmental processes including outsourcing ecological guidelines, engaging environmental research program, and reprocessing. These three correaltions reveals mostly a neutral impact on the operational speed performance level of the companies.

Table 4.5: Correlation of the environmental processes with the operational cost

Variables	Reducing operational cost				
Environmental Processes	Very poorely	Poorely	Neutrally	Strongly	Very strongly
Outsourcing ecological guidlines	-0.057	0.142	0.286	0.578	0.043
Engaging environmental research program	-0.421	-0.428	0.157	0.140	0.059
Reprocessing	0.074	0.285	0.471	0.143	0.041

Relating the engament of these environmental processes to the operational cost, Table 4.5 indicates that outsourcing ecological guidelines contributes effectively to optimizing the operational expenses of the responding companies.

Table 4.6: Correlation of the market driven strategies with the customer loyalty level

Variables	Increasing customer loyalty level				
Market driven strategies	Very poorely	Poorely	Neutrally	Strongly	Very strongly
Redesigning existing products	-0.034	0.157	0.482	0.710	0.152
Introducing new environmentally sensitive products	0.112	0.247	0.280	0.134	-0.041
Advertising environmental benefits of products	0.095	0.192	0.208	0.214	0.131

Table 4.6 establishes the correlation between the level of customer loyalty and the market driven strategies implemented by the companies counting redesigning existing products, introduction new environmentally sensitive products, and advertising the environmental benefits of the products or services available within the organization. The statistics present a strong relationship between redesigning the existing products and increasing the customer loyalty level rather than just marketing or introducing new products.

Table 4.7: Correlation of the market driven strategies with the competition level

Variables	Increasing competition level				
Market driven strategies	Very poorely	Poorely	Neutrally	Strongly	Very strongly
Redesigning existing products	0.025	0.034	0.102	0.102	0.127
Introducing new environmentally sensitive products	0.034	0.015	0.244	0.244	0.900
Advertising environmental benefits of products	0.114	0.081	0.327	0.891	0.402

However, involving the same market driven strategies with the competition level in the market confirms that advertising the environmental benefits of products or services plays an essential role in greatly increasing the competition level of the company, and confirms that launching new environmentally sensitive products marks the company as highly competitive as shown in Table 4.7.

Table 4.8: Correlation of the process driven strategies with the delivery performance

Variables	Increasing delivery performance				
Process driven strategies	Very poorely	Poorely	Neutrally	Strongly	Very strongly
Enviromentally production processes	0.330	0.720	0.551	0.184	0.153
Reducing and treatment of watses	0.076	0.059	0.357	0.152	0.127
Renewable energy	0.071	0.164	0.512	0.030	0.025

Table 4.8 presents the relationship between the delivery performance of the responding companies and the process driven strategies such as environmentally production processes, reducing and treatment of waste, and engaging renewable energy. The statistics demonstrate a minor increase in the delivery effectiveness when implementaing environmentally production processes.

Table 4.9: Correlation of the process driven strategies with the innovation parameter

Variables	Increasing innovation parameter				
Process driven strategies	Very poorely	Poorely	Neutrally	Strongly	Very strongly
Enviromentally production processes	0.071	0.073	0.031	0.621	0.991
Reducing and treatment of watses	0.033	0.071	0.051	0.611	0.631
Renewable energy	0.005	0.012	0.010	0.299	0.676

When comparing the same process driven strategies related to sustainability with the innovation parameter of the company, the three approaches have a significant impact on increasing the innovation factor in such companies leaded by implementing the environmentally production processes.

To sum things up, the correlation analysis examines the empirical results of the survey tackling the impact of implementing sustainability on the operational level of the participant petroleum companies in Türkiye. It implicates the positive association between market driven strategies and leading achievement of competitive objectives of organizations from one side, and the direct link of the process driven strategies and increasing of the innovation parameter from the other side. Nevertheless, the caculation indicates a minor impact of adopting environmental processes on optimizing the operational costs of the same responding companies.

5. CONCLUSION

The supply and demand of oil and gas have been vital players in the worldwide economy in a globalized market over the last decade. A huge amount of investment is spent yearly on planning and operating the petroleum chain driven by several organizations to conduct safe, efficient and effective modes of delivery to customers. Due to the complexity and the uncertainties in the petroleum supply chain, literature highlights the importance of optimizing the petroleum supply chain over the years and reveals key factors to reduce costs and increase the profits of companies contributing to both upstream and downstream segments. For instance, these features embrace demand management, scheduling and effective delivery service through quality management as well as implementation of sustainability with innovative strategies applied in the industry. Yet, the oil sector is global and includes several commodities which require numerous tactical decisions tackling calibration of the production rate, allocation of the distribution centers and selection of the mode of transportation.

In this research, the main objective is to identify the managerial strategies and tactics applied to optimize the petroleum supply chain in Türkiye in the upcoming decade. Hence, this study evaluates the development stage of delivering efficient gasoline and fuel to different demanding nodes in Türkiye by designing deterministic models simulated by SCM software for tactical and strategic planning of the petroleum supply chain. Two different scenarios were executed to assess the reduction in costs related to the mode of transport, location and allocation of the distribution centers in the studied area thereby selecting the multimode model operating at the minimum total downstream supply chain cost. The single mode model considers transporting gasoline and fuel with pipeline only while the multimode model incorporates three types of transportation scheduling in the strategic design of the whole supply chain, enhances the efficiency and improves performance through the control of distribution centers including their locations, capacities, routes, mode and cost of transport. Comparing thoroughly the two scenarios validates the cost efficiency by employing the multimode design which optimizes the location of the distribution centers and matches the optimum mode of transportation at each stage of the supply chain to satisfy all the demanding nodes.

Sensitivity analysis was also conducted using SCM model on the demand parameter in the stochastic model to suggest future planning recommendations and key insights to decision makers in the petroleum supply chain. The results show that the multimode supply chain configuration is re-optimized to minimize the overall impact of demand on supply chain design and budgets by opening three new distribution centers and lowering the cost of transportation and thus the total cost.

In addition to the strategic and tactical optimization applied in the stochastic and deterministic contexts, this study evaluates further operational measures such as sustainable strategies and innovation. Thus, an online survey was proposed to investigate the impact of the main drivers of sustainability and innovation implemented in Türkiye to optimize the petroleum supply. The conceptual model established an empirical relationship between sustainable petroleum supply chain and organizational competitive advantages at the environmental, economic and social level. The results reveal investments, strategies and performance assessments of 14 petroleum companies operating in Türkiye. The collected data approves significant dimensions of sustainability reporting systems affecting the performance of most of the players of the petroleum supply chain.

However, this research focuses mainly on the petroleum downstream sector for refined products of gasoline and fuel, and as such the generalization of results could not be extended to the entire petroleum supply chain. Hence, it would be critical to develop efficient decomposition techniques in the research direction to emphasize large scale models including rising products like liquified natural and petroleum gas. Also, the optimized model was limited to the input number of variables considered in the simulation while the petroleum supply chain is complex and involves a larger number of constraints in a highly dynamic market. In this regard, further measures and indicators of performance beyond the contribution of this research are analyzed for future studies such as profitability, time of delivery, production lead time and customer response. This ramification opens new groundwork in terms of sustainable innovative petroleum supply chain management strategies to improve and optimize the control of the fascinating natural resources of the world.

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APPENDIX

A. <u>Company Background Information</u>

1. Company Name: ………………………………………….
2. Year of Establishment: ……………………………………
3. Number of Employees:
    - Up to 50.
    - 51-200.
    - 201-500.
    - 501-2000.
    - More than 2000.
4. Industry Sector:
    - Upstream: Exploration & Production.
    - Midstream: Transportation, Logistics & Storage.
    - Engineering Consulting.
    - Engineering Services: Reservoir, Drilling, Facilities & Equipment.
    - Downstream: Refinery, Distributor & Allied Services.
5. Average Turnover per year:
    - Up to 100K $.
    - 101K $ - 500K $.
    - 501K $ - 1M $.
    - 2M $ - 10M $.
    - More than 10M $.

B. <u>Level of Sustainability Practices</u>

6. Sustainability Duration Status:
    - None.
    - 1 – 2 years.
    - 3 – 5 years.
    - 6 – 10 years.
    - More than 10 years.
7. Initial Sustainability Investment Amount:
    - Up to 5K $.
    - 6K $ - 50K $.

- o 51K $ - 200K $.
- o 201K $ - 500K $.
- o More than 500K $.

8. Indicators of Sustainability:

- o Economic.
- o Environmental.
- o Equity.
- o Legal.
- o Other …………………….

9. System of Performance Assessment:

- o Environmental Sustainability Index (ESI).
- o Ecological Footprint (EFP).
- o Operational Performance Index (OPI).
- o Human Development Index (HDI).
- o Other ……………………….

10. Sustainability Indicators Functions:

- o Anticipate Information.
- o Compare Situations & Organizations.
- o Scaling Larger Systems.
- o Other …………………...

C. <u>Drivers of Sustainability</u>

11. To which extent do you believe the following measures and strategies affect the operational performance of the company?

Environmentally friendly processes *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Reducing waste *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Engaging free emission processes *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Using renewable energy *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Using outsourcing ecological guidelines & Reprocessing *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Engaging into environmental research programs *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

D. Sustainability Strategies Implemented

12. What are the sustainability market driven strategies adopted in your company?

- ○ Introducing new environmentally sensitive products.
- ○ Redesigning existing products to make it environmentally sensitive.
- ○ Advertising environmental benefits of products.
- ○ Dealing with material recycling & selling wastes.
- ○ Other…………………

13. What are the sustainability process driven strategies adopted in your company?

- o Environmentally friendly production.
- o Reducing & Treatment of wastes.
- o Using renewable resources.
- o Designing free emission process.
- o Other…………………….

14. What are the difficulties confronting the implementation of sustainability strategy?

- o Higher operational cost.
- o Shortage in competence.
- o Lack of expertise & information.
- o Inappropriate infrastructure.
- o Other…………………….

15. What is the time expected to return your investment after the sustainability strategy is adopted?

- o Up to 2 years.
- o 3-5 years.
- o 6-8 years.
- o More than 8 years.

E. <u>Competitive Advantages</u>

16. To which extent the following competitive objectives are priorities in your operation?

Speed *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High

Cost *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High

Delivery *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High

Quality *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High

Innovation *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High

Customer Loyalty *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High

Relative Performance to Competitors *

	1	2	3	4	5	
Very Low	○	○	○	○	○	Very High