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**SMALL-SCALE LNG SUPPLY CHAIN: A MODEL FOR LNG BUNKERING
IN TURKEY**

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İZMİR-2021

DOCTORAL THESIS
APPROVAL PAGE



DECLARATION

I hereby declare that this doctoral thesis titled as “**Small-Scale LNG Supply Chain: A Model for LNG Bunkering in Turkey**” has been written by myself in accordance with the academic rules and ethical conduct. I also declare that all materials benefited in this thesis consist of the mentioned resources in the reference list. I verify all these with my honour.

28/05/2021

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ABSTRACT
Doctoral Thesis
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Small-Scale LNG Supply Chain: A Model for LNG Bunkering in Turkey
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Emission control measures are becoming stricter in the shipping industry in order to comply with the UN's global emission targets. LNG provides a viable option for emission control measures. As an alternative marine fuel, its supply chain is still developing across the world. The small-scale LNG supply chain is a relatively new and the literature on this issue is limited. This study aims to fill the gap in this context by investigating this alternative fuel option in shipping and by proposing a model for LNG bunkering development in Turkey. In order to fulfil this aim, seven research objectives were formulated and organised sequentially. Qualitative and quantitative research methods were employed. In order to explore small-scale LNG supply chain and LNG bunkering; semi-structured interviews and participant observation methods were utilized. To analyse Turkey's bunkering dynamics, multiple regression and forecasting tools were employed. In order to determine optimum LNG barge size and capacity, mixed integer linear programming which considers split delivery, and heterogenous fleet within the ship-to-ship bunkering context was utilised. In order to evaluate the LNG bunkering option in Turkey, in addition to the aforementioned methodologies, semi-structured interviews were conducted. The research findings indicate that collaboration between small-scale supply chain stakeholders is the main driver for LNG bunkering development. It should be supported by public opinion, standardisation and transparency in the global context. In Turkey case, according to different demand scenarios, the optimum

number and size of the bunker barges were determined along with breakeven freight for LNG bunkering. Turkey has potential for small-scale LNG bunkering development; however, it is dependent on the collaboration of the stakeholders. This collaboration should be supported by subsidies, incentives and regulatory body involvement in order to generate a new market for this promising alternative fuel in the maritime industry.

Key Words: Small-Scale LNG, LNG Bunkering, LNG as Marine Fuel, Emission Control, Supply Chain, Mathematical Modelling, Mixed Integer Linear Programming, Optimisation, Maritime Transportation, Ship Operations



ÖZET

Doktora Tezi

Küçük Ölçekli Sıvılaştırılmış Doğalgaz Tedarik Zinciri: Türkiye için

Sıvılaştırılmış Doğalgaz (LNG) Yakıt İkmali Modeli

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Birleşmiş Milletlerin küresel emisyon hedeflerine ulaşmak için denizcilik endüstrisinde emisyon kontrol önlemleri daha sıkı hale gelmektedir. LNG, emisyon kontrol kuralları için geçerli bir seçenek sunmaktadır. Alternatif deniz yakıtı olarak LNG nispeten yeni bir yakıt türüdür ve tedarik zinciri dünya çapında henüz gelişme aşamasındadır. Küçük ölçekli LNG tedarik zinciri ile ilgili literatür oldukça sınırlıdır. Bu çalışma, deniz taşımacılığındaki bu alternatif yakıt seçeneğini araştırmak ve Türkiye'de LNG yakıt ikmalinin geliştirilmesi için bir model önererek literatürde bu konudaki boşluğu doldurmayı amaçlamaktadır. Bu doğrultuda yedi araştırma hedefi oluşturulmuş ve birbirini tamamlayacak şekilde organize edilmiştir. Nitel ve nicel araştırma yöntemleri bu hedefleri gerçekleştirmek için beraber kullanılmıştır. Küçük ölçekli LNG ve LNG yakıt ikmalini irdelemek için yarı yapılandırılmış görüşmeler ve katılımcı gözlem yöntemlerinden yararlanılmıştır. Türkiye'nin yakıt ikmal dinamiklerini analiz etmek için çoklu regresyon ve öngörü araçları kullanılmıştır. Optimum LNG barç boyutunu ve kapasitesini belirlemek için, gemiden gemiye yakıt ikmal bağlamında bölünmüş teslimatı, heterojen filoyu dikkate alan karışık tam sayılı doğrusal programlama yöntemi kullanılmıştır. Türkiye'de LNG yakıt ikmal seçeneğini değerlendirmek için yukarıda belirtilen yöntemlere ek olarak yarı yapılandırılmış görüşmeler yapılmıştır. Araştırma bulguları, küçük ölçekli tedarik zinciri paydaşları arasındaki iş birliğinin LNG yakıt ikmalinin geliştirilmesinin ana itici gücü olduğunu göstermektedir. Küresel bağlamda LNG

yakıt ikmalinin gelişimi kamuoyu oluşturulması, standardizasyon ve şeffaflıkla desteklenmelidir. Türkiye modelinde, farklı talep senaryolarına göre optimum barç sayısı, kapasitesi ve kritik LNG fiyatı belirlenmiştir. Türkiye küçük ölçekli LNG tedarik zinciri gelişimi için bir potansiyele sahiptir. Bu gelişim ancak tedarik zincirindeki paydaşların iş birliği ile mümkündür. Oluşturulacak bu iş birliği; düzenleyici kurumların sağlayacağı sübvansiyonlar, teşviklerle ve yasal düzenlemelerle desteklenmelidir. Bu şekilde alternatif bir yakıt olarak LNG'nin ihtiyaç durduğu pazar oluşturulabilir.

Anahtar Kelimeler: Küçük Ölçekli LNG, LNG Yakıt İkmalı, Deniz Yakıtı Olarak LNG, Emisyon Kontrolü, Tedarik Zinciri, Matematiksel Modelleme, Karışık Tam Sayı Doğrusal Programlama, Optimizasyon, Deniz Taşımacılığı, Gemi Operasyonları

SMALL SCALE LNG SUPPLY CHAIN: A MODEL FOR LNG BUNKERING IN TURKEY

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ABBREVIATIONS

AIC	Akaike Information Criterion
ARIMA	Autoregressive-Integrated-Moving Average
ARMA	Autoregressive Moving Average
BOG	Boil-off Gas
CAPEX	Capital Expenditure
CIS	Commonwealth of Independent States
ECA	Emission Control Area
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operation Index
EGR	Exhaust Gas Recirculation
EIA	Energy Information Administration
EMRA	Energy Market Regulatory Authority
EMRA	Energy Market Regulatory Authority
ESD	Emergency Shutdown
ETS	Emission Trading System
EU	European Union
FC	Fuel Cell
FLNG	Floating Liquefied Natural Gas
FSRU	Floating Storage and Regasification Units
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HSFO	High-Sulphur Fuel Oil
IACS	International Association of Classification Society
IAPH	International Association of Ports and Harbors
IEA	The International Energy Agency
IGF	International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels
IGU	International Gas Union
IMO	International Maritime Organization
KPSS	Kwiatkowski–Phillips–Schmidt–Shin
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas

MARPOL	The International Convention for the Prevention of Pollution from Ships
MBM	Market Based Measures
MENR	Minister of Energy and Natural Resources
MOTI	Ministry of Transport and Infrastructure
MPA	Maritime and Port Authority of Singapore
MTPA	Million Tonnes per Annum
NBP	National Balancing Point
NECA	NO_x Emission Control Areas
OCIMF	Oil Companies International Marine Forum
OECD	The Organisation for Economic Co-operation and Development
OPEX	Operational Expenditure
SCR	Selective Catalytic Reduction
SECA	Sulphur Emission Control Area
SEEMP	Ship Energy Efficiency Management Plan
SGMF	Society for Gas as a Marine Fuel
SIGTTO	Society of International Gas Tanker and Terminal Operators
SIMOPS	Simultaneous Operations
TCMB	Central Bank of the Republic of Turkey
TTF	Title Transfer Facility
UN	United Nations
UNCTAD	The United Nations Conference on Trade and Development
USCG	United States Coast Guard
VHF	Very High Frequency
VIF	Variance Inflation Factor
VOC	Volatile Organic Compound
WST	World Seaborne Trade
WSTF	World Seaborne Trade Forecast

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INTRODUCTION

Research Background

IMO fuel emission control measures forced shipowners to look for alternatives to comply with the new regulations. The shipping industry has a number of alternatives to comply with stricter emission control regulations that have been set by IMO as part of global emission targets of 2050 (IMO,2019). Sulphur emission restriction compliance is dependent on the shipowners and operators of the fuel-use strategy. Environmental impacts, fuel prices, and, payback time of investments are the considerations for choosing emission mitigation measures (Acciaro, 2014). Gilbert (2014) suggests three main sulphur emission reduction strategies for emission compliance: scrubbers, low sulphur distillates, and liquefied natural gas (LNG). As an alternative to emission control measures, LNG fuel's sulphur content is practically zero. LNG powered vessels produce significantly lower NO_x emission and reduces CO₂ emission about 22% (DNV-GL, 2015). However, LNG fuelled engines have a problem with methane slip and methane gas causes 25 times higher global warming potential than CO₂ emissions (Brynolf et al., 2014).

Shell LNG outlook 2019 indicates that more than 70% of energy demand growth will be met by gas and renewables combined with gas supplying more than 40% of the additional demand (Shell, 2019). The report also points out that consumption of LNG in transport has strong growing pace in heavy-duty trucks and buses as well as marine LNG, 143 LNG-fuelled ships in operation (Shell, 2019). China is the main driver for increase in LNG demand due to the shift from coal to gas as a result of environmental policies that improve air quality (BP, 2019). Environmental awareness is a strong driver for LNG. Although LNG as ship fuel gets benefit of this advantage, there are still some barriers such as lack of infrastructure, high investment cost or LNG prices (Wang & Notteboom, 2014; Fevre,2018). Compared to other clean fuel options, LNG supply chain already exists and is open to development at bunkering phase. Strategic partnership of stakeholders such as terminals, and suppliers extend

LNG supply chain to marine end users as LNG bunkering supply chain (Wang and Notteboom, 2015).

Research problem, aim and scope of the study

There are two dimensions in the literature. One side explores the ship side: engines, emission control measures, sustainability, and economic feasibility; another side investigates port developments, and feasibility as LNG bunkering. The other studies can be grouped as safety standards, operational, and technical challenges for LNG bunkering development. The general two-sided approach in the literature is reflected in real life as the ‘chicken-egg’ problem. These arguments could be categorized as Safety, Operational Challenges, Technical Challenges, Regulatory Framework, Commercial Factors, and Sustainability. The shipping industry is in a truly international context, and taking a further step is not an easy decision. Therefore, understanding barriers in LNG bunkering development, a holistic approach that merges different perspectives, and covering not only various stakeholders but also different regions across the world, is needed. There are limited number of studies focusing on the factors affecting LNG bunkering development. However, no specific research has been found in the literature regarding the factors affecting LNG bunkering supply chain development and analysing it with holistic approach at global scale. Small-scale LNG supply chain literature is very limited, there are only few articles specifically considering small-scale LNG supply chain optimisation. Within these few articles, there is no specific ship-to-ship LNG bunkering supply chain optimisation study prioritising maritime perspective.

LNG marine fuel provides a viable alternative for emission control measures and overall emission targets of shipping. It’s relatively a new issue as alternative fuel and new supply chain out of conventional LNG supply chain. It motivates the researcher to focus on this relatively new topic in maritime industry. Turkey is an important country in shipping with a considerable fleet, newbuilding and repair industry, provision and bunker supplies, appreciable country’s economic volume, various sorts of ports and having such two worthwhile straits as Çanakkale and Istanbul straits. Therefore, LNG pathway in shipping industry is worth being

investigated in terms of both national and international concerns. The originality of the research sits on the attempts to investigate small-scale LNG supply chain in a global context with different stakeholders. Moreover, the study proposes a model for ship-to-ship LNG bunkering supply chain development in maritime context.

The aim of the research is to *investigate small-scale LNG supply chain and propose a model for LNG bunkering in Turkey.*

In order to fill the gap in the small-scale LNG supply chain literature and contribute to knowledge of LNG bunkering, the study employs a comprehensive qualitative analysis while taking into account the views of the related supply chain stakeholders and also utilises quantitative methods that provide strong decision support tool. The research carries out analysis through transaction cost economics theory (TCE) that justifies economic reasoning, organisation theory and law. Moreover, allocation of resources, interlinked activities of supply chain stakeholders are analysed through Network Theory (NT) lens.

Based on the relevant literature, following research questions have been formulated in this research in order to address small-scale LNG supply chain and LNG bunkering development with a holistic approach:

RQ1- How is the structure of LNG supply chain at small scale?

RQ1 is important to explore small-scale LNG phenomenon and draw and provide a deep understanding of the topic.

RQ2-What are the main factors affecting LNG bunkering development?

RQ2 is critical to identify the present challenges in LNG bunkering, which creates barriers in global development.

RQ3-How do different stakeholders contribute to LNG bunkering supply chain development?

RQ3 is formulated to address how to cope with challenges and define those which stakeholders have priority to deal with.

As the study aims to propose a potential model for Turkey LNG bunkering application, the following research questions have been formulated:

RQ4- What are the bunkering dynamics and the bunkering outlook in Turkey?

RQ4 is important to gain insight for Turkey's present bunkering structure, supply locations and volumes. Moreover, it aims to understand how it's correlated with global economic variables and the future trend of bunkering in Turkey.

RQ5- How could Turkey's LNG bunkering model be utilized?

RQ5 is critical to determine potential utilization of LNG bunker barges, numbers, size and the optimum model with minimum cost objective.

In order to answer those research questions and achieve the basic research aim, the following objectives must be fulfilled.

- 1-To explore small-scale LNG supply chain structure.
- 2-To define challenges of LNG bunkering development.
- 3-To identify stakeholders' relations in order to propose a pathway to cope with challenges in LNG bunkering supply chain.
- 4-To explore Turkey's bunkering dynamics.
- 5-To predict the future demand of Turkey for bunker.
- 6-To evaluate the optimum barge size and capacity to be utilized according to minimum cost scenarios.
- 7-To make recommendations for Turkey's LNG bunkering development.

The Model of The Research

The study utilizes both qualitative and quantitative data sources. In order to increase the quality of the research and provide in-depth understanding to phenomenon, mixed-methods research has been employed with pragmatic approach. Triangulation of quantitative and qualitative methods provides framework to answer research questions and achieve research objectives.

The study was conducted mainly in three stages and followed sequential mixed methods as qualitative, quantitative and qualitative stages in a row. Literature review is the base methodology that provides understanding of small-scale LNG and LNG bunkering. It's on the core of the other methods that underpins the rationale of the research. For the first stage of the research, as the aim of the study requires understanding of small-scale LNG and proposes a LNG bunkering model for Turkey, face-to-face semi-structured interviews were conducted during and just after LNG

bunkering summit in January 2019, Amsterdam. Findings of semi-structured interviews and literature review provides framework for LNG Bunkering observation that is conducted in Port of Rotterdam.

The second stage of the study involves quantitative methods. Secondary data which is obtained through reports and time series data were utilized to analyse Turkey's bunkering dynamics. Multiple regression provides statistically significant benchmark for forecasting. Mathematical model uses findings from forecasting and semi-structured interviews as well as the relevant literature.

The third stage of the study comprises semi-structured interviews as qualitative method. In this stage findings of mathematical model and semi-structure interview findings which are conducted in international context were evaluated with experts who are potential stakeholders of LNG bunkering. Seven research objectives were proposed addressing research questions in order to achieve the research aim.

Exploring small-scale LNG and LNG bunkering structure is part of a qualitative exploratory study. Semi-structured interviews with experts who represent different stakeholders in small-scale supply chain provided in-depth understanding of the phenomenon. Participant observation, which provides opportunity to witness one of the Truck-to-Ship LNG bunkering operations in Port of Rotterdam ensured real time experience. Participating in before-during and after stages of the bunkering operation, witnessing onboard applications and shifting manoeuvring, conducting unscheduled interviews with experts and crew onboard provided in-depth understanding of the small-scale LNG supply chain and LNG bunkering operation. Understanding the phenomena is essential to define challenges for LNG bunkering development.

The third objective was proposed to address, the third research question which requires defining different stakeholders in small-scale LNG supply chain. Semi-structured interviews were conducted with different experts who represent, suppliers, shipowners, ports, technical service providers, flag and classification societies.

The fourth objective aims to explore Turkey's bunkering dynamics as a case. Literature review, technical reports and time series data obtained through various sources were evaluated through multiple regression. The fifth research question requires further study that Turkey's bunkering sales projection was carried out with forecasting based on the model which is obtained through multiple regression.

The sixth research question involves case study and incorporates second and third stages of the research. The findings of forecasting provided a benchmark for demand points which are the important parameters of mathematical modelling. Mathematical model variables also encompass the secondary data obtained from technical reports as well as information obtained from industrial experts during face-to-face interviews. Three different scenarios were developed based on different demands forecasts. Different scenario outcomes were compared and evaluated. As objective function formulated with minimum cost perspective, number of the barges, optimum capacity, minimum cost of the models and potential distribution of the bunker are represented at the results of the models. Research framework linking research questions and research methodology are summarised in Table 1.

Table 1: Research Framework

RQ No	Research Questions	Research Objectives	Methodology
1	How is the structure of LNG supply chain at small scale?	1-To explore small-scale LNG supply chain structure	Literature Review, Semi-structured Interviews and Participant Observation
2	What are the main factors affecting LNG bunkering development?	2-To define challenges of LNG bunkering development	Literature Review and Semi-structured Interviews
3	How do different stakeholders contribute to LNG bunkering supply chain development?	3-To identify stakeholders' relations in order to propose a pathway to cope with the challenges in LNG bunkering supply chain	Literature Review and Semi-structured Interviews
4	What are the bunkering dynamics and the bunkering outlook in Turkey?	4-To explore Turkey's bunkering dynamics	Literature Review and Regression Analysis
		5-To predict future demand for of Turkey bunker sales	Literature Review and Forecasting
5	How could Turkey's LNG bunkering model be utilized?	6-To evaluate optimum barge size and capacity to be utilized according to minimum cost scenario	Literature Review and Mathematical Modelling
		7-To make recommendations for Turkey's LNG bunkering development	Literature Review, Mathematical Modelling and Semi-structured Interviews with Turkish Experts

Source: Author

As the seventh objective of the research requires recommendation for LNG bunkering development in Turkey, further discussion is needed. LNG bunkering has no ship-to-ship application in Turkey, yet. The outcomes of the mathematical model need to be reviewed by the experts in that field. Therefore, the findings of the first stage provides global insight to small-scale LNG supply chain and the findings of mathematical model is evaluated through triangulation strategy. The arguments are supported by expert views in Turkey.

Structure of The Study

This study is systematically structured into five chapters in order to address the research objectives and questions. The first chapter provides overview of liquefied natural gas supply chain along with theoretical structure of supply chain management and logistics management. The chapter focuses on supply chain development, functions of logistics and maritime transportation. The chapter also investigates components of the LNG supply chain process and explores LNG market in order to understand overall LNG supply chain with theoretical background.

The second chapter focuses on small-scale LNG supply chain and LNG bunkering. The purpose of this chapter is to understand the exiting small-scale LNG supply chain and LNG bunkering. In order to achieve this, the rationale of the LNG as marine fuel is investigated through sustainability of shipping, emission control measures and alternative fuels. Small-scale LNG supply chain is reviewed with LNG bunkering, infrastructure, regulatory framework, safety and commercial aspect.

Chapter three provides information regarding Turkey's natural gas overview. The purpose of this chapter is to explore Turkey's present natural gas perspective, infrastructure, and market overview. The chapter analyses the current natural gas market in Turkey and investigates natural gas and LNG development.

The fourth chapter justifies research philosophy, research approach, methodological choices, research strategy and data collection method. The chapter also provides theoretical underpinning of the study. Semi-structured interviews, participant observation, multiple regression, forecasting, mixed-integer linear programming

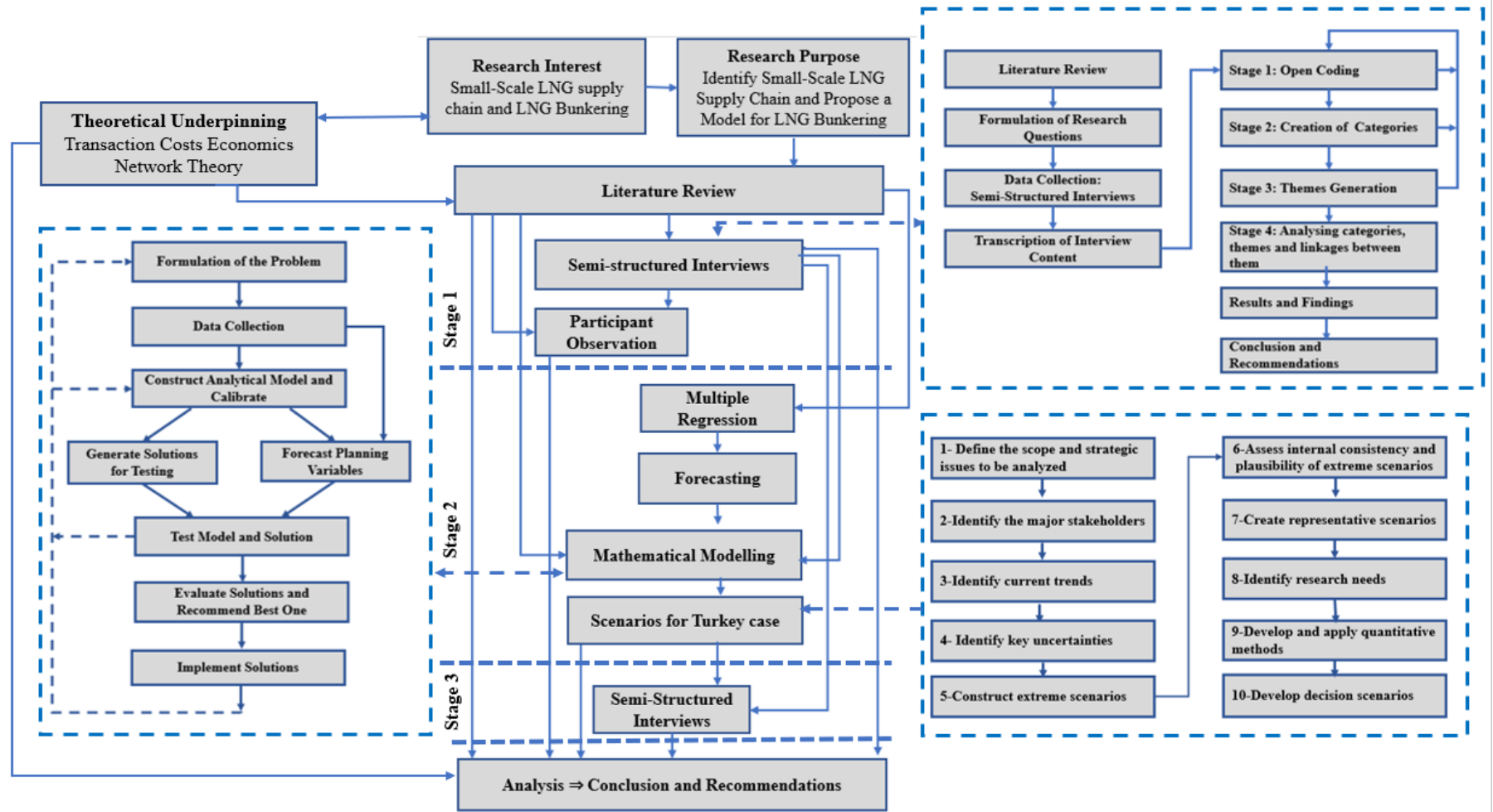
methods are explained with connection of the research objectives. The chapter is concluded with quality, validity and reliability of the research.

Chapter five is empirical section of the study. The chapter analyses semi-structured interviews and participant observation as the first stage of the study. At the second stage, Turkey's bunkering dynamics is investigated with multiple regression and demand forecasting is carried out to provide data for mathematical modelling. Following the findings of forecasting, mathematical model is utilised with deterministic approach. At the third stage of the study, the findings of the qualitative and quantitative methods are analysed with the support of semi-structured interviews conducted with experts in Turkey.

Conclusion and recommendation part discusses how objectives of the study have been fulfilled addressing the research questions. The study is concluded with academic, managerial implications, recommendations for policy makers and practitioners along with further research directions.

Research process, methodologies and stages of this research is summarised in Figure 1.

Figure 1: Research Process



Source: Author, compiled from Ortuzar & Willumsen (2011); Schoemaker (1993)

CHAPTER ONE

OVERVIEW OF LIQUEFIED NATURAL GAS SUPPLY CHAIN

1.1. SUPPLY CHAIN MANAGEMENT

The supply chain is defined by APICS dictionary as “*processes from the initial raw materials to the ultimate consumption of the finished product linking across supplier-user companies,*” or as the “*functions within and outside a company that enable the value chain to make products and provide services to the customer*”(Fredendall and Hill, 2001:3). The chain links supplier and customer, beginning with production of raw material and ending of product with consumption. It consists of facilities, supplies, products, costumers and methods of controlling inventory, distribution and purchasing (Sabri and Beamon, 2000). There are other definitions in the literature that need to be indicated. Christopher (2005:5) defines supply chain management as: (Christopher, 2005:5)

‘The management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole’

Another definition which is more detailed and it leads to several observation:

‘Supply chain management is a set of approaches used to efficiently integrate suppliers, manufacturers, warehouses, and stores so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time in order to minimize systemwide costs while satisfying service-level requirements (Simchi-Levi et al., 2004:2).

Mangan et. al. (2012) take into account physical flows of materials, information flows that inform the supply chain and resources that contributes to effectiveness of the supply chain. Therefore, Mangan et al., (2012:28) have defined the supply chain management as follow:

‘Supply chain management (SCM) is the management, across and within a network of upstream and downstream organisations, of both relationships and

flows of material, information and resources. The purposes of SCM are to create value, enhance efficiency, and satisfy customers'

In addition to these definitions, supply chain concept involves customer satisfaction, customer relation, financial flow and information flow by promoting more integrated and complex groups of activities in logistics functions including minimising costs, maximising profits and leading to which includes aim of minimizing costs, maximizing profits and leading to customer satisfaction (Yercan & Yıldız, 2015).

1.1.1. Fundamentals of Supply Chain Management

Supply chain activity basically connects producers/manufacturers/suppliers with distributors/consumers with dedicated services (Branch, 2007). Each supply chain has its own unique character, operational challenges and market structure. However, five critical elements should be taken into account and generate own supply chain decision database: Production, Inventory, Location, Transportation and Information (Hugos, 2003). Parallel to Hugos (2003), Shapiro (2001) argues that supply chain database is important to operate these services effectively and it could be found in company's products, vendors, and customers. Direct and indirect cost relationships; warehousing, transportation, production and inventory management; cost and capacity information; order information and forecasts of demand are the elements of the supply chain decision database (Shapiro, 2001).

A company's supply chain covers dispersed facilities where raw materials, intermediary products, or finished products are warehoused or sold. These components are connected with transportation links which provides product flow. Mangan et al. (2012) emphasise that the focus point of the supply chain is to manage relationships of the parties in the chain in order to obtain more profitable outcome. However, this is also challenging for the entire supply chain, because one party's benefit may not fit to overall supply chain benefit.

1.1.2. Objectives of Supply Chain Management

In traditional perspective, minimizing total supply chain costs to meet demand is the objective of the supply chain management. The cost associated with supply chain includes following items:

- Raw material,
- Inbound transportation,
- Facility investment,
- Manufacturing costs,
- Distribution costs,
- Inventory holding costs,
- Outbound transportation costs

Chopra and Meindl (2016) argue that boosting the overall value generated should be the aim of every supply chain. The value, -called supply chain surplus, is defined as difference between what the final value product is to the customer and costs incurred by the entire supply chain to fulfil the customer's demand (Chopra and Meindl, 2016).

Elements of supply chain such as assets, information, product and funds should be handled appropriately for effective supply chain management. In this case, value - called surplus, can increase the total size of the pie, and members of the supply chain get advantage from this growing pie (Chopra and Meindl, 2016).

Michael Porter (1998) describes the value chain as below:

Every firm is a collection of activities that are performed to design, produce, market, deliver, and support its product. A firm's value chain and the way it performs individual activities are reflection of its history, its strategy, its approach to implementing its strategy, and underlying economics of the activities themselves.

By adding value to supply chain, company identifies successful implementation of strategy which requires delicate synchronization of activities at operational level. Value added success of the supply chain rely on the sources of value, revenue and the cost. Simchi-Levi et. al. (2004) point out that the objective of the supply chain is to be effective across the entire supply chain, while aiming to minimise

transportation cost, distribution to inventories of raw materials, work in process and total systemwide costs (Simchi-Levi, Kaminsky and Simchi-Levi, 2004).

Modelling a supply chain is formulated over two approaches: minimum cost and maximum profit. Which approach is appropriate depends on the available data, if demand is fixed and given, expected gross revenue is also fixed, therefore minimizing the cost will lead to maximizing the revenues in the supply chain. Cost control in strategic and tactical level provides insight into product cost which should be adjusted for suitable sales and increase net revenues (Shapiro, 2001). Basic formulation of the net revenues is indicated as follows:

$$\text{Net revenues} = \text{gross revenues} - \text{total cost}$$

1.1.3. Supply Chain Strategy

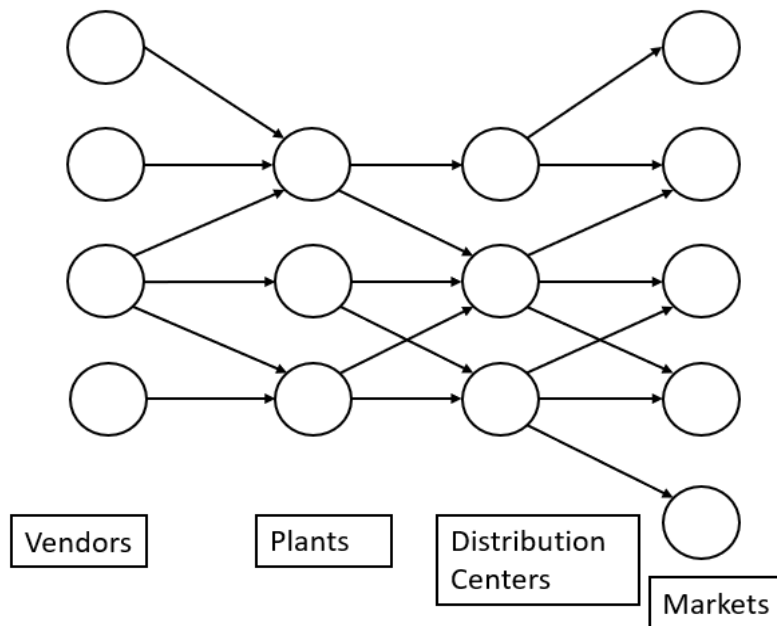
Strategy is required for companies to meet their business goals, and support their missions and objectives. It's usually evaluated in three levels as corporate strategy, business strategy and manufacturing strategy (Fredendall and Hill, 2001). Corporate strategy determines in *what* business a firm will compete. On the other hand, business strategy decides *how* a firm will compete. At the third level, manufacturing strategy, determines what a firm must do to achieve strategic business plan (Fredendall and Hill, 2001). Supply chain management is an fundamental part of supply chain's strategy as business strategy of each partner (Stadtler and Kilger, 2008). It has inter-organisational structure and implementing strategy throughout the supply chain is difficult and requires overall strategy for the stakeholders. Strategy literature overwhelmingly is discussed along with pure competition. However, in supply chain management, strategy comes up with *collaboration* as an important part of integration (Stadtler and Kilger, 2008). Supply chain partners should take into account overall benefit of supply chain. Collaboration may also be required for competing supply chains to consolidate demand for purchasing power (Stadtler and Kilger, 2008).

1.1.4. Supply Chain Network

The supply chain usually represents network which connects the nodes with transportation. How these nodes are connected is the decision of a company's supply chain management. Figure 2 shows simplified version of supply chain network design. Networks provide a model for supply chain development. Although Figure 2 is simplified version of a supply chain network development, it illustrates products flow from vendors to plants, plants to distribution centres, distribution centres to markets.

Supply chain management is highly related to integrated planning which gathers functional integration in terms of purchasing, manufacturing, transportation; spatial integration across distributed vendors, facilities and markets; and to intertemporal integration which represents strategic, tactical and operational planning horizons. Intertemporal integration is also called as hierarchical planning, which encompasses reliability and consistency among overlapping supply chain decisions at the different stages of planning.

Figure 2: Supply Chain Network



Source: (Shapiro, 2001)

Designing and operating a supply chain is challenging while taking into account minimizing total cost and maintaining service level in overall chain. Supply chain consist of uncertainty in nature; demand cannot be forecasted firmly, travel times may change, and equipment and vessels may be broken down. Supply chain needs to be developed to reduce uncertainty as much as possible (Simchi-Levi, Kaminsky and Simchi-Levi, 2004).

1.1.5. Supply Chain Planning

Intertemporal integration of supply chain could be achieved by combination of strategic, tactical and operational decision process of the company (Ganeshan *et al.*, 1999). Aggregate planning is necessary to accomplish company' objective within planning horizon. The planning horizon is defined as the time period over the which aggregate plan is to produce as solution. Planning horizon should be determined as weeks, months, quarters or years (Chopra and Meindl, 2016). Simchi-Levi et al. (2004) point out that as the supply chain encompasses efficient integration of suppliers, stores, warehouses and manufacturers; it compromises of business activities at different levels as strategic, tactical and operational.

1.1.5.1. Strategic Level

Strategic level decisions are made within multiple time horizons which covers usually from monthly to multi-year planning. These includes site selection, new product introductions, new products, new markets along with go or not go decisions which corresponding with company's objectives and strategies. Addressing company's strategy, firstly, objectives and policies for whole supply chain should be developed and to be analysed whether these are fit with company needs. Secondly, supply chain should be designed and thirdly, how supply chain can contribute to competitive advantage of the company (Stevens, 1989).

1.1.5.2. Tactical Level

Tactical level decisions usually cover coming days, weeks or months. As the higher-level decisions are determined in strategic level, tactical level planning make adjustments according to local requirements or demand deviations. Main purpose is to minimise total supply chain cost while meeting the fixed demand or maximize net profits (Shapiro, 2001). Tactical decision could be categorized in four main areas: Relations development, transportation and distribution, integrated operations, and Systems (Ganeshan et al., 1999). Decision in tactical level consists of allocation of customers, the inventory policy, delivery frequencies to customers, and the configuration of the transportation fleet (Romero and Morales, 2000). Romero and Morales (2000) point out that tactical level decisions depend on strategic level choices that affect decisions at distribution network. The most critical decisions in tactical level are the number, the size and the location of the production facilities of plants and distribution centres.

1.1.5.3. Operational Level

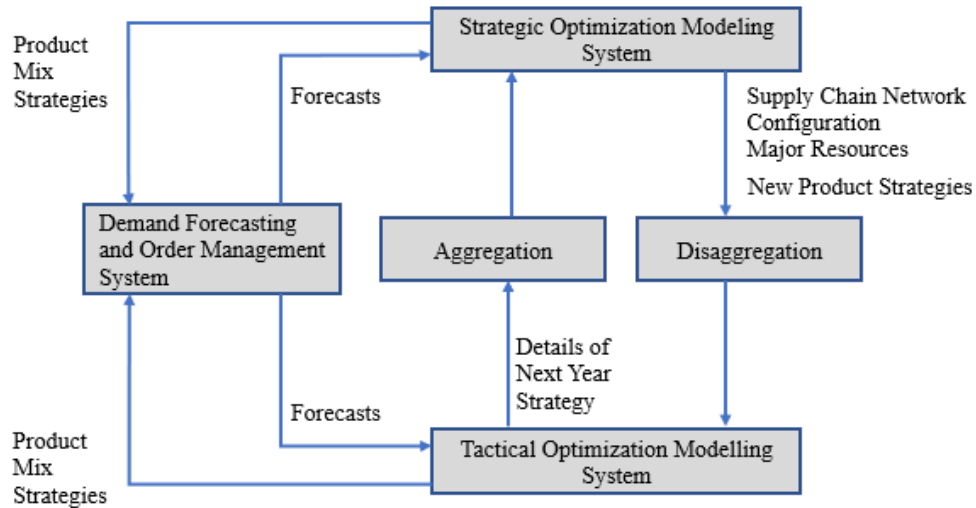
Operational level decisions indicate day to day operations usually up to two weeks ahead (Ganeshan et al., 1999). The planning policies and supply chain configuration are already fixed at the operational level. In operational perspective, handling incoming customers and orders are the main concerns. Allocation of shipping list, warehouse pick up list, daily scheduling of trucks or replenishment of orders need to be decided in the short term such as minutes, hours or days as there is fewer uncertainty in terms of demand information (Chopra and Meindl, 2016). Efficient operation of the supply chain is accounted to operational level and ensured by appropriate controls and performance measures (Stevens, 1989).

1.1.5.4. Strategic and Tactical Optimization Modelling System

Strategic level optimization model assists senior level managers to decide long-term configuration of company supply chain design. In this context, major resources

and new product strategies are determined. How to imply these decisions is the part of tactical level decision process as illustrated in Figure 3.

Figure 3: Linkages among Strategic and Tactical Optimization Modelling



Source: (Shapiro, 2001)

Tactical level model provides detailed feedback to strategic level regarding how these facilities are to be used and how market demand is to be met over the first year of the strategic planning horizon. Demand forecasting and order management systems provide mid-term and long-term projections to both strategic and tactical level(Shapiro, 2001).

1.2. LOGISTICS MANAGEMENT

There are various views and explanations about the definition of the logistics. The Council of Supply Chain Management Professionals advises the following definition for the logistics (Simchi-Levi et al.,2004):

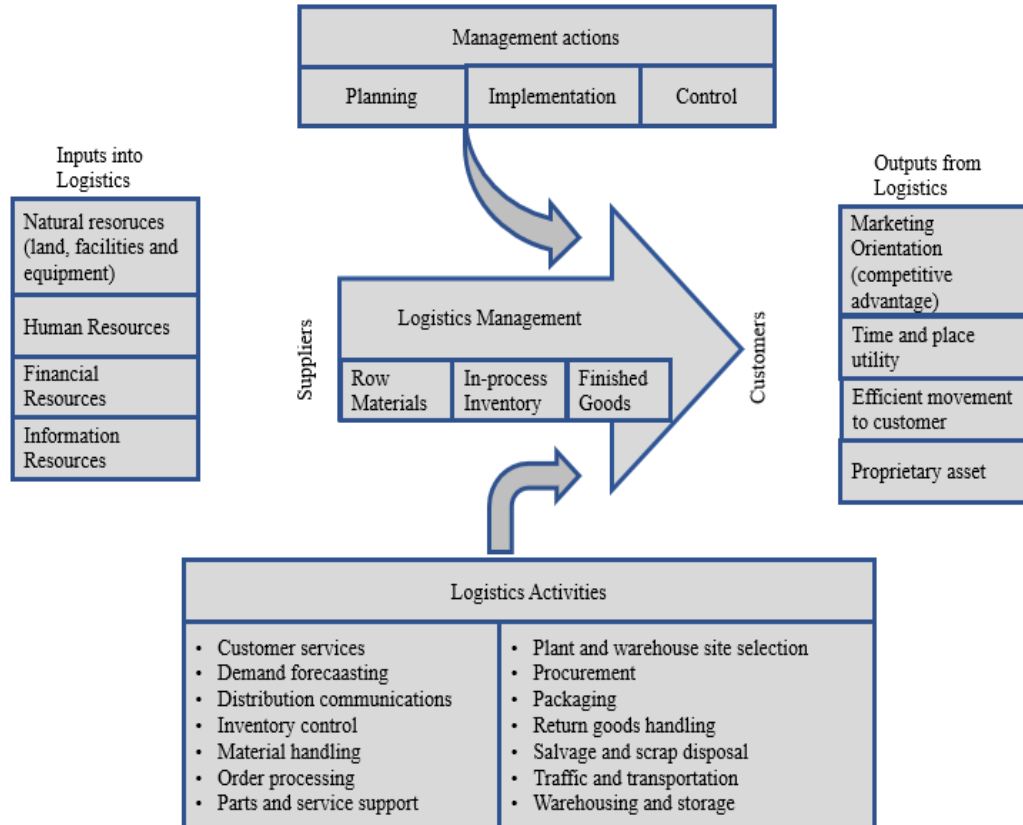
‘Logistics is the process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods including services, and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements. This definition includes inbound, outbound, internal, and external movements.’

As the logistics definition involves several activities, controlling and managing these activities are also crucial. Logistics management framework involves these activities to plan, implement, and control the effective flow and storage of the goods. Basically, logistics management includes inbound and outbound transportation management, warehousing, fleet management, network design and supply/demand planning (Bramel and Simchi-Levi, 1997).

Logistics management aims to make sure that product meets customer requirements from supplier to customer through warehouse to distribution centres. Secondly, logistics management provide efficient and profitable service across the system while minimizing the costs. As planning, implementing and controlling are the critical parts of the logistics network, logistics management comprises strategic, tactical and operational level activities (Christopher, 2005).

Logistics management encompasses logistics activities and management activities. Figure 4 illustrates this relation, process and related activities.

Figure 4: Components of Logistics Management



Source: (Lambert et al., 1998)

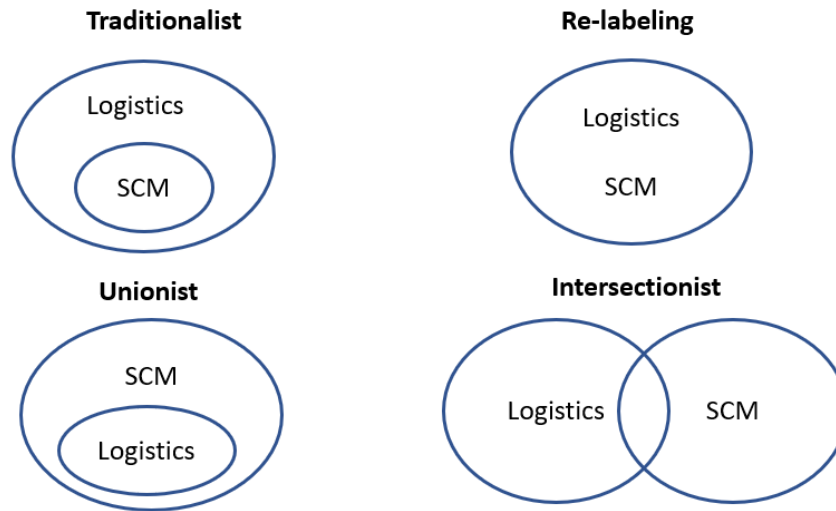
As the main activity of logistics management is to deliver goods through raw material supplier to final customer, all kind of organisational sources inputs creates logistics outputs (Lambert et al., 1998). Managerial activities such as planning, control and implementation are supportive functions to logistics management and overall process brings competitive advantage, time and place utility, and effective movement (Lee et al., 2015). However, as the supply chain and logistics overlap in certain activities, the relevant literature has been investigated for further clarification.

1.2.1. Logistics and Supply Chain Management

There are several approaches in the literature to clarify logistics and supply chain concept. Coyle et al. (2011) argue that supply chain is evolutionary outcome of the logistics, as supply chain integrates logistics functions with additional activities of strategic planning, information technology, marketing and finance. Managerial functions in logistics are limited with material management physical flow of goods and information. Supply chain management is an extended organisation from the original vendor to end customer in which all companies in the stage take part (Coyle *et al.*, 2011).

Larson and Halldorsson (2004) indicate that there are four main views in the literature to define logistics and supply chain concepts, as illustrated in Figure 5. Traditionalist view takes supply chain management as 'logistics outside the firm' that makes supply chain subset of the logistics. Re-labelling view basically re-names logistics as supply chain management with all its functions. Unionist approach defines supply chain management as business process and it covers logistics along with marketing, forecasting, production, purchasing, information system, finance and customer service (Larson and Halldorsson, 2004). On the other hand, inter-sectionist view argues that supply chain management includes strategic, integrative elements of logistics, marketing, operations management and purchasing. Although they have overlapping areas, they are different.

Figure 5: Logistics and Supply Chain Management



Source: (Larson and Halldorsson, 2004)

Lee et al., (2015) categorize the two concepts through approaching view and focusing point. Logistics primary concern is optimising flows within the organisation. On the other hand, supply chain management involves external integration among organisations. Unlike logistics, supply chain focus is multiple relationships of all parties in the network. Logistics focus point is efficient flow of services and information of an organisation by optimising all the processes. However, supply chain management pursues coordination between processor of the stakeholders in the network as well as the logistics plans which enables effective flow of the product and information. Mangan et al (2012), argue that logistics is part of supply chain management which is wider, integrates companies and encompasses boundary-spanning concept. Martin Christopher (2011:2) follows unionist view as well. He points out that:

“Logistics is essentially a planning orientation and framework that seeks to create a single plan for the flow of products and information through a business. Supply chain management builds upon this framework and seeks to achieve linkage and co-ordination between the processes of other entities in the pipeline, i.e. suppliers and customers, and the organisation itself”.

There is no consensus in the literature regarding concepts of logistics and supply chain management. Activities of the logistics management offer effective flow

of goods and information (Christopher, 2011). Critical activities of logistics management are discussed in the next section.

1.2.2. Functions of Logistics

As the logistics management and supply chain managements concepts have different approaches in the literature, major functions of the logistics, inevitably, are affected from these terminological discussions. Inventory control, material handling, warehousing, transportation are the key activities which represent broad agreement in the literature. On the other hand, demand forecasting, purchasing, recycling, order processing logistical packaging and information are classified under supply chain management or logistics management.

1.2.2.1. Demand Forecasting and Planning

Demand forecasting and planning are the key logistics functions (Lambert, Stock and Ellram, 1998). The logistics flow and services are planned according to demand forecast. Reliability of the demand forecast over customer requirements has substantial effects on quantity of purchasing, production, inventory level and service quality over the time and cost (Franklin, 2019). Demand forecasting is and direct logistic requirement that encompasses delivery to customer and receipt of raw materials. This also works in alignment with planning and scheduling (Wood et al., 2002). Therefore, this function is indicated as one of the most important logistics activities.

1.2.2.2. Purchasing

Purchasing or procurement is also arguable functions in the literature. It comprises decision of selection the best vendor for raw materials or other intermediate goods. Taking into account geographical constraints, quality of the products, amount to be taken are critical decisions which have direct impact over transportation and inventory cost (Lambert, Stock and Ellram, 1998). International sourcing carries

additional risks as the political stability, exchange rates, and currency gain importance. Quality of the vendor and quality of the product should be evaluated carefully (Wood *et al.*, 2002). Wood *et al.* (2002) point out that sourcing decisions are taken after fixing total cost that comprises price of product, transportation, packaging, and inventory investment.

1.2.2.3. Inventory Control

Inventory may require substantial money and affects capital control and cash flow of a company. It requires places and additional manpower to control. On the other hand, keeping inventory is essential as buffer against uncertainty in demand, hedge against price fluctuations, and maintain supply of scarce supply etc.(Mangan *et al.*, 2012) As the customer demand is random at some points, retailers need to decide how much and when to re-order new products. Ordering new products typically consists of two dimensions, fixed and variable costs. The fixed part is independent from the size of the products and need to be paid each and every times equally, such as cost of sending vessels to certain distance. The variable part depends on the quantity of the order (Bramel and Simchi-Levi, 1997). Inventories are used as protection barrier against unforeseen demand, lags in resupply or just for managerial error (Wood *et al.*, 2002). Keeping inventory level at minimum is critical for the company so as to avoid high logistics cost, storage and transportation. Therefore, frequency, quantity and time of order are inventory control's major contributions to efficient logistics management.

1.2.2.4. Warehousing Management and Material Handling

Logistics activity involves warehouse management as well. Storage of the goods, raw materials, finished or semi-finished goods are related with warehouse management (Wood *et al.*, 2002). It consists of several activities such as controlling, labelling, assembling materials and holding the stocks. In relation with inventory control, optimizing and planning flow of the goods has significant impact on overall efficiency of the logistics activities (Mangan *et al.*, 2012).

Material handling capacity is crucial for movements of the goods that can create bottleneck for the operations while loading/unloading goods, picking and packing of the goods or movements of the goods within warehouse. As it's a critical element in movement of the goods, optimum speed, capacity management is necessary for smooth flows of the goods (Lambert et al., 1998).

1.2.2.5. Recycling, Waste Disposal and Returns

Waste management is getting an important logistics activity. The waste either can be recycled or disposed. In any case, wastes need to be treated properly. On the other hand, defective products or mistaken purchases cause high costs and time losses that company need to deal with. As the retail business reach out even distant places with online orders, arranging return items, recycling and waste disposal became crucial for the logistics activities (Wood et al., 2002). Reverse logistics activities take important parts in the logistics management. It's more complicated than primary logistics activity as there is less control over customers. Coordination among participants is vital and requires regulatory standardisation in compliance (Iyer, 2015).

1.2.2.6. Transportation

Transportation is the base and major function of the logistics. Function of international transportation is even more crucial as involves in long distances under different jurisdiction. Therefore, planning in strategic, tactical and operational level planning is very important for transportation function. Transportation connects all the components within the logistics network. However, Long (2003) argues that although transportation is considered as the function of the logistics, it may be classified as stand-alone sector. Transportation is divided in five segments as air, road, water, rail and pipeline. Although each of them has different dynamics, basic transportation theories such as economies of scale, distance economy are critical for any modal choice (Mangan et al., 2012). Economies of scale and distance economy are the fundamentals of the transportation, as the amount of the cargo transported per shipment, in other words, shipment per unit provides of economies of scale. As the

distance of the shipment increases, cost of cargo per nm decreases (Long, 2003). There are also five elements that characterise the transportation service: transit time, security, capability, accessibility and reliability. (Coyle et al., 2011). Transit time is critical for inventory control and could affect both shippers and receivers as well as associated costs. Consistency of transit time is referred to reliability. Reliability allows shippers and receivers to optimise their services, minimise the stocks and cut related costs. The transportation provider's ability to move the freight between two points is called as accessibility. Failing to arrange direct service between origin and destination may result in additional transit time and cost. Capability is ability of carrier to handle the related freight based on its physical and marketing characteristics. The last item is security which covers safety of the goods in transit. During the transit, shipment could be damaged or lost and it could be rejected by the receiver. The cost associated with security risk is reflected in inventory and stockout costs (Coyle et al., 2011).

1.3. MARITIME TRANSPORTATION

Maritime transportation is the main utilizer of the global trade and the industrial supply chain as more than 80% of the world trade by volume is handled by sea (UNCTAD, 2020b). It's strongly connected with the development of intra-regional as well as international trade flows (Wilmsmeier, 2016). In addition to maritime transport's historical role in the global trade, it has been a key facilitator for globalization, particularly by introduction of standardised container shipping. Increase in world trade creates derived demand for transport services and the maritime transportation (Stopford, 2013). Maritime transportation takes important part in a logistics system as well. It's accounted for carrying and handling cargoes and connects customers, suppliers, plants, warehouses. Effective maritime operations are crucial for logistics and supply chain systems (Lee, Nam and Song, 2015). Moreover, maritime transportation provides optimum economies of scale and distance economies for trade compared to other transportation modals (Long, 2003). Wilmsmeier (2016) argues that two definitions of the economies of scale can be attributed to shipping. Firstly, external economies of scale where the unit cost is subject to size of the shipment. Secondly,

internal economies of scales where the unit costs subject to the size of the individual transport unit -as ship, container, port and shipment.

1.3.1. Maritime Transportation Overview

Uncertainty remains critical for global trade and maritime transportation. Growth forecasts are to be renewed according to Covid19 effect, natural disasters, trade tensions, tariff escalations, climate changes, environmental regulations, and emission targets. In 2019, slow-down in maritime trade reached its lowest level since 2008-2009 depending on several factors such as policy tensions, sanctions, supply-side disruptions and low oil demand growth (UNCTAD, 2020c). Moreover, it was also observed that negative outlook in 2020 due to pandemic and its effect over world economics, transport and consumption patterns, manufacturing activities in supply chain caused a global recession in 2020 (UNCTAD, 2020c). Maritime transportation is evolving through moderation in global economic growth as well as expanding regionalisation of supply chains and trade patterns.

1.3.1.1. World Fleet

Current development of the maritime transportation is evaluated under UNCTAD annual reports. The report classifies the vessels under five principal types: Bulk carriers, oil tankers, container ships, general cargo ships and other types such as gas carriers, chemical tankers, offshore vessels, ferries and passenger ships. UNCTAD 2020 report indicates that global tonnage capacity increased 4.1%. Oversupply is still structural feature in all segments as it keeps pressure on freight rates (UNCTAD, 2020b). Gas carriers segment has the highest growing rate (6.5%) among the others in parallel to increasing demand on liquefied natural gas sector. Oil tanker fleet, unlike in 2019, showed fast growing as 5.8% which takes second place as growth rate after gas carriers. Bulk carriers, containers and chemical tanker segments showed slow growth rate as 3.9%, 3.3% and 2.9% respectively (UNCTAD, 2020c).

1.3.1.2. Shipbuilding and Demolition

Japan, China and South Korea are the leader countries in terms of ship building by the number and capacity and represent 92.5% of the global production. New orders declined in early 2020. It was attributed to the price of new buildings, freight rates, geopolitical instability, financial difficulties and uncertainty over fuel and technology choices (UNCTAD, 2020c). Pressure from regulatory side, global emission targets, new restrictions are forcing new building industry for innovation and energy-efficient transportation solutions.

Scrapping sector has mostly been occupied by three countries, Bangladesh, India and Turkey, which accounted for 90.3% of the ship recycling activity in 2019 (UNCTAD, 2020c). Turkey is the only country among the top 5 recycling countries which increased its ship demolition activity in 2019. It's in parallel to EU approved facilities and Turkey's ratification to Hong Kong (China) International Convention for the Safe and Environmentally Sound Recycling of ships (UNCTAD, 2020c). China's share is declining as parallel to the regulations that forbid foreign flag vessels' demolition within own territory. New regulations, IMO Hong Kong International Convention for the Safe and Environmental Sound Recycling of Ships, EU regulations, and voluntary initiatives trigger the sector to shift more environmental friendly structure.

1.3.2. Maritime Logistics

Maritime logistics concept involves integration which is attributed to intermodal, economic/strategic, or organisational decisions (Panayides, 2006). Therefore, Maritime logistics involves implementing, planning, and managing the movement of the goods and information in shipping. Three key functions of maritime logistics are defined in literature: shipping, port/terminal operations and freight forwarding (Lee et al., 2015). Major function of shipping moves cargoes between ports. Documentation of the related trade, tracking information and intermodal services are other logistics services of shipping. Freight forwards' main function is booking vessels, and documentation on behalf of shipper in container transport.

Inventory management, packing and warehousing are supportive logistics activities of freight forwarding. On the other hand, port/terminal operation's main function is loading/unloading cargoes, stevedoring and providing connection to inland transport. Moreover, logistics function of port/terminal operation provides warehousing, storage, testing, repairing, inland connection for smooth and effective delivery of the cargoes (Lee et al., 2015). Port/terminal operations are vital for effective supply chain management. Song & Panayides, (2008) argue that port/terminals are considered as part of cluster organizations in which different logistics and transport operators participate in creating value to the last customer. Higher degree of coordination and co-operation are essential for overall supply chain efficiency.

On the other hand, maritime transportation and maritime logistics relation is usually credited to integration of transportation modes which is facilitated by containerisation as well as customer demand who requires application of logistics concept. Containerised goods has become crucial for door to door shipment in multimodal transport and it necessities logistics functions and characteristics for competitiveness and effectiveness throughout the supply chain (Panayides, 2006).

1.3.3. Maritime Transportation in Energy Trade

Maritime transportation has no significant account for energy transportation before industrial era, apart from oil lamp fuel trade which relied on olive oil in amphoras or animal fats. Industrial developments increased energy demand as power generation and transportation fuel. This demand was fulfilled by coal. Increased coal demand has necessitated specialized bulk carries which are able to carry coal between production centres and demand centres as well as using marine fuel in steamships. This traditional structure is reflected in modern energy markets as *concentration of production* and *dispersed consumption* (Notteboom, Pallis and Rodrigue, 2021). Notteboom et al (2021) argue that concentration of products is the main characteristic of economies of scale in energy markets in terms of large volume of extraction, processing, and transportation. Energy takes substantial share in global shipping. World seaborne trade reached to 11076 millions of tons by the end of 2019 (UNCTAD,

2020a). Shipping activities in coal, crude oil, petroleum products, gas transportation and bunker fuel segments are serving at major energy markets.

Bulk carries are used for shipments of coal which is still important power generation sources despite growing emission concerns. It's the second largest commodity after iron ore and usually carried by handy-size and over ship segments. Australia, Indonesia and Russia are main coal exporters and China, India and Japan are major coal importers (Narula, 2019).

The second important segment is tankers which are utilized to carry crude oil and petroleum products. Petroleum products play significant role in energy markets as major transportation fuel, industrial production as well as power generation. Oil consumers are industrialised countries in the world such as Japan, China, USA, and Western Europe. Middle East is still the main hub for crude oil production but USA, Canada, Russia are other major crude oil producers (Narula, 2019).

Natural gas is classified as cleanest fossil fuel and gaining importance for power generation due to competitiveness in relation to petroleum and coal. Distribution of natural gas is carried out via pipelines and LNG carriers. Natural gas is liquefied through a cryogenic process to cool down to -160degC which enables to reduce its volume 600 times to carry on large gas tankers -called LNG carriers (Notteboom, Pallis and Rodrigue, 2021). Qatar and Australia are the main exporters of LNG, while Japan, South Korea and China are the major importer of LNG (BP, 2020a).

Bunker fuel is another important energy market for shipping. Bunkering operations could be conducted either at ports or anchorage areas. Although bunkers as ship fuel is available across the world, market is concentrated over major shipping routes, six countries which are accounted for 60% of the market. IMO 2020 regulations and upcoming further restrictions force shipowners to seek alternative fuels. LNG is one of the promising alternatives due to environmental benefits and availability (Notteboom, Pallis and Rodrigue, 2021).

Energy security, environmental considerations and sustainability are main challenges for the world. LNG brings viable solutions for these concerns. In this chapter liquefied natural gas (LNG) characteristics are investigated in order to understand supply chain constraints and operational restrictions.

1.4. LNG SUPPLY CHAIN

Natural gas is one of the major energy commodities in the world. It's being used for decades as relatively clean source for power generation. As natural gas sources mainly are found in reachable locations, pipelines are the major distribution modal during 20th century that provides safety, stability and economically affordability. However, technical developments provide opportunity to reach new and rich gas reserves that are located at more remote areas. Liquefied natural gas (LNG) industry is able to deliver these remote gas reserves into markets and designs supply of energy for those countries are highly depended on oil or natural gas delivered by pipelines (Mokhatab *et al.*, 2014). This delivery process requires supply chain in high technical standards with economic concerns. LNG supply chain is investigated in the following sections.

1.4.1. Basics of LNG

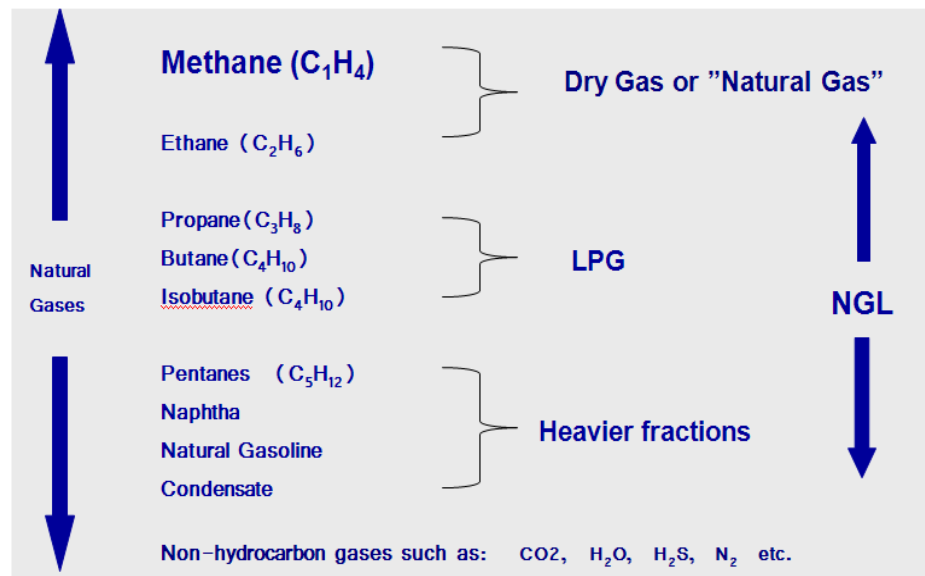
LNG is one form of the natural gas and it's distinguished from the other forms that are used in gas literature such as NGL, CNG, LPG and ANG. NGLs (Natural Gas Liquids) that are hydrocarbons such as propane, ethane, isobutene, butane and natural gasoline (pentanes) extracted from natural gas production stream in natural gas processing plants and stored in liquid forms (EIA, 2019). NGLs are generally at small percentage in gas wells compared to crude oil reserves. LPG is liquefied petroleum gas which is crude oil distillation and consists of propane, butane and mixture of the two. LPG energy content is much higher than natural gas (Mokhatab *et al.*, 2014). CNG is compressed natural gas stored in gaseous state, typically in 200-250 bars high pressure cylinders. On the other hand, LNG refers to cooled natural gas at the liquefaction facilities and the main content of the LNG is methane.

Natural gas to liquefied natural gas process is done by cooling down the gas at atmospheric pressure at a temperature of -162°C and enables to transport approximately 600 times bigger volumes compared to gas phase (SIGTTO, 2016)

LNG has no odour or colour and it's non-corrosive cryogenic liquid at normal atmospheric pressure. The configuration of the LNG depends on the reserve of the gas

and fractionation records. Figure 6 illustrates elements of the natural gas. Main component of the LNG is methane and it varies from 87% to 99% by mole. Other composition of the LNG is hydrocarbons C_2 to C_4 , ethane, propane, butane and nitrogen. LNG contains almost zero sulphur, very low nitrogen oxide as a promising clean energy source.

Figure 6: Natural Gases



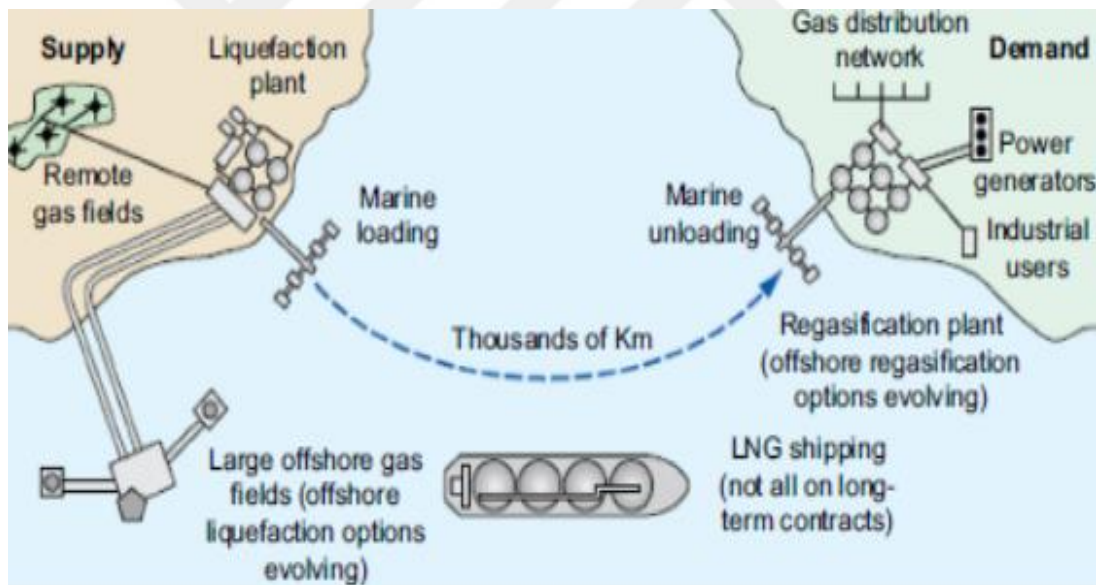
Source:(Keller, 2012)

LNG 's density is usually between 430kg/m^3 and 470kg/m^3 which makes LNG less than half of the water. Therefore, LNG spill over water floats on top and vaporizes quickly. Boiling point of LNG depends on composition, however typically it's -162 . LNG vapours are heavier than air only at initial stage, however once it starts to warm up due to environment conditions, approximately at temperatures of -110°C , vapor density becomes lighter than air. Flammable limits for methane/air mixtures are between 5% and 15% by volume in air. Out of this range methane/air mixture is not flammable. Small quantity of LNG leakage at well-ventilated area or open air will rapidly mix with air and dissolve to less than 5% concentration (Mokhatab et al., 2014). On the other hand, LNG is nontoxic, however, any gas release from LNG can cause asphyxiation due to lack of oxygen in an enclosed area and can be ignited if mixed with air within flammable limits.

1.4.2. LNG Supply Chain Process

LNG is fossil origin and comes from natural gas reserves. Although renewable LNG could be obtained from biomass or electricity as Bio-LNG or Power-to-LNG, fossil sourced LNG is dominated the market. Traditionally, LNG is produced from natural gas on liquefaction plants, transported to import terminals and after regasification process delivered to end users. However, LNG has increasing demand as end product as well, meaning that without regasification process, LNG is stored in cryogenic tanks and delivered to end users as marine fuel or heavy duty trucks or buses (Shell, 2019a). The LNG supply chain has mainly four components from well to end users: 1-Exploration and Production, 2-Liquefaction, 3-Shipping and 4-Storage and Regasification.

Figure 7: LNG Supply Chain



Source: (Mokhatab et al., 2013)

Figure 7 illustrates typical LNG supply chain components such as remote gas fields, liquefaction plant, marine loading, LNG carrier, marine unloading, regasification plant and distribution to end users. Details of the entire supply chain is discussed in following sections.

1.4.2.1. LNG Exploration and Production

Exploration and production are upstream stage of oil and gas industry. LNG exploration involves millions of dollars and highly risky to find a dry well. Exploration either could be onshore or offshore. Seismic surveys, environmental assessments, drilling processes could take over years. Strong financial sources and economic feasibility are always decisive to start drilling out the reserve. Gas gathering and transferring to liquefaction plants are critical parts of the system. It is argued that a liquefaction plant requires about 1.5 Tcf of natural gas reserve in order to produce each million tons per year of LNG (47 Bcf per year) for 20 years(IEA, 2019a).

Conventional natural gas sources are underground wells which are usually non-associated gas, condensate reservoirs (pentanes and heavier hydrocarbons) and large oil fields (associated gas). Unconventional gas sources are: (a) Tight Sands Gas which is trapped in sandstone and carbonate; (b) Coalbed Methane is extracted from coal mines which is observed by the solid coal particles; (c) Shale Gas is trapped in clay particles which is formed in low permeability shale rock; (d) Methane Hydrates are usually formed deep under Arctic permafrost that methane molecules are trapped in a form of porous ice (IGU, 2017).

1.4.2.2. Liquefaction

Liquefaction process of the natural gas reduces its volume by factor of 600. This is far more than reduction which is obtained through compression. Liquefaction is the critical process in order to carry natural gas by ships, to be used as fuel or for storing which makes natural gas tradable commodity in world-wide scale out of pipeline restrictions.

There are different sizes of the liquefaction plants according to where they are located. Centralised plants liquefy the gas on large scales on production centres. Decentralised centres are located at natural gas networks that are close to consumption centres or in small-scales local natural gas sources (Shell, 2019a). These are called, large-based load, peak-shaving, and small to medium scale plants. Large-based load LNG plants are mostly located where large gas reservoirs are available. These plants

consist of ‘trains’ which allows the plants to continue production. According to plant requirements, train size could be less than 0.5 MTPA (Algeria) or up to 8.7 MTPA (Qatar)(Mokhatab et al., 2014).

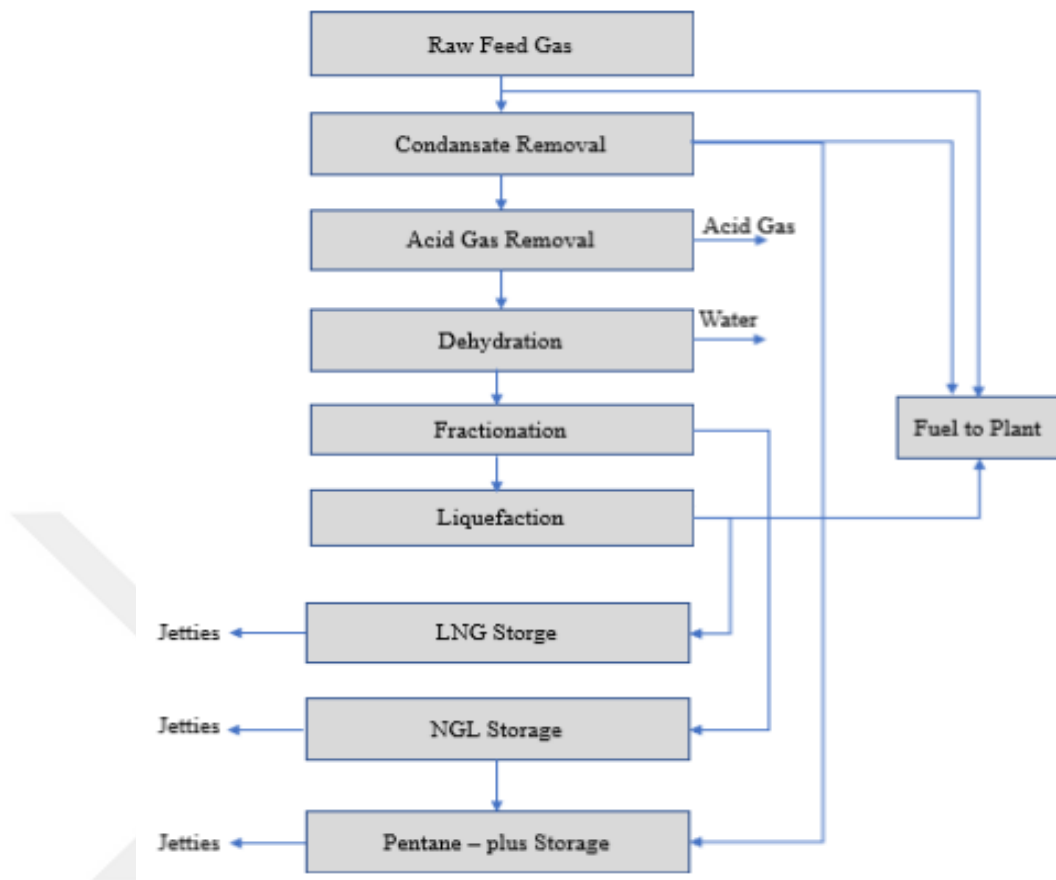
Peak-shaving plants are usually in small size and main purpose is to balance winter and summer demand fluctuations while storing excessive gas during summer and to be used in winter season to compensate higher demand. As the larger gas reservoirs are depleting and smaller reserves are explored in remote areas, medium-scale plants range from 0.3 to 1.5 MTPA brings opportunity to enter market with increasing LNG production technology. Small-scale LNG plants capacity could be as low as 0.01 MTPA which gains economic feasibility where excess capacity of gas pipeline is available. LNG could be loaded to trucks or barges to reach remote locations or to be used as alternative fuels.

Raw natural gas content varies according to location. However, natural gas liquids (NGL) -smaller quantities of hydrocarbons, are contained in raw gas in different quantities. In order to produce LNG and to use as fuel, these heavy hydrocarbons and non-hydrocarbon components should be removed. This treatment process is summarised in Figure 8.

Firstly, condensate is removed from raw gas. This is followed by stripping of carbon dioxide and hydrogen sulphide which freeze at higher temperature than LNG’s atmospheric boiling point. As the acid gas removal saturates the gas stream with water vapor, content is removed at dehydration stage. Following dehydration, in fractionating unit, NGLs are removed and butane and propane are generated at further stage. Main gas flow, as mostly methane, arrives to liquefaction stage to produce LNG (SIGTTO, 2000).

Liquefaction process is carried out in three different ways: 1-Pure refrigerant cascade process, 2-Mixed refrigerant process or 3-Pre-cooled mixed refrigerant. Pure refrigerant process is the old system that is effective in three cooling stages following propane, condensation of ethylene, and the last stage utilising methane is involved. Mixed refrigerant process, contrary to first method is utilised in one cycle usually for methane, propane, ethane, and nitrogen. The third one is the most common process nowadays which is basically combination of the pure refrigerant process and mixed refrigerant process (SIGTTO, 2000).

Figure 8: Flow Diagram of LNG Liquefaction



Source: (SIGTTO, 2000)

In 2019, 42.5 MTPA liquefaction capacity was added, and global capacity reached to 430.5 MTPA. According to IGU 2020 report, currently 907.4 MTPA of liquefaction capacity is under final investment decision stage, which is mostly from USA and Canada. Qatar, the market leader in liquefaction capacity, is also planning to expand in capacity (IGU, 2020)

1.4.2.3. LNG Transportation

Liquefied natural gas is being transferred to regasification facilities mainly by ships or trucks which have specialized design to carry the cargo below -160°C. LNG Ships are utilised to carry large volumes and trucks are usually used to deliver the LNG in remote inland locations (Mokhatab et al., 2014).

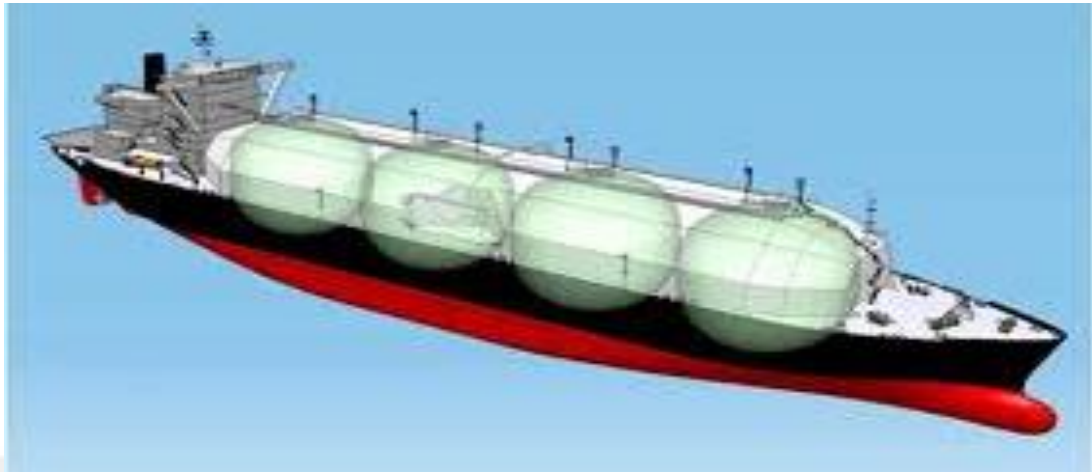
1.4.2.3.1. LNG Carriers

LNG carriers are designed to carry large volumes of LNG from liquefaction plants to regasification facility, at atmospheric boiling point of about minus -162°C . The first LNG transportation by sea was carried out in 1959 from USA to the UK. The first purpose-built LNG carrier was Methane Princess, 27400cbm capacity, prismatic shaped Type A tanks and worked between Algeria and the UK. LNG Carriers are classified as refrigerated gas carriers according to International Maritime Organisation, International Gas Carrier Code (IGC).

As LNG contains different gases in different percentages, LNG vaporisation is not homogenous. The components with lower boiling points such as methane and nitrogen evaporate faster than heavier components. As a result, LNG composition becomes heavier -called ageing or weathering, heating value and Wobbe Index of LNG increase. The tank design of the LNG carriers is quite critical as they carry the cargo below -160°C . Tank design integrated with hull systems provides insulation for LNG storage. However, boil-off gas cannot be prevented totally, it could be between 0.10 % to 0.15% per volume in a day. It must be removed from the tank to keep pressure stable (Mokhatab et al., 2013). BOG can be treated onboard with couple of ways. It could be as fuel in engine if it's gas driven or dual fuel engine; or could be used in boiler to produce steam or re-liquefied and re-sent to cargo tank.

There are two main cargo tank types in LNG carries: Moss Rosenberg and Membrane Tanks Systems. Figure 9 shows typical Moss type LNG carrier. Moss type tanks are spherical and made of aluminium alloys with additional insulation. They are separated spheres and allow partial loading. However, they also have some disadvantages as the tanks are heavy and the space between the tanks prevent being used effectively onboard space and high superstructure causes stability and aerodynamics issues (SIGTTO, 2016).

Figure 9: Moss Type LNG Carrier



Source:(GCaptain, 2014)

Membrane type tanks provide more effective use of onboard space, they are separated from ship hulls rather permanently installed. They produce lower BOG due to their design but at the same time more prone to sloshing effect. Partial loading is also subject to extra reinforcement(SIGTTO, 2016).

The size of the LNG carriers is also increased in parallel to growing LNG trade(SIGTTO, 2016). However, new retail LNG trade such as LNG bunkering, create demand for small LNG carriers, bunker barges and feeders(Shell, 2019a). New LNG carriers capacity has reached to approximately 265000 cbm called Q-Max LNG, with 345m LOA, trading in special supply chain routes as they face with port restrictions. Q-Flex tankers' capacity is about 210000cbm and both type of vessels are equipped with twin propeller, slow-speed diesel engine, on board reliquefaction system (Mokhatab et al., 2014). Figure 10 shows typical membrane type LNG carrier's tank cross section.

Figure 10:Membrane Type LNG Carrier



Source: (Liquefiedgas, 2020)

International Gas Union (IGU) 2020 report indicates that globally there are 541 active LNG carriers and 42 of them are new built vessels as of 2019. Representing 8.4% increase in a year. 4 new FSRU have been put into service and the number of FSRUs has reached to 34. In parallel to growing LNG demand, total of 5701 voyages have been performed, as an 11% increase compared to previous year. Parallel growing in number of fleet and LNG trade is a good indicator for LNG shipping and trade. Moreover, 126 vessels are already on the order book of shipyards by the end of 2019 and approximately 20 vessels in laid up. (IGU, 2020).

1.4.2.3.2. Trucks

Trucks provide delivery to inland users at small parcels, either on road trailer or in ISO cryogenic containers. Trucks deliver LNG to inland customers to be used for industrial purpose. Growing demand of LNG fuel in heavy-duty vehicles create new supply chain for retail stations. Delivery of LNG is carried out by typically vacuum-insulated, cryogenic semi-trailers. Gross capacities are ranging 48075ltrs to 61702ltrs (Mokhatab *et al.*, 2014).

1.4.2.4. LNG Regasification and Storage

Regasification stage is performed in receiving terminals and LNG is supplied to final users in gaseous form via distribution pipelines. Receiving terminals are functioned in three ways: 1-Converting LNG to gaseous state, 2- Providing storage facility, 3-Reloading either to truck or feeder ships in LNG form.

LNG Receiving facility either could be offshore or onshore. LNG terminals receive the cargo via typically three discharging arms to a single tank. In addition to three discharging arms one vapour return line is connected. Stored LNG is discharged by low-pressure (LP) send-out pump which is installed inside the storage tank. The high-pressure (HP) send-out pump is installed between tank and vaporiser and designed to take suction from Boil of Gas re-condenser. LNG is converted to gaseous phase via vaporizers. Vaporizer systems are designed according to terminal requirements. The line is connected to distribution pipeline (Mokhatab *et al.*, 2014).

Global regasification capacity is measured as 821 MTPA as of February 2020 by 23.4 MTPA expansion capacity in 2019. Market growth in regasification capacity is mainly driven by Asia, particularly India. Moreover, new countries are on the way to start their first regasification facilities in near term such as Philippines, S. Cyprus, Vietnam and El Salvador. Some other countries such as Myanmar, Germany, Morocco have already proposed additional regasification capacity (IGU, 2020).

In 2019, LNG receiving terminal storage capacity has reached to 65 Million cubic meters (mmcm) with seven new receiving terminals and three expansion projects. Storage capacity distribution is similar to regasification facilities and 50% of the global capacity was located in Japan, South Korea and China (IGU, 2020). Storage capacity is important for the supply security as it provides flexibility and protection against seasonal fluctuations.

1.4.3. LNG Terminals

LNG terminals could be installed permanently onshore, which provides a more permanent solution with longer term supply security. Larger storage capacity and lower operating expenditures (OPEX) are advantages of onshore terminals (IGU,

2020). On the other hand, liquefaction, regasification and storage processes could be performed on offshore facilities. These are mainly built in purpose for specific area and have limited flexibility in terms of storage capacity and time in use (Shell, 2019a). However, on positive side, provides flexibility in land and port requirements, requires lower capital expenditure (CAPEX) and allows quick fuel switching as energy sources. Although it depends on the location, generally requires fewer regulations (IGU, 2020). Currently, there are 352 LNG import terminals and their size ranging from 0.001 mmt/y to 29 mmt/y by the end of January 2021. There are also 191 export terminal across the world and their size range is between 0.04 mmt/y to 15.6 mmt/y (LNGjournal, 2021).

Figure 11: Gladstone LNG Terminal, Australia



Source: (Total, 2020)

Figure 11 shows typical export terminal in Australia. It's located on Curtis Island off the coast on Gladstone with capacity of 7.2 mt/year (Total, 2020).

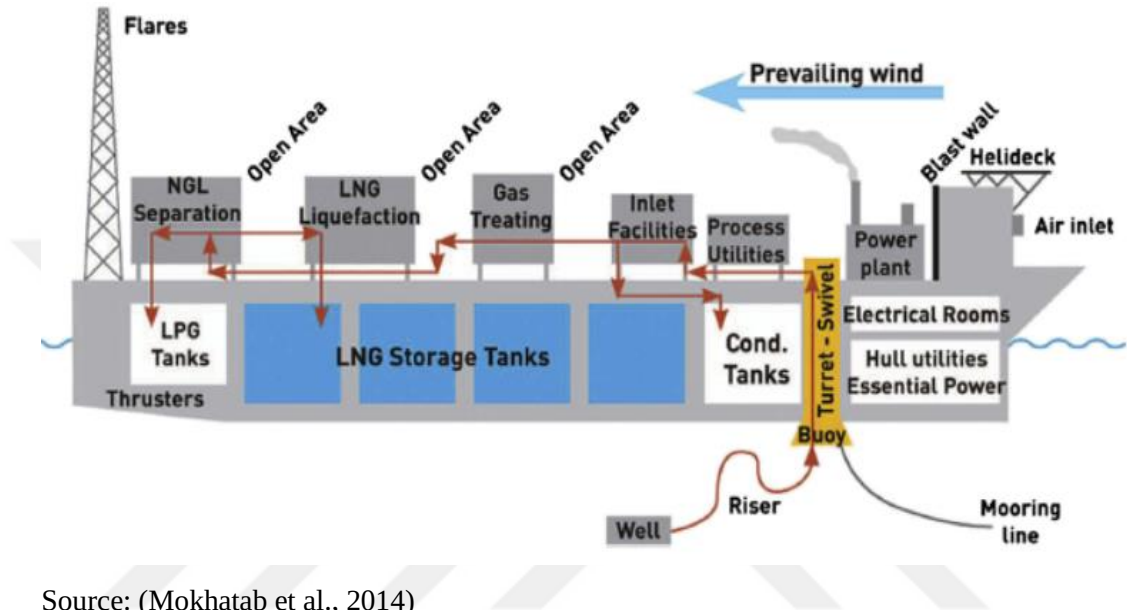
1.4.3.1. LNG Floating Production Storage and Offloading (FPSO)

FPSO vessels make it possible to produce oil and gas from deep-water fields and they have been in use since 1970s. Offshore LNG installation market is growing in parallel to LNG demand. Offshore production makes it possible to take gas reserves

without export piping and highly costly onshore infrastructure. Moreover, it minimises security and geopolitical risks.

LNG FPSO is basically designed over LNG carriers, modules are installed on the deck. Figure 12 shows typical LNG FPSO layout.

Figure 12: Typical LNG FPSO Layout



Source: (Mokhatab et al., 2014)

They are designed with strict safety requirements which separates living quarters and cargo areas. As the facility is dealing with cryogenic fluids, special precautions are taken for spill risks. Large amounts of seawater is lifted for cooling process during production, intake and overboard discharge lines are positioned accordingly. Tank venting systems and production facility flare systems are generally combined. Location and height of the flare systems are determined according to back pressure, crew accommodation. The space is very limited in offshore facilities. Taking into account volume of the hydrocarbons, relatively high pressure at congested places is required with special precautions. High-pressure and low-pressure interface exist between modules on top and storage tanks. The risk of the system should be minimised by pressure control safety devices. Mooring systems of the offshore systems are other critical factors, vessels movement under extreme weather conditions, current, swell, tide conditions, bottom analysis, anchoring and mooring methods should be designed and analysed with operational perspective.

1.4.3.2. FLNG (Floating Liquefied Natural Gas)

FLNGs are special purpose offshore vessels designed for natural gas liquefaction. World's first offshore FLNG facility started operation in 2018, 300nm off the west coast of Australia. The vessel conducts its operations at 250m at sea depth. Annually FLNG produces 3.6 million tons of LNG out of 5.3 million tons of liquid (Shell, 2019a). FLNG vessels are designed not to produce flares under normal operating conditions. Gas treating plant, low NOx burner, gas turbine waste heat recovery systems are installed to increase efficiency of the vessels and minimise the emissions.

1.4.3.3. Floating Storage and Regasification Unit (FSRU)

FSRUs provide flexible alternatives to onshore regasification facilities. FSRUs could be moored to a jetty or can be located near-shore or offshore. The facilities take receiving vessel roles when LNG carrier comes alongside to discharge her cargo and ship-to-ship transfer is carried out. FSRUs could be built in purpose or can be converted from ex-LNG vessels with regasification facilities onboard along with storage tanks (SIGTTO, 2016). However, compared to onshore terminals, FSRUs have higher boil-off-gas (BOG) rate, in order to cope with this problem, a vapour recovery system should be installed. Depending on to location where they are in service, additional heating system may be required in winter particularly in the arctic regions(Mokhatab et al., 2014).

1.4.4. LNG Price

Unlike crude oil, LNG does not have harmonized global price which have regional segmentation in contracts. The world's first gas markets have been created in USA since 1990s. Gas buyers and sellers began using these markets for physical trade along with traders, marketers and aggregators. Henry Hub was selected by NYMEX (New York Mercantile Exchange) in 1990 as natural gas futures contract (EIA, 2017). Currently, there are three main markets in LNG pricing: The Asia Market with Japan

custom-cleared crude price index, The European market with National Balancing Point (NBP) price index and The North American market with the Henry Hub price index (Energy, 2016). LNG pricing structure is evolving from oil indexed to gas-on-gas pricing structure according to well-established global reference points.

The USA market has derived from a transparent market-based mechanism since Federal Energy Regulatory (FERC) issue order in 1992. Deregulation of natural gas commodity along with extensive natural gas pipeline network has allowed to develop a natural gas market. Henry Hub, Louisiana, is the main hub, in addition to some as AECO Alberta, Dominion South Point.

Reforms in USA followed by European Union and development of gas market have begun in Europe. National Balancing Point (NBP) and Title Transfer Facility (TTF) have emerged as gas hubs in the UK and the Netherlands respectively.

Asia-Pacific market started emerging in the early 2010s with the signing of Henry-Hub based LNG tolling contracts. Following this, Singapore Exchange created a price index and SGX LNG Index group, launched derivative contracts in January 2016. Another price indexing was established as JKM (Japan-Korea-Marker) (Miyamoto et al., 2017).

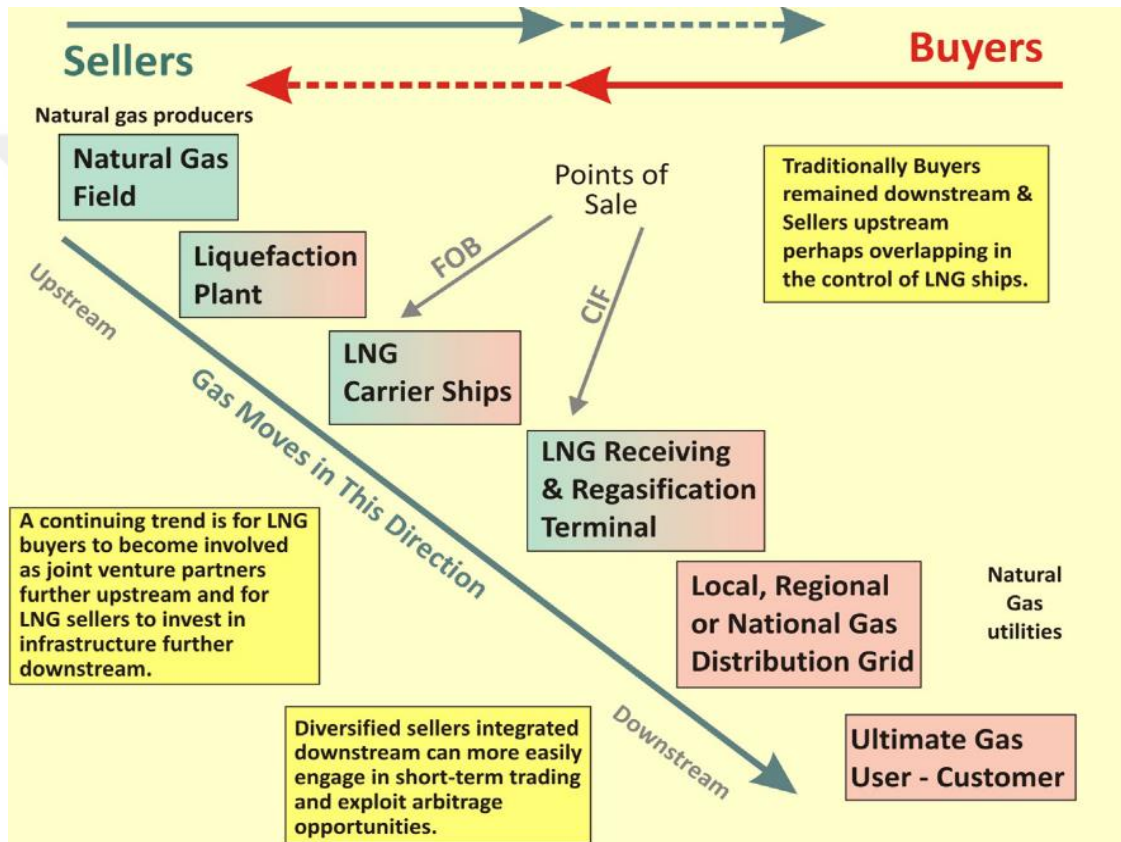
Growing LNG spot market and short-term contracts allows market to go divertible and uncommitted structure. As record low of international gas prices, in Asia average spot LNG prices were recorded as 5.49USD per MMBtu in 2019 (IGU, 2020). Increasing USA's LNG exports shape the market with new business models, as they take the Henry Hub as reference, despite the dominated oil indexed price, now there is increasing trend to tie NBP, TTF and JKM for hybrid pricing models (IGU, 2020).

Netback concept is important benchmarking particularly for producing countries as it allows to understand differing value of LNG in different markets. It is determined by taking the net revenues from downstream sales of LNG/natural gas in the destination market, less all cost associated with gas till getting it to the market. The starting point of the netback could be well at the liquefaction plant inlet or at the exit of liquefaction plant. Delivery point of the LNG depends on the contract of the parties; free onboard (FOB), costs insurance and freight (CIF) as at the liquefaction facility; or delivered at terminal (DAT), delivered at place (DAP) sale at the destination point (Energy, 2016).

1.4.5. LNG Contracts

Gas projects could have different contracts at the different stage of the supply chain. In parallel to growing LNG market and diversifying supply chain, contracts are evolving more flexible or short-term trading agreements. Different contractual components of the LNG supply chain are illustrated in Figure 13.

Figure 13: Involvement of Buyers and Sellers in the LNG Supply Chain



Source: (Mokhatab et al., 2014)

Traditionally buyers and sellers position remained at downstream and upstream respectively. However, trend in LNG market shows that buyer side extend its control further upstream by joint venture structure. On the other hand, integration of diversified sellers allows them to engage in short-term trading. Integrated upstream groups and downstream groups contracts were utilised as long-term contracts with CIF or DES terms and take-or-pay terms. This type of contracts was provided to sellers guaranteed sales, low-risk return for investments. However, during 1990s, emerging

non-integrated LNG supply chains which allows buyers to operate ships and to make FOB agreements brought flexibility to buyers, particularly Japan and Korea. Expanding their LNG fleet also help them to influence over long-term shipping charters (Mokhatab et al., 2014).

However, traditional integrated LNG supply chain is evolving away from this structure (Mokhatab et al., 2014). Changing market structure with new buyers and uncertain long-term gas requirements affected LNG contracts. Renewable energy sources' contribution, declining costs and increased competition create different risk profile for developing markets, which are seeking more speculative contracts, consequently, buyers' demands are transformed to lower demand volumes and greater delivery flexibility.

1.5. LNG MARKET OVERVIEW

LNG is an important source in world energy market. Supply chain dynamics have shaped the market structure of the LNG. LNG market has been reviewed under world energy outlook, natural gas outlook and LNG trade.

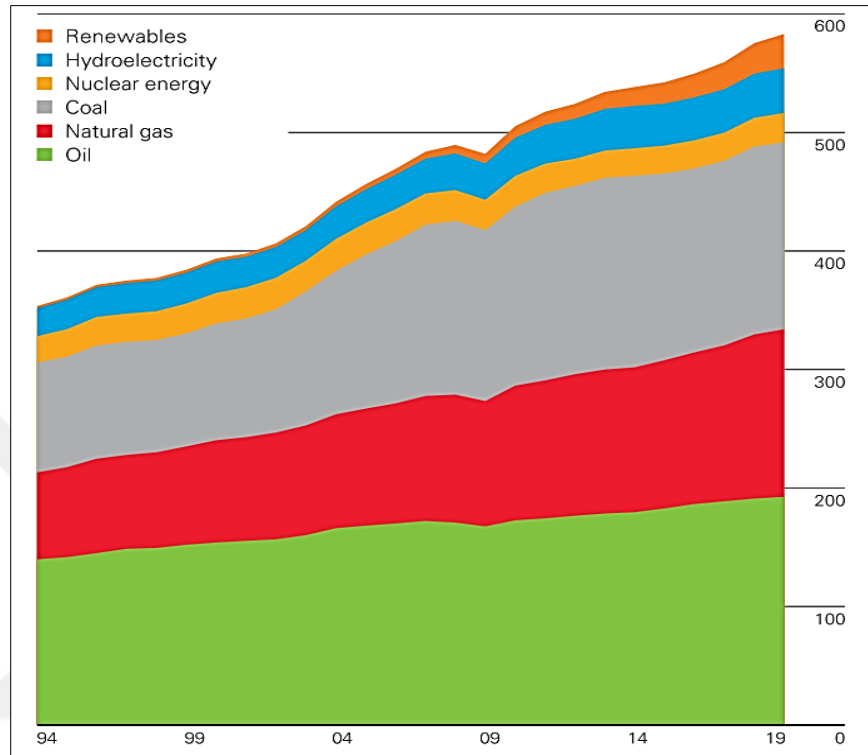
1.5.1. World Energy Outlook

The weaker economic growth was reflected in world energy demand in 2019, particularly in USA, Russia and India. However, China followed different trend than those big economies and kept accelerating energy demand. Apart from natural gas, China took largest increment to demand for each energy source. Shifting in fuel mix towards to renewables has positive impact on slowing carbon emissions. However, reaching 2050 targets still needs much more effort (BP, 2020c).

BP statistical review indicates that primary energy consumption rose below 10 years average and reached to 583.9 EJ. Energy growth demand in Africa, Middle East, South & Central America and Asia was balanced with decline in North America, Europe and CIS countries. Increase on renewables and natural gas demand was the main contributor for growing energy demand. Apart from nuclear energy, all energy consumptions growth rate are less than 10 years average. Moreover, coal consumption

decreased four times in the last six year (BP, 2020c). World consumptions as exajoules are illustrated in Figure 14.

Figure 14: World Consumptions as Exajoules



Source: (BP, 2020c)

Oil takes the largest part in consumption as energy sources. Daily consumption was increased 0.9 million barrels in 2019. Growth in consumption was driven by China as daily demand was measured as 680000 barrels. Ethane and LPG demand increased in product segment as a result of substitution of the naphtha. IMO 2020 regulations have positive impact on marine diesel oil demand, in parallel to this demand, high sulphur fuel oil reduced as 320000 b/d. OPEC's overall production declined as 2 million b/d which is recorded as the largest reduction since 2009. The biggest increase in production was observed in USA as 1685000 b/d, in contrary, Iran and Venezuela recorded the biggest decreases in production.

Coal's share in world energy mix have declined to 27% and recorded as the lowest point in last 16 years. This fall has mainly resulted from energy shift in the power sector from coal to natural gas and renewables. However, consumption of the

coal increased in some emerging economies such as China (1.8 EJ), Indonesia (0.6 EJ) and Vietnam (0.5 EJ). On the contrary, OECD recorded its lowest coal consumption year since 1965. This reduction was mainly led by USA (-1.9 EJ) and Germany (0.6 EJ). Production increased by 1.5% in 2019 compared to 2018. Consumption and production imbalance is reflected in coal price as significant drop in Northwest Europe and China as much as 34% and 14% respectively.

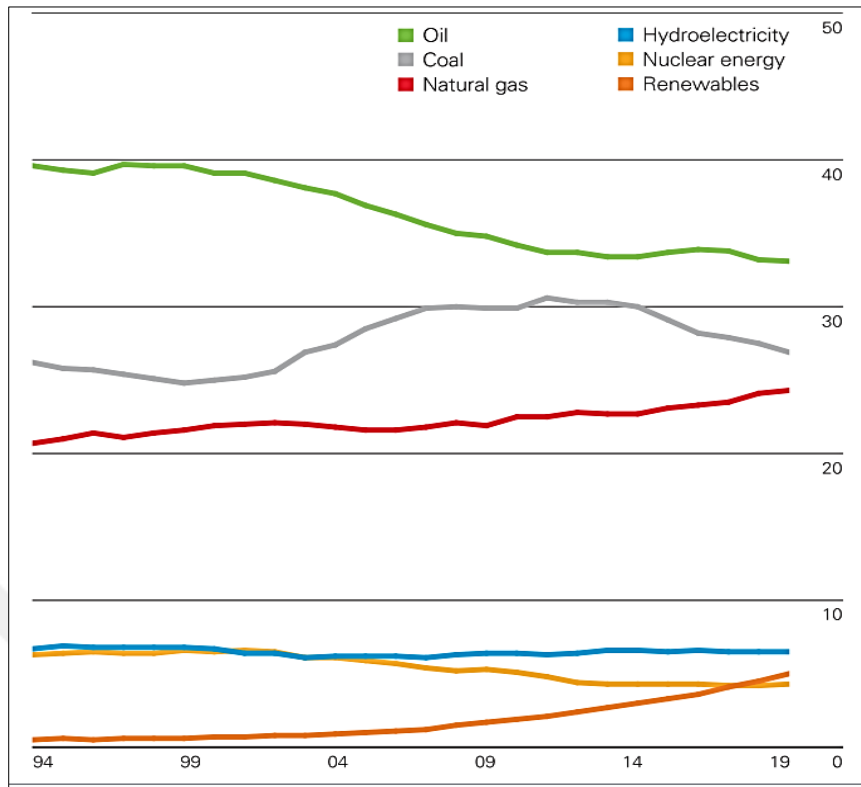
Natural gas consumption globally increased 2% in 2019, this is below the 2018 figure which is recorded as 5.3% rise. On the other hand, gas production grew 3.2% - more than the consumption. This was driven by USA, China and Australia. LNG exports increased 12.7% in 2019 which is the largest annual increase ever.

Renewables energy consumption has strong pace to grow. 3.2 EJ increase on renewables energy consumption is accounted for 40% increase globally. As a result renewables share took 5% in energy mix at the end of the 2019. China recorded the biggest grow (1.2 EJ) in renewables energy consumption and followed by USA (0.3 EJ) and Japan (0.2 EJ). The largest renewable energy source is wind (1.4 EJ) and followed by solar (1.2). Other renewables are biomass, and geothermal took important parts.

Hydroelectricity consumption increased by 0.8 EJ. China and Turkey are two countries which recorded the biggest increase on hydroelectricity. Nuclear energy consumption was raised 3.2% in 2019 compared to 2018 mainly by China and Japan.

Despite the decrease on the coal consumption, it still takes the largest part in power generation source. The largest growth in electricity production is observed in renewables and natural gas. Renewables' share increased to 10.4% and for the first time recorded as more than nuclear based electricity generation. Figure 15 illustrates shares of global primary energy sources as percentage.

Figure 15: Shares of Global Primary Energy as percentage

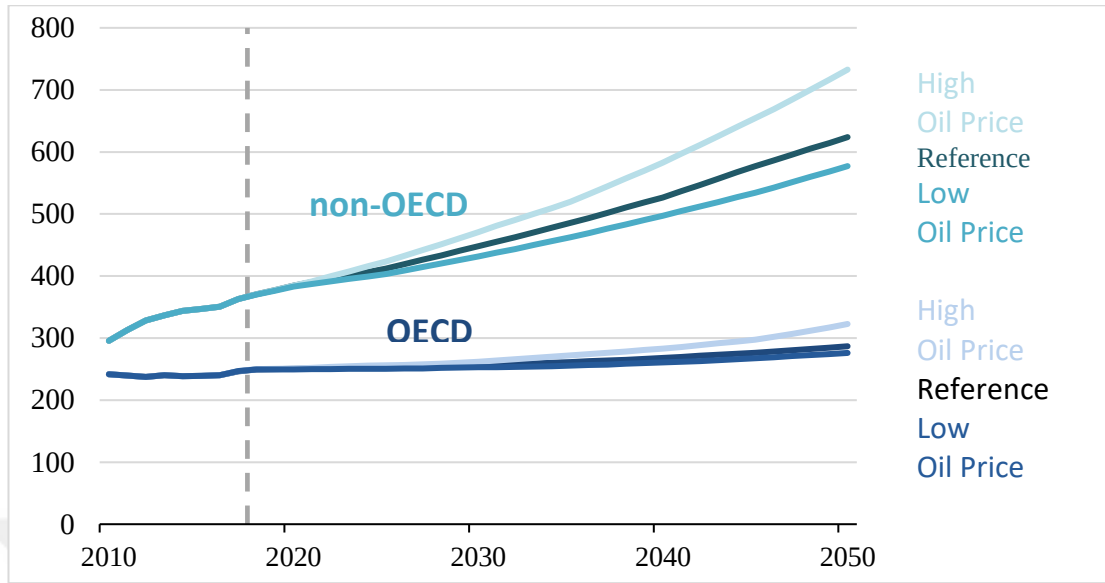


Source: (BP, 2020b)

US Energy Information has two different scenarios for future energy consumption as high economic growth and low economic growth. International Energy Outlook 2019 report indicates that there will be significant variation between OECD and non-OECD countries. In OECD countries GDP increase is projected as between 1.1% and 2.1% as high and low growth scenarios between 2018-2050. Non-OECD countries' projection is between 3.2% and 4.6% for the same period. According to reference case that takes average of the high and low scenarios; world energy consumption will be 911 quadrillion Btu in total, 624 quadrillion Btu in non-OECD and 287 quadrillion Btu in OECD countries. Figure 16 illustrates projection for world energy consumptions in high and low economic growth cases (IEO, 2019).

International Energy Agency (IEA) future projection is evaluated under three scenarios: Stated Policies, Sustainable Development, and Current Policies. According to Stated Policies scenario, growing demand is mostly met by renewables (50%) and gas (35%). Increasing fuel efficiency and pressure from electrification of mobility keep oil demands stable by the 2030s.

Figure 16: Energy Consumption (quadrillion British thermal unit)



Source: (IEO, 2019)

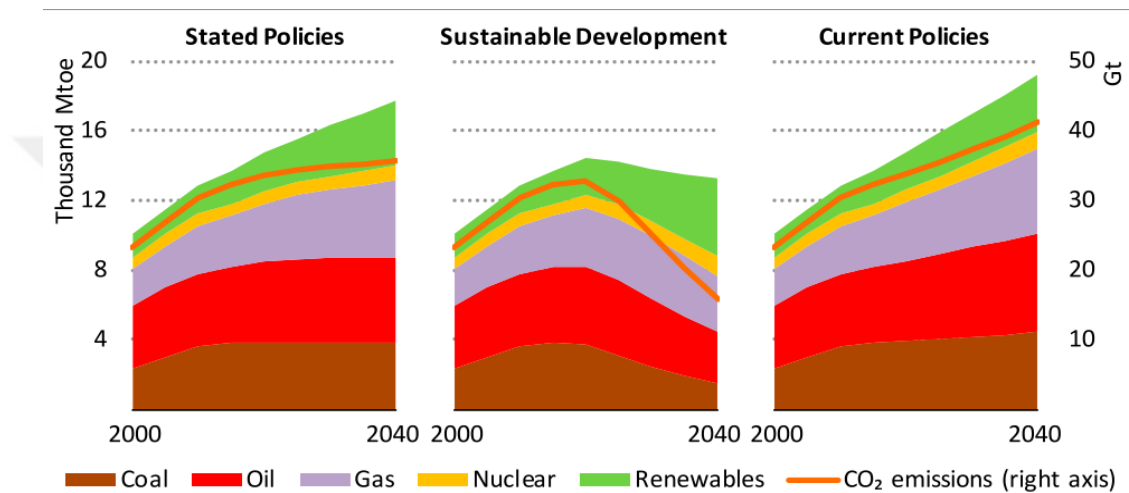
Sustainable Development Scenario is projected under emission control goals and air quality. Stringent emission control and energy efficiency policies lead to lower energy demand in 2040 compared to today, even though world economy grows 3.4% per year in average. Gas demand decreases after 2030, substantial reduction in coal use accompanied by decline on oil market down to level of 1990s are the components of the Sustainable Development pathway (IEA, 2019b).

In all three scenarios, China is the largest energy consumer, on the other hand, India represents larger demand growth. As it is focused in the 2019 Outlook, Africa's demand growth is increasing and expected to have significant effect on global energy trends in the future with their policies and implications on energy source selections.

Stated Policies Scenario predicts that a 60% increase in electricity demand will be compensated by a low-carbon generation mix. Solar photovoltaics (PV) and wind energy provides significant contribution to meet demand and overtake coal in the fuel mix as of mid-2020s. However, Stated Policies Scenario has no peak year for CO₂ emission, despite to renewables contribution and coal's cut in the fuel mix. It continues to increase with growing economy and population. Only Sustainable Development Scenario foreseen emission cuts and it requires ambition in terms of energy efficiency, decarbonisation of fuels, technology improvements and investment (IEA, 2019b).

Energy security is still a concern. Oil prices and supply chain are at the risk of volatility. Dramatic drop in oil prices could have significant effect on scenarios. However, increased volume in natural gas trade globally, mainly due to LNG, provides flexibility. It's predicted that LNG overtakes pipeline gas by the late 2020s as main method for inter-regional trade. Figure 17 illustrates world energy demand by fuel and related CO₂ emissions by three scenarios.

Figure 17: World Energy Demand by Fuel and Related CO₂ emissions



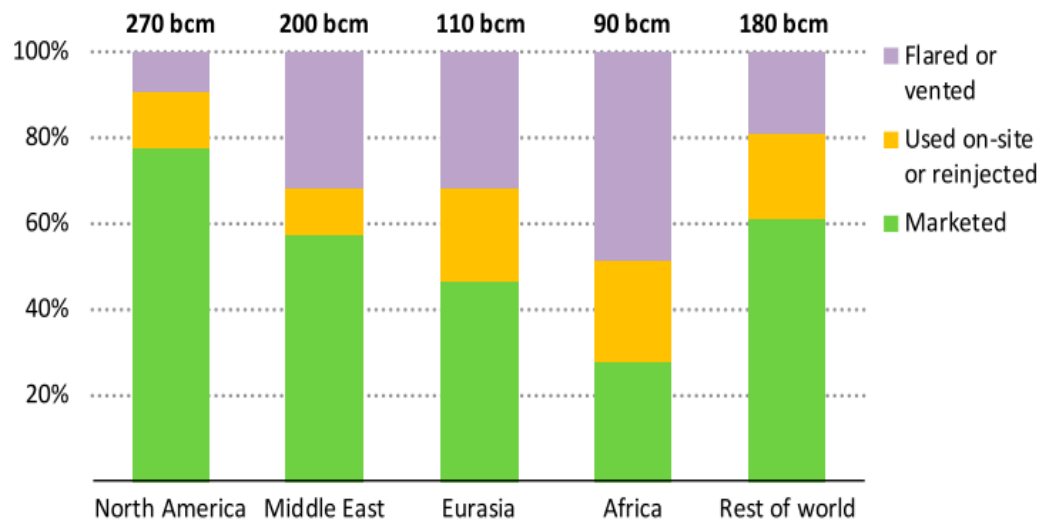
Source:(IEA, 2019b)

Growing importance of the LNG is a critical factor in future emission control scenarios. LNG market is reviewed in following sections in terms of demand, supply and price behaviours.

1.5.2. Natural Gas Outlook

Oil reserves usually rise to surface along with mixture of the hydrocarbons such as natural gas liquids, condensates, and natural gas. Although there is no consensus on definition, if the gas is more than 60%, it's classified as non-associated gas. Below this figure is called as oil well that is also produce gas. As oil and gas usually came to surface together, it's not so easy to consider two markets totally different. Gas is released during extraction of oil flared, used on site or reinjected, or marketed. Figure 18 illustrates use of related gas by region.

Figure 18: Use of associated gas by region 2018



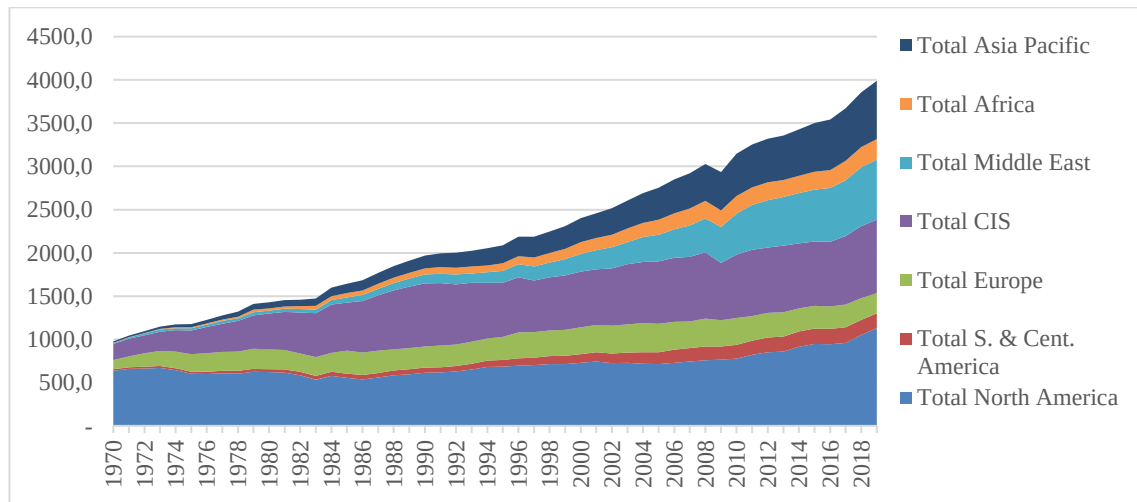
Source: (IEA, 2019b)

In Africa, almost half of the associated gas has been vented or flared, however, in North America, this is less than 10%. Meaning of this waste of gas is not only economic loss but also significant environmental effect (IEA, 2019b).

1.5.2.1. Natural Gas Production

Despite the fact that production of associated or non-associated gas volume change over the years, natural gas reserves increased to 198.8 trillion cbm by the end of the 2019 (BP, 2020b). Natural gas production increased to 3989.3 billion cbm as well. It means that global production is 3.4% more than 2018. North America is the largest contributor to this increase in production along with Asia Pacific countries. On the other hand, South America and Europe productions are 1.5% and 6.1% less than 2018 figures respectively. By the end of the 2019, North America takes the largest share in cumulative natural gas production as 28,3%, followed by CIS countries as 21.3%.

Figure 19: Gas Production by Region 1970 to 2019- Billion cbm



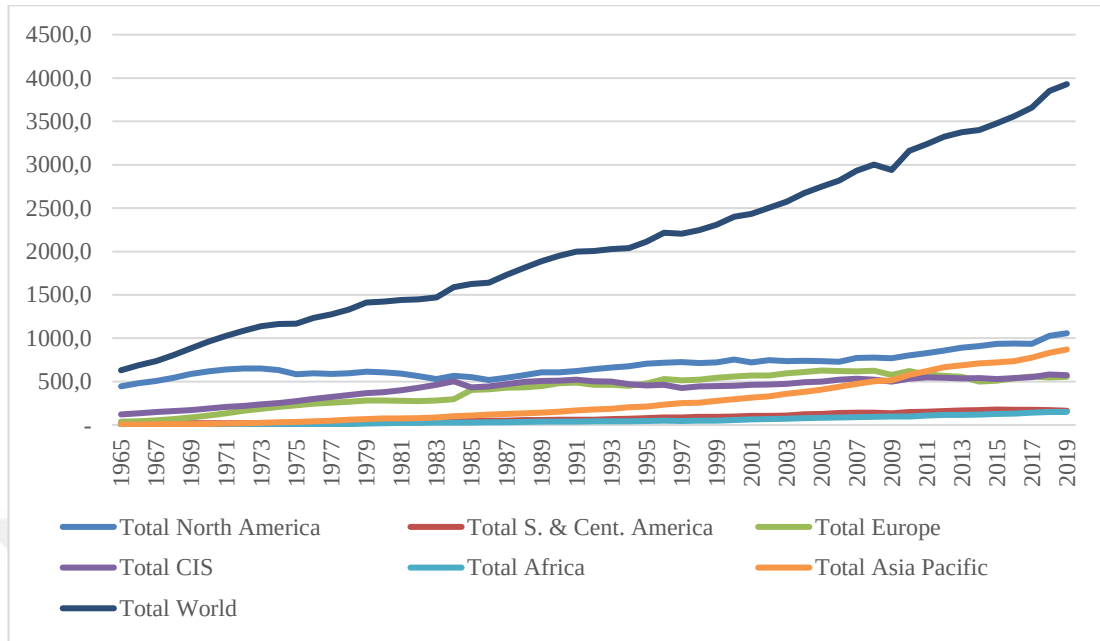
Source: Author, compiled from (BP, 2020a)

Figure 19 illustrates gas production breakdown by region between years 1970 to 2019. Middle East, Asia Pacific and Africa have been added as important gas producers after 2000.

1.5.2.2. Natural Gas Consumption

By the end of the 2019, total natural gas consumption has increased 2% compared to 2018. However, this figure is below the 2008-2018 average, as it was recorded as 2.5%. North America takes the largest part (26.9%) in natural gas consumption as it is in production. Asia-Pacific consumption takes the second largest share as 22.1%, despite the decrease in annual grow rate, it was calculated as a 4.7% increase in consumption compared to 2018. On the other hand, this is the biggest increase rate compared to other regions. Figure 20 illustrates historical natural gas consumption trend by region.

Figure 20: Natural Gas Consumption by Region 1965-2019, Billion cbm



Source: Author, compiled from (BP, 2020a)

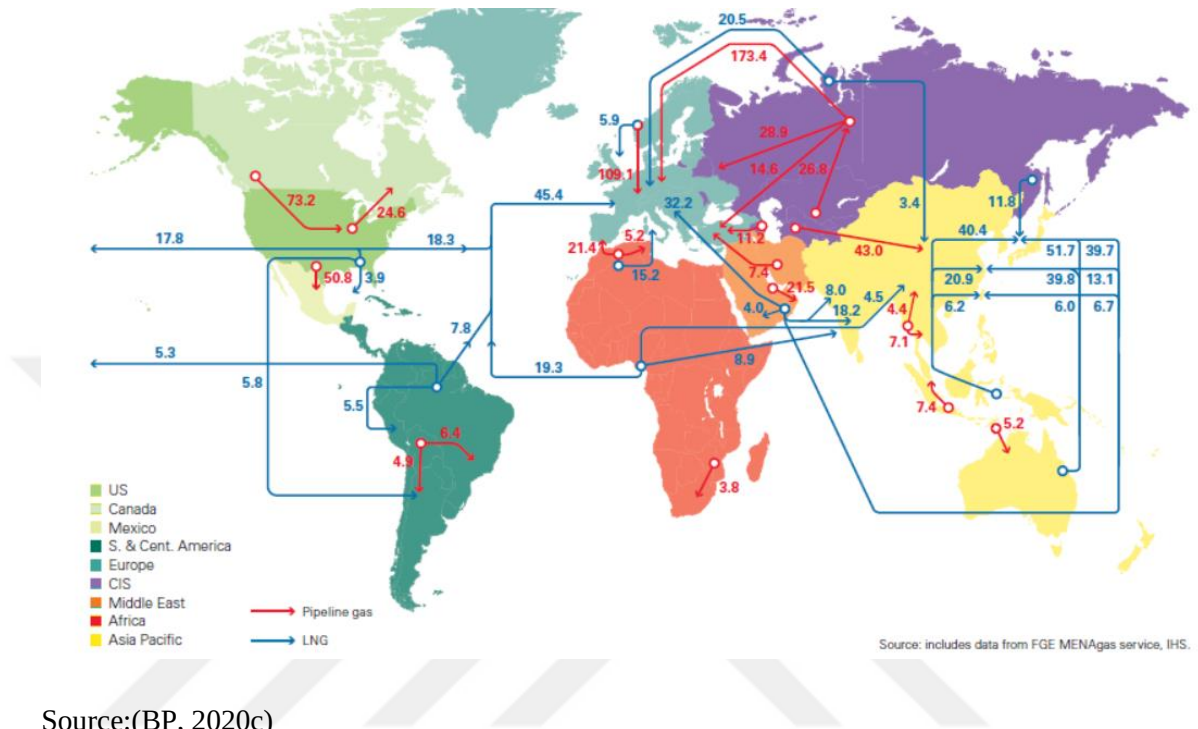
Europe's natural gas demand slightly increased and reached to 554.1 billion cbm by the end of 2019. The share of the OECD countries take the 45.8% of the total consumption of the natural gas in 2019. USA, Russian Federation and China take the largest portion of the natural gas consumption as 846.6 billion cbm, 444.3 billion cbm and 307.3 billion cbm respectively.

1.5.2.3. Natural Gas Trade Movements

Natural gas is delivered to demand points either as LNG by ships or as gas in pipeline. The share of the pipeline and LNG is almost equal by the end of the 2019. However, strong growing rate of the LNG is expected to make LNG option primary mean of natural gas trade. Trade movement of the gas is changing dramatically for the last years as USA's production capacity change their position from net importer to net exporter. Europe's pipeline imports decreased 28% in 2019, on the other hand pipeline imports form CIS country other than Russia increased 21.5%. Russian pipeline imports just slightly declined 2.1% in 2019. On the contrary, Europe's LNG imports increased 68.1% in 2019 which is recorded high taking into consideration 2008-2018 average as

2.2%. Total 353.3 billion cbm natural gas imports, makes Europe the biggest market for natural gas trade. Figure 21 shows the trade movements of natural gas in 2019.

Figure 21: Trade Movements of Natural Gas in 2019



Russia's total exports increased 4.2% in 2019 and reached to 256.6 Billion cbm and sealed their critical position in gas supply with 26.1% share. Primary means of natural gas exports of Russia is pipeline and Europe is the primary customer. 217.2 cbm out of 256.6 billion cbm of natural gas distribution is carried out via pipelines. However, Russia recorded 57.9% increase on LNG exports in 2019 and it brings flexibility to Russian gas sales.

1.5.3. LNG Trade

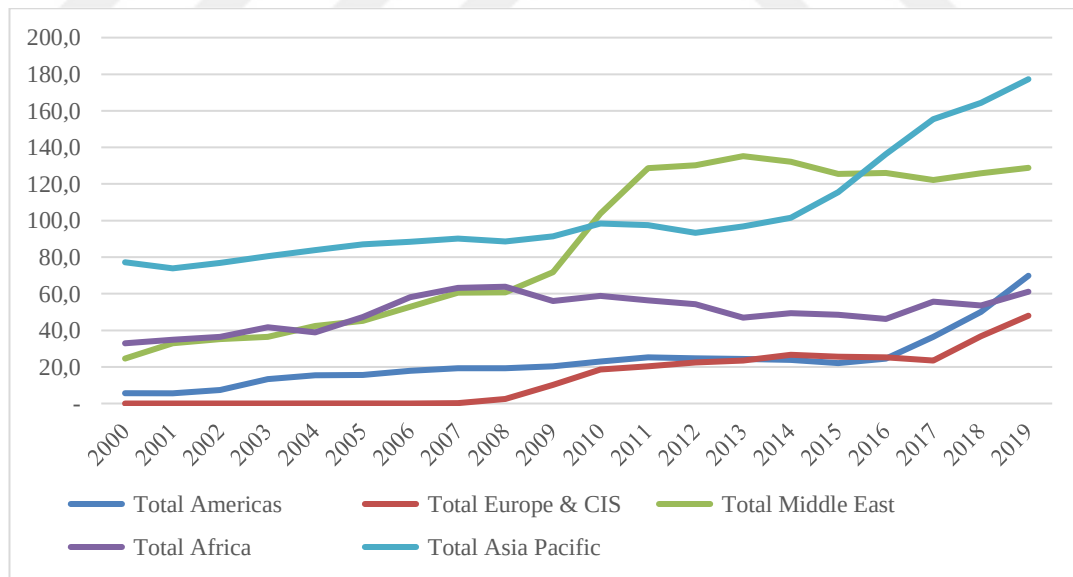
Pipeline gas has been the main way to transport natural gas over the years. However, developing economies in Asia, new reserves, technological improvements lead to making LNG more competitive against pipeline gas. Despite the fact that significant uncertainties as the scale and stability of demand for LNG, in 2019, LNG

inter-regional trade rose 12.7%. IEA report also points out that market share of LNG in total gas demand growing from 20% in 2018 to 40% by 2040 (IEA, 2019b).

1.5.3.1. LNG Exports

LNG exports reached to 430.6 billion cbm by the end of 2019. Asia-Pacific takes the largest part in LNG exports and measured as 164.3 billion cbm as of 36.5% share. Since 2015, Asia-Pacific has taken the leadership from Middle-East which represents 26.5% share by 2019. Relatively steady exports increased only 2.3% which is the lowest positive difference compared to other regions. Strong growth observed at North America (39.5%) as out of its historical trend and reached 69.8 billion cbm. The second biggest increase observed at Europe and CIS region as 30.8% and reached to 36.7 billion cbm by the end of 2019. Another export region Africa is relatively stable and reached to 61.2 billion cbm, despite the 14.2% increase in 2019. Figure 22 illustrates historical trend of LNG exports by region.

Figure 22: Total LNG Exports by Region 2000-2019, Billion cbm



Source: Author, compiled from (BP, 2020a)

Distribution of LNG exports in 2019 is illustrated in Table 2. Qatar keeps its largest LNG importer position narrowly ahead of Australia and takes 22.1%.

Australia's ambition for LNG exports are growing over the years and reached to 104.7 billion cbm by the end of 2019.

Table 2: Distribution of LNG Exports by Country

Country (Billion cbm)	2019 total	2019 Growth Rate	2019 Share	Cumulative
Qatar	107.1	2.0%	22.1%	22.1%
Australia	104.7	14.0%	21.6%	43.7%
USA	47.5	66.3%	9.8%	53.5%
Russia	39.4	57.9%	8.1%	61.6%
Malaysia	35.1	6.5%	7.2%	68.9%
Nigeria	28.8	3.3%	5.9%	74.8%
Trinidad & Tobago	17.0	2.6%	3.5%	78.3%
Algeria	16.6	26.4%	3.4%	81.7%
Indonesia	16.5	-20.8%	3.4%	85.1%
Oman	14.1	3.6%	2.9%	88.0%
Others	58.4	11.9%	12.0%	100%

Source: Author, compiled from (BP, 2020a)

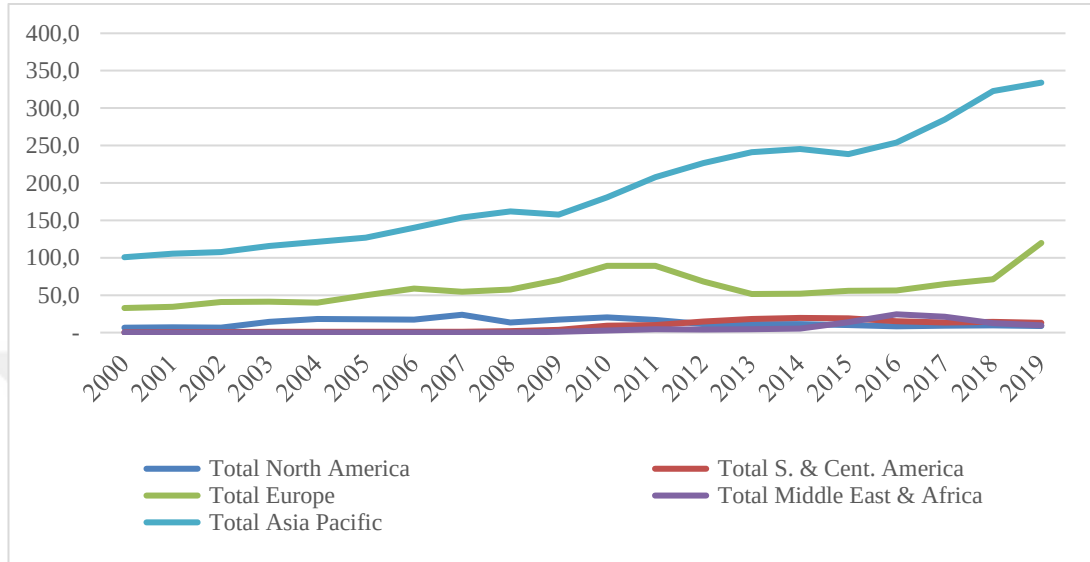
USA and Russia recorded the highest growth rate in 2019, as 66.3% and 57.9% respectively among important exporter countries. However, the biggest increase was observed in Egypt exports as 129.8% globally, compared to 2018. Egypt's export quantity reached to 4.5 Billion cbm and take 0.9% share at global market. Indonesia is the only country negatively differentiated among top LNG exporter countries as it observed significant decline at LNG exports, although they have one of the world's largest gas reserves. Interesting reflection of the table is that top 10 exporter countries take 88% of the total global exports and only three countries accounted more than 50% of the whole exports.

1.5.3.2. LNG Imports

LNG demand increased 12.7% in 2019 and reached to record-high as 485.1 billion cbm. Figure 23 indicates that LNG import distribution is not homogeneous by region. Asia-Pacific is far the largest importer region as 68.9% share and 334.1 Billion cbm quantity. Europe is the second largest market and accounted for 24.7% by the end of 2019. The rest of the regions are not taking share more than 2.7% of global imports. Although production has more homogenous distribution for LNG, demand

centres are concentrated in Asia-Pacific and Europe. LNG trade, pricing, and security are shaped according to this market overview.

Figure 23: Total LNG Imports by Region, 2000-2019, Billion cbm



Source: Author, compiled from (BP, 2020a)

Regional imbalance is reflected in LNG distribution by countries in Table 3. Japan takes the highest share in LNG imports with 21.7% as 105.5 billion cbm by the end of 2019, despite the 6.6% decline in 2019. China is the second LNG importer with 15.4% growing rate and was recorded as 84.8 billion cbm by the end of 2019. This is behind the last ten years growth average 2008-2018 as it was 31.8%. South Korea's imports declined 7.6% and were recorded as 55.6 billion cbm. However, South Korea keeps its third largest LNG importer position and contributes to the domination of Asia-Pacific's in global market. A record-high increase in the demand was observed in the United Kingdom as it increased from 7.2 billion cbm to 18.0 billion cbm. All European countries have significant increases on LNG demand by 2019, ranging between 46% (Spain) and up to %117.9 (Belgium) and reflected in total quantity in Europe as 119.8 billion cbm. Turkey has the modest increase on LNG demand compared to other European countries, despite the 12.9% positive change. Significant increase on Europe's LNG imports compensated decline in domestic production and pipeline imports. On the negative side, USA's LNG imports narrowed 30.9% and recorded as just 1.5 billion cbm.

Table 3: Distribution of LNG Imports by Country in 2019

Country (Billion cbm)	2019 total	2019 Growth Rate	2019 Share
Japan	105.5	-6.6%	21.7%
China	84.8	15.4%	17.5%
South Korea	55.6	-7.6%	11.5%
India	32.9	7.4%	6.8%
Other EU*	23.4	74.7%	4.8%
France	22.9	79.8%	4.7%
Taiwan	22.8	-0.5%	4.7%
Spain	21.9	46.0%	4.5%
United Kingdom	18.0	151.9%	3.7%
Italy	13.5	64.2%	2.8%
Turkey	12.9	12.4%	2.7%
Others	70.9	15.4%	14.6%

*Other EU countries rather than France, Spain, Italy, United Kingdom and Belgium

Source: Author, compiled from BP, 2020a

1.5.3.4. LNG Demand

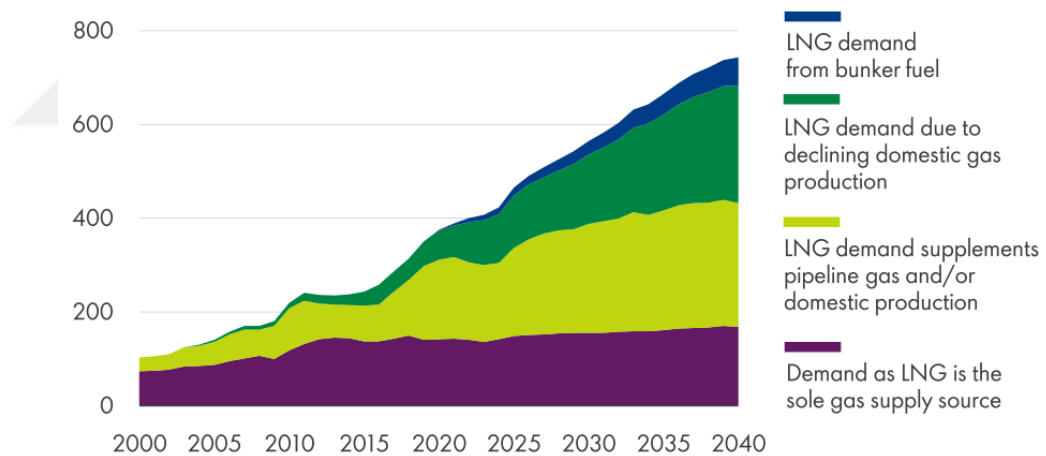
Environmental policies are a strong driver for LNG demand (IGU, 2019). Electricity generation by gas emits less greenhouse gas between 45% and 55% compared to coal (Shell, 2019b). Coal to gas switch plays important role for air quality. It was observed in Beijing that winter air quality has been improved 78% in last five years as a result of replacing coal with gas (Shell, 2019b). However, changing the source is not easy for the energy systems. Zero carbon fuels are the only option to meet emission control targets at long run. Natural gas is the cleanest fossil fuel in terms of SO_x, NO_x and PM. Despite methane slip problems, gas is a viable option to oil and coal while taking into account life cycle assessment (IEA, 2019b).

Shell (2019b) report indicates that LNG will be fastest growing gas supply source and 70% of energy demand growth to be met by gas and renewable sources. China and India are putting in force environmental policies which lead to shift from coal to gas. Gas takes the fastest growing portion in China's energy demand. China's doubling LNG import over the last two years, makes them worlds largest gas importer. This demand is accounted to industrial use (+44%) and residential and commercial use

(+38%). India also compensated drop in domestic gas production with LNG and share of LNG in total gas supply mix exceed 50% (Shell, 2019b).

Demand for LNG is also potential form of marine fuel and heavy-duty transport sector. Europe is predicted to have over 280,000 trucks on the road by 2030 and China already have over 300,000 trucks and bus on the road (Shell, 2019b). LNG truck-loading service has been doubled up and bunkering facilities of the LNG, particularly in maritime field, have been tripled over the last five years in Europe (IEA, 2019b). Small-scale LNG development unlock further usage of LNG as marine fuel and power generation. Figure 24 illustrates potential LNG demand due to bunker fuel, declining domestic gas production, pipeline gas or domestic production and as a sole gas supply source till 2040. According to projection, the biggest increase to be observed due to declining domestic gas production.

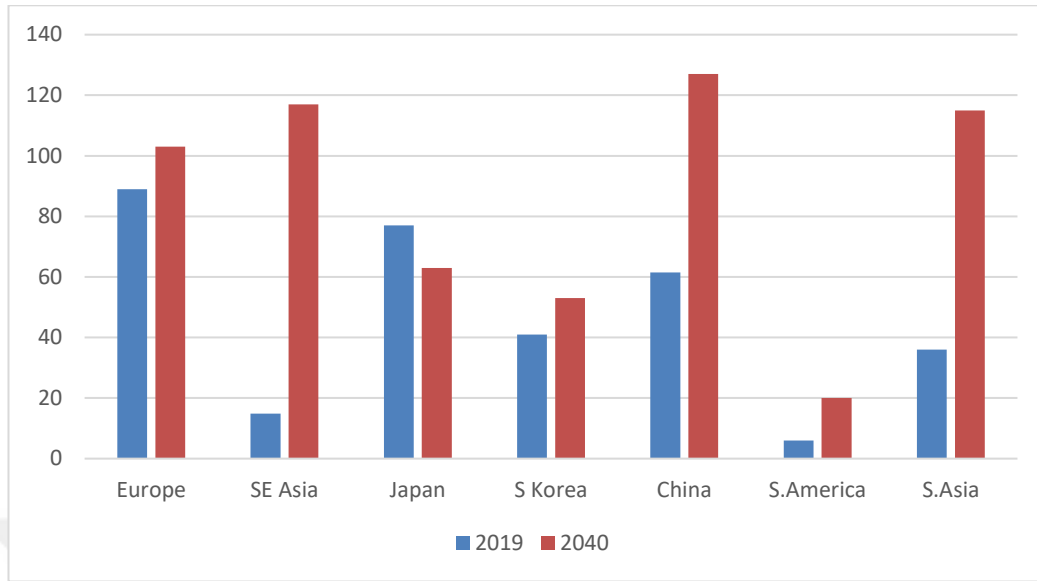
Figure 24: Demand Drivers for LNG, MTPA



Source: (Shell, 2020a)

Figure 25 shows some countries' and regions' LNG demand forecast as MTPA. Despite the decline in Japan and South Korea, there are significant increase expectations on the rest of the region, particularly South East Asia and South Asia. Europe may lose its leading position in LNG imports, despite the increase in LNG imports.

Figure 25: LNG Demand Forecast Comparative to 2019 figures, MTPA

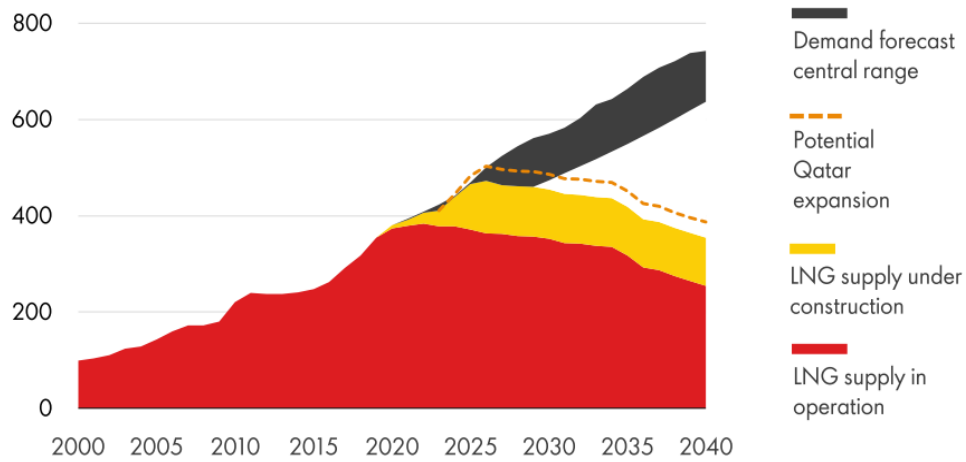


Source: (Shell, 2020b)

Average duration of mid/long-term contracts are calculated as 13.9 years. Although, duration is less than 2018 figures (16.4 years), it's above the previous last three years as observed minimum 11.5 years in 2017 (GIIGNL, 2020). Long-term contracts provide healthy demand projection for LNG markets. On the other hand, in 2019, spot and short-term volumes reached to 119 mt. It means that spot and short-term contracts volume increased 19.8% compared to 2018 figure and accounted for 34% of total LNG trade. This growth is mainly supported by USA's and Australia's flexible volumes which are handled by traders and portfolio players. Spot volumes which represents deliveries within three months from for the transaction date, took 27% of total imports. Moreover, Europe accounts for 58% of total re-exports volume 0.91 mt and France keeps leading position in the market (GIIGNL, 2020).

Figure 26 illustrates potential LNG supply-demand gap as MTPA. Growing LNG demand will be met by new LNG supplies under construction, Qatar's potential volume expansion. However, this is not satisfactory according to demand forecast. Figure 13 illustrates Shell's forecast scenario and demand gap based on independent consultancy group calculations. Potential supply shortage against demand will shape the LNG price and contracts.

Figure 26: Emerging LNG Supply-Demand Gap, MTPA



Source: (Shell, 2020a)

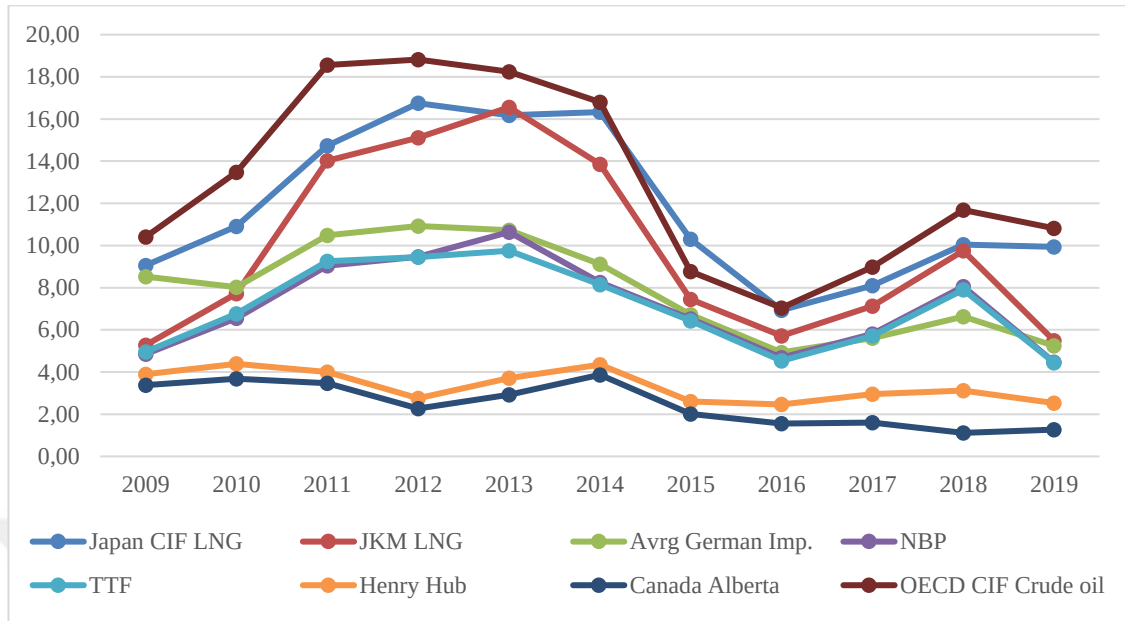
LNG's supply structure provides flexibility to meet seasonal and short-term demand requirements, as well as security of supply. It has potential to compensate rapid supply changes in renewable sources such as solar and wind. Small-scale option creates opportunity to expand markets for further usage. Price fluctuations and relative prices to oil indexes are other points to be considered for natural gas and LNG markets.

1.5.3.5. Natural Gas and LNG Price

There are three main supply side factors and three demand side factors that drive the natural gas prices. Quantity of natural gas production, amount of natural gas in storage, amounts of natural gas imports and exports are the supply side factors. On the demand side, differences in winter and summer weather, level of economic growth, availability and prices of competing fuels affect the prices (USDot, 2019).

The natural gas price has been affected by oversupply when the natural gas has flooded the market. Spot natural gas prices are good indicators for regional differences. As they are usually linked, transportation costs are reflected in the price. On the other hand, if the delivery is not practical between two regions, prices could differentiate independently (USDot, 2019).

Figure 27: Natural Gas Prices, USD per million BTU

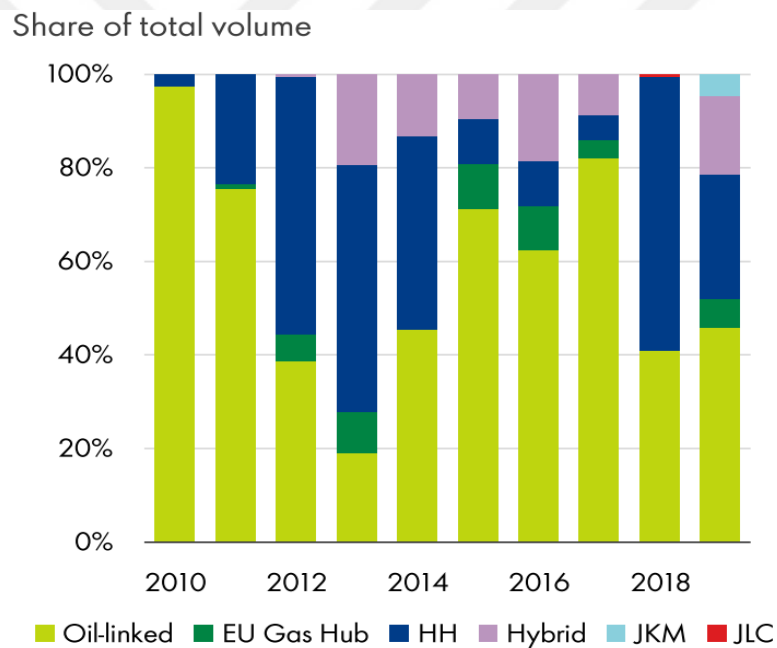


Source: Author, compiled from (BP, 2020a)

Figure 27 illustrates some hub prices, Japan CIF LNG, Japan Korea Maker LNG and OECD CIF Crude Oil price average's historical trend between 2009-2019. Canada Alberta prices are historically lower in the market. Henry Hub, as a most important natural gas hub in the USA, provides base for the natural gas market. In Europe, three important hubs are listed in the graph: The Netherland TTF, UK NBP and Average German Imports. All three follows the same trend historically. In 2019, NBP and TTF recorded 45% and 44% decreases respectively, however, German average import prices decreased only 21% and gap between Japan Korea Maker (JKM) LNG and Average German Import narrowed to 0.24 USD. Japan CIF price is recorded as 9.94 USD with decline from 10.05USD. Despite the relative lower price in historical trend, still above the 2016 and 2017 figures as they were 6.94 USD and 8.10 USD respectively. Crude oil CIF price for OECD countries are above the LNG prices in historical trend. Only exception is 2015 Japan CIF LNG price, which was 1.54 USD more expensive than OECD CIF Crude Oil price. In 2019, gap between crude oil price and Japan CIF LNG is reduced to 0.88 USD. This is resulted from Japan CIF LNG price behaviour which is out of the trend compared to other indices.

Traditionally, gas price has been linked to oil prices to provide reliable reference point for large-scale investments in transport pipelines, LNG terminals as well as in upstream projects. Figure 28 illustrates trend in LNG contracts volumes by price indexation. Oil related price takes less than 50% in 2019. The use of oil indexing is usually related with region. In North America market, it has been seen as ‘gas-on-gas’ competition and the market determines the price according to buyers and sellers interaction in a spot market and trades between hubs. In Europe, the price is determined by mixture of oil indexing and gas-on-gas competition. However, in Asia market, the price mechanism is dominated by oil indexation and only small part is connected to gas traded on the short-term spot markets.

Figure 28: New LNG Contracts Volumes by Price Indexation



Source: (Shell, 2020a)

Figure 28 indicates new LNG contracts volume by price indexation. IEA (2019a) report argues that price of LNG and gas are increasingly determined by its own supply/demand structure rather than oil indexing or other alternative fuels. Therefore, it's expected to see less than 20% of the LNG trade worldwide remain in oil indexing structure by 2040.

1.6. SUMMARY

In order to fulfil research objective one, supply chain planning and LNG supply chain literature reviewed with articles, books and relevant sectoral reports. Natural gas could be carried for long distances and to locations where pipeline connection is not practical in LNG form. LNG is liquefied form of natural gas at -162°C and reduces natural gas volume 600 times. Cryogenic form of natural gas could be carried by LNG ships to long distances economically. LNG supply chain involves production, gasification, transportation, and regasification stages before delivery to end users. It's an important energy market and has a momentum to increase its share as energy sources. It's the cleanest fossil fuel to fight air pollution. However, contribution to CO_2 mitigation targets is limited and arguable. LNG requires high technical capability throughout the supply chain and market structure developed according to this technical difficulty, natural gas reserves and demand centres. Being an energy source for power generation and domestic use at home has gained another dimension in shipping as alternative fuel. Rationale of emission control measures, alternative fuels and LNG bunkering option are discussed in the following chapters.

CHAPTER II

SMALL-SCALE LNG SUPPLY CHAIN IN SHIPPING

2.1. SUSTAINABILITY IN SHIPPING

Sustainability issues are under debate in the literature with different perspectives and different definitions. Shipping is not free from these discussions, parallel to regulatory pressure which closely affects this industry. Sustainability in this regard, has some widely accepted definitions but there is not standard and categorised definition (Moore et al., 2017). UN World Commission on Environment and Development determines some key points under sustainability concept (WCED, 1987):

‘It is associated with fulfilling today’s needs without risking future generations to meet their own risks. It’s a process to provide a balanced change while maintaining human needs and requirements’ (WCED, 1987)

NHS Institute for Innovation and Improvement (2007:9) defines sustainability as follow:

‘Sustainability is new ways of working and improved outcomes become the norm. Not only have the process and outcome changed, but also the thinking and attitudes behind them are fundamentally altered and the systems surrounding them are transformed in support. As a result when one looks at the process or outcome one year from now or longer, one concludes at minimum that it has not reverted to the old way or old level of performance. Further, it has been able to withstand challenge and variation; it has co-evolved with other changes in the context, and perhaps has actually continued to improve over time.’

In general, sustainability covers three major pillars: environmental, social and economic considerations (WCED, 1987). As shipping industry makes cargo, passengers transfers between different locations, it has various direct and indirect socio-economic and environmental effects over marine environments and human settlements (Carter and Rogers, 2008; Yliskylä-Peuralahti, 2017). Environmental

perspective includes life cycle assessments, alternative fuels, and air pollution resulted from shipping industry. Social dimension incorporates with these environmental considerations and their effects over people at port cities. Economic perspective usually takes into account regulatory measures and their economic effects on shipping industry. Although sustainability is described in three pillars, in maritime industry all three dimensions are interrelated in terms of environmental effect, social impact and economical results.

Social dimension is gaining importance in shipping industry as many ports are located on the city centres and ships exhaust gases, noise effects, port related activities are major concerns for public(Lee, Kwon and Ruan, 2019). Multiple dimensions could be considered to tackle with social sustainability of shipping including health and safety, training and education, labour practices, human rights to be considered (Al-Haidous and Al-Ansari, 2020). As needs of people and requirements are on the focus of the social responsibility, companies in shipping industry should improve employee's job satisfaction, customer loyalty, relationship with community and authorities(Lam, 2015). Therefore, social dimension of sustainability in maritime sector incorporates with concerns addressed by organizational stakeholders.

Economic perspective of sustainability is formed by continuity, flow of the financial resources throughout stakeholders of the organisation as well as impact on environment and society (Gimenez et al., 2012). New technologies, green shipping practices and regulatory frameworks put shipping industry under pressure at economic performance. There are number of studies in the shipping literature analysing these new technologies, new regulations and their effects(Jiang, Kronbak and Christensen, 2014; Schinas and Butler, 2016; Horvath, Fasihi and Breyer, 2018). Economic sustainability in shipping and maritime supply chain requires higher level integration in order to minimise the cost and maximize the profits (Lam, 2015). However, economic performance is not sufficient for long lasting sustainability in shipping, environmental pressure is vital for any organisation. While environmental sustainability investigation has high academic interest (Lam, 2015), it's not a coincidence that stricter regulations are being entered into force.

Environmental dimension is widely discussed in shipping literature covering ports, maritime logistics and maritime transport (Corbett et al., 2007; Han, 2010;

Perera and Mo, 2016; Lindstad et al., 2017; Y. Zhang et al., 2017; Seithe et al., 2020). International Maritime Organisation as governing body of the maritime industry and division of United Nations, adapted several regulations and protocols which are aiming ‘sustainability’ in shipping (Lee et al., 2019). Following United Nations Sustainable Development Goals; clean water and sanitation, affordable and clean energy, decent work and economic development, industry innovation, climate action and life below water are related with maritime industry (Koilo, 2019). Maritime Labour Convention (MLC), London Convention and London Protocol (LC/PC), Hong Kong Ship Recycling Convention, along with SOLAS (Safety of Life at Sea), STCW (Standards of Training, Certification and Watchkeeping for Seafarers) and MARPOL (Prevention of Pollution from Ships) are regulating international shipping and providing framework for sustainability development. As shipping is accounted for global warming and pollution in certain level, environmental regulations are primary drivers for shipping industry that have direct and indirect impact on economic and social performance.

2.2. EMISSION CONTROL IN SHIPPING

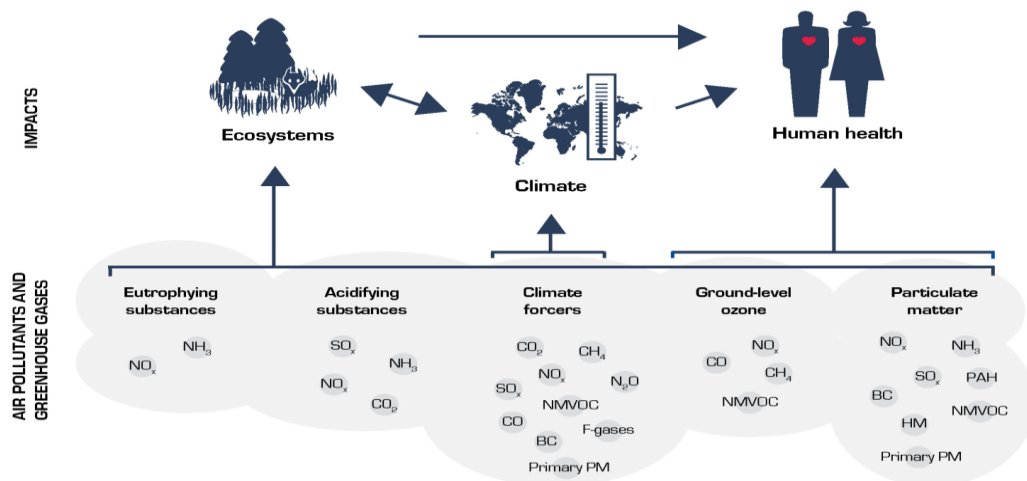
Shipping is responsible for a significant amount of air pollution. International Maritime Organization(IMO) GHG (Greenhouse Gas) study indicates that CO₂ emissions from shipping industry could grow by 50% to 250%, depending on economic development and energy demand (IMO, 2015). In addition to the effects of climate change, shipping-related emissions such as nitrogen oxides (NO_x), particulate matter (PM), sulphur oxides (SO_x), and unburned hydrocarbons (UHC) can deplete the ozone layer, cause acid rain, and contribute to greenhouse gas (GHG) emissions.

UN NDC Global Outlook Report (2019) indicates that GHG emissions from human activities have increased to new record highs this century, hitting 50.8 billion tonnes GHG emission in 2016, up to 48 percent since 1990 (UNNDC, 2019). Energy supply has the biggest responsibility for these GHGs that cover 34 percent of emissions worldwide in 2016, followed by industry (22 percent) and transport (14 percent). Global energy related emissions rose 1.7% in 2018 as it marks the highest rise since 2013. So-called ‘Paris Pause’ between 2014-2016 was broken. And dramatically,

heat-trapping CO₂ in the atmosphere climbed to 415 parts per million in May 2019. This is higher than those observed in nature in at least 800,000 years (UNNDC, 2019). Today we already observe climate change impacts such as more crop diseases, soil erosion, reduced clean water availability, hunger and malnutrition, heat-related illnesses, wildfires, shifting fish stocks, losses of habitat for wildlife and a melt-down of ice and snow that is raising sea levels (UNNDC, 2019).

The main source of shipping-based air pollution is fossil fuels. Sulphur oxides (SO_x), nitrogen oxides (NO_x), carbon dioxide (CO₂), volatile organic compounds (VOC), carbon monoxide (CO), black carbon (BC), and particulate organic matter (PM) are all generated during the combustion phase of the main and auxiliary engines (Eyring et al., 2010), as well as transitional and alkali earth metals (V, Ni, Ca, Fe) and their soluble or insoluble chemical forms (sulphides, sulphates and carbides) (Blasco et al., 2014). How major air pollutants effect ecosystem, climate and human health is illustrated in Figure 29.

Figure 29: Major Air Pollutants' Interactions for Human Health, Eco System and Climate Change



Source : (EEA, 2011)

In addition to the effect of shipping over climate change; shipping-related emissions such as NO_x, particulate matter (PM), SO_x, and unburned hydrocarbons can reduce the ozone layer, generate acid rain and GHG impact on ecosystem (Han, 2010). The majority of ships tend to spend only about 20% of their time at open sea. In other

words, 80% of shipping activity is within the port limit or near a coast (Han, 2010). Additionally, Corbett et al. (2007) research indicates that 70 to 80% of ship emissions arise within 400km of land. PMs have a direct impact on human and ecosystem health, while SOx and NOx primarily contribute to ocean and soil acidification and climate change.

PMs have been linked to serious health consequences such as asthma, heart attacks, and hospital admissions in exposed populations, as well as a rise in premature cardiopulmonary, lung cancer, and cardiovascular hospitalization. (Tian et al., 2013; EEA, 2019).

2.2.1. IMO Air Pollution Prevention Measures

IMO GHG study estimates that shipping is liable for 12% of global SOx emissions and 13% of global NOx emissions (IMO, 2015). As international regulatory body of shipping, IMO adopted the first air pollution prevention regulations by MARPOL Annex VI in order to reduce emission in shipping. The first regulations came into force in May 2005. MARPOL Annex VI established the standards for ozone depleting substances (regulation 12), NOx (regulation 13), SOx (regulation 14), VOC (regulation 15), and identified emission control areas for SOx and NOx emissions with more stringent emission restrictions (IMO, 2008).

2.2.1.1. Ozone-depleting substances (ODS)

Ozone-depleting substances (ODS) are the chlorofluorocarbons (CFC) and halons used in refrigeration, and firefighting systems have been prohibited to install on ships after 19 May 2005. Hydrochlorofluorocarbons (HCFC) which is a intermediate replacement for CHC was not permitted to install ships constructed on or after 1 January 2020 under MARPOL Annex VI Regulation 12(IMO, 2020d).

2.2.1.2. Nitrogen Oxides (NOx)

Since nitrogen oxides (NOx) have the potential to cause acidification and eutrophication, it is important to limit NOx emissions from shipping. (Bengtsson et

al., 2012). NO_x restrictions for marine diesel engines are specified in MARPOL Annex VI regulation 13 in order to reduce NO_x emissions by requiring engine technology.

Table 4: NO_x Emission Limits

Tier No	Ship construction date on or after	NO _x emission limit, g/kWh n= rated engine speed (crankshaft revolution per minute)		
		n < 130	130 ≤ n < 2000	n ≥ 2000
Tier I	2000-2011	17	45 x n ^{-0.2}	9.8
Tier II	2011	14.4	44 x n ^{-0.23}	7.7
Tier III	2016	3.4	9 x n ^{-0.2}	1.96

Source:(IMO, 2013a)

NO_x emission limits are illustrated in Table 4 based on the revolutions per minute (RPM). During the IMO's Maritime Environmental Protection Committee's 66th session, it was decided to keep Tier III NO_x limits in place for all ECAs beginning in January 2016 (IMO, 2013a).

2.2.1.3. SO_x and Particulate Matter (PM)

Major component of the PM is sulphate aerosols or sulphur-containing particles are emitted by SO_x from marine diesel engines (Chu Van *et al.*, 2019). SO_x and Particulate Matter (PM) emission controls apply to fuel oil, therefore all equipment -main and auxiliary engines, boilers, IG systems are included. The regulation has two applications: within Emission Control Area and outside an Emission Control Area.

Table 5: SO_x and PM Emission Limits

Outside an ECA established to limit SO _x and particulate matter emissions	Inside an ECA established to limit SO _x and particulate matter emissions
4.50% m/m prior to 1 January 2012	1.50% m/m prior to 1 July 2010
3.50% m/m on and after 1 January 2012	1.00% m/m on and after 1 July 2010
0.50% m/m on and after 1 January 2020	0.10% m/m on and after 1 January 2015

Source: (IMO, 2013b)

Emission limits according to inside and outside of ECA are summarised in Table 5. IMO 2020 regulation reduced global sulphur limit to 0.5%(IMO, 2013b). Reducing global sulphur cap from 3.5% to 0.5% is a dramatic shift in bunker market. Achieving maritime sulphur targets is subject to homogeneous enforcement of regulations at global level (Zis and Cullinane, 2020).

2.2.1.4. Emission Control Areas

MARPOL Annex VI applies stringent emission restrictions for particular areas (Table 6) so called Emission Control Areas. These areas have been determined not only according to vessel traffic, navigation patterns, prevailing winds or oceanographic concerns, but also human population, environmental risks and emission impacts to ecosystem. Moreover, IMO has accepted North Sea and Baltic Sea as NO_x emission control area in effect from 1st of January 2021. NECA regulation is required to all vessels built after 2021 reduce NO_x emissions by complying Tier III requirements and reduce NO_x emissions 80% compared to present values(IMO, 2017). Table 6 summarises Emission Control Area (ECA) timeline.

Table 6: Annex VI: Prevention of air pollution by ships (Emission Control Areas)

Special Areas	Adopted	Date of Entry into Force	In Effect From
Baltic Sea (SO _x) NO _x	26 Sept 1997 7 July 2017	19 May 2005 1 Jan 2019	19 May 2006 1 Jan 2021**
North Sea (SO _x) NO _x	22 Jul 2005 7 July 2017	22 Nov 2006 1 Jan 2019	22 Nov 2007 1 Jan 2021**
North American (SO _x ,and PM) NO _x	26 Mar 2010	1 Aug 2011	1 Aug 2012 1 Jan 2016*
United States Caribbean Sea ECA (SO _x , and PM) NO _x	26 Jul 2011	1 Jan 2013	1 Jan 2014 1 Jan 2016*

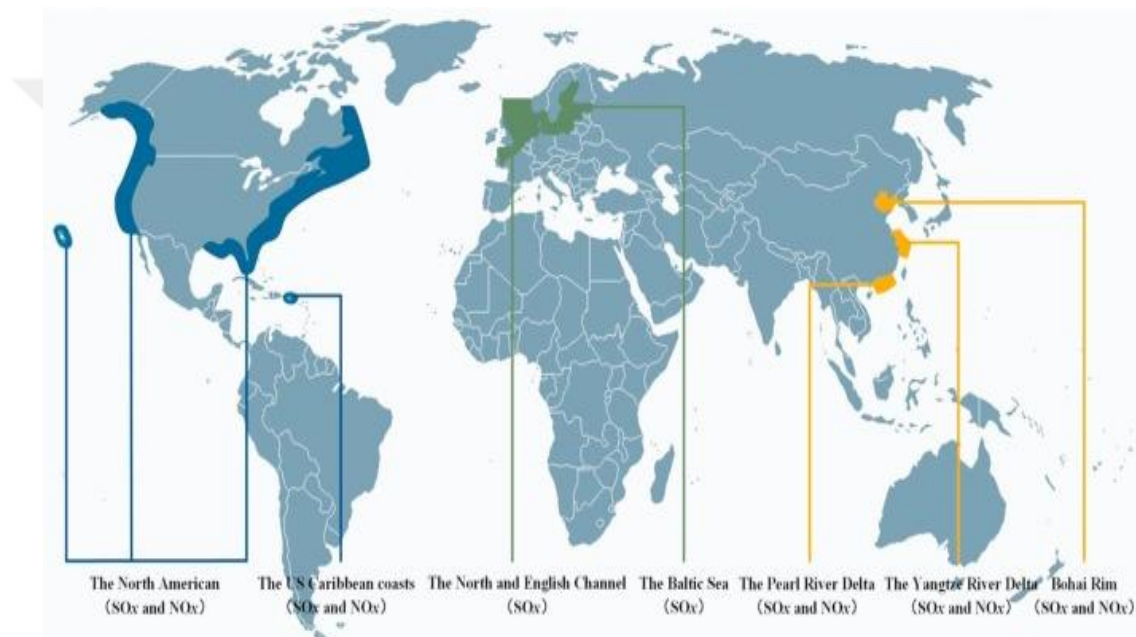
* A ship constructed on or after 1 January 2016 and is operating in these emission control areas shall comply with NO_x Tier III standards set forth in regulation 13.5 of MARPOL Annex VI.

** A ship constructed on or after 1 January 2021 and is operating in these emission control areas shall comply with NO_x Tier III standards set forth in regulation 13.5 of MARPOL Annex VI

Source: (IMO, 2014)

Implementation of emission control areas and a global cap on fuel sulphur would significantly reduce ship-based emissions. Regulations, on the other hand, would raise the operating costs of vessels, especially those that operate in controlled areas. (Acciaro, 2014; Jiang, Kronbak and Christensen, 2014). However, vessels time spending in ECA and out of ECA have different outcomes, and competitiveness of the maritime transport in terms of green image is subject to stricter emission regulations (Svindland, 2018). Figure 30 illustrates ECAs over the world.

Figure 30: Emission Control Areas



Source: (Zhen *et al.*, 2018)

In addition, new emission control areas designation is being debated. Future emission control areas are potentially the Arctic region, Hong Kong, Japan, Mediterranean, Turkish Straits, Australia, Antarctica, Mexico, and Panama. (Meech, 2010). Mediterranean Emission Control has already been proposed to IMO by the Barcelona Convention and expecting to come into force after completing process in IMO(UNEP, 2017). China has already started implementing emission control measures within territorial waters. Moreover, up to 100nm from the territorial baseline which is expected to control 90% of the ship emissions, emission control area has been proposed by China (Qin *et al.*, 2019).

2.2.1.5. Volatile Organic Compounds (VOC)

Volatile Organic Compounds (VOC) emission through ships is regulated by MARPOL Annex VI Regulation 15. It's applied only to tankers, and it requires 'vessel emission control system' (VECS) with vapour return line. Cargo vapour along with inert gas is pushed back to shore via vapour return line in accordance with VOC management plan(IMO, 2013c).

2.2.2. GHG Emission Reduction Measures of IMO

The measures such as Emission Control Areas, global sulphur cap, NO_x Tier I-II-III requirements have come into force in order to cope with the air pollution generated by shipping. IMO 3rd GHG study estimates that maritime transport is responsible for about 2.5% of global greenhouse gas (GHG) emissions and shipping emissions could increase between 50% and 250% by 2050 if no measures are taken. IMO's initial strategy on reduction of GHG emissions from ships is to reduce the total GHG emissions by at least 50% by 2050 compared to 2008 (IMO, 2020a).

By July 2011, IMO acknowledged technical and operational measures to lessen ships' emissions of greenhouse gases (GHG). These methods included the Ship Energy Efficiency Management Plan (SEEMP), Energy Efficiency Design Index (EEDI), the, and the Energy Efficiency Operational Indicator (EEOI). The first climate change - GHG control measures were introduced on January 2013 with EEDI and SEEMP manual based on global CO₂ emission targets of 2050 (IMO, 2020b).

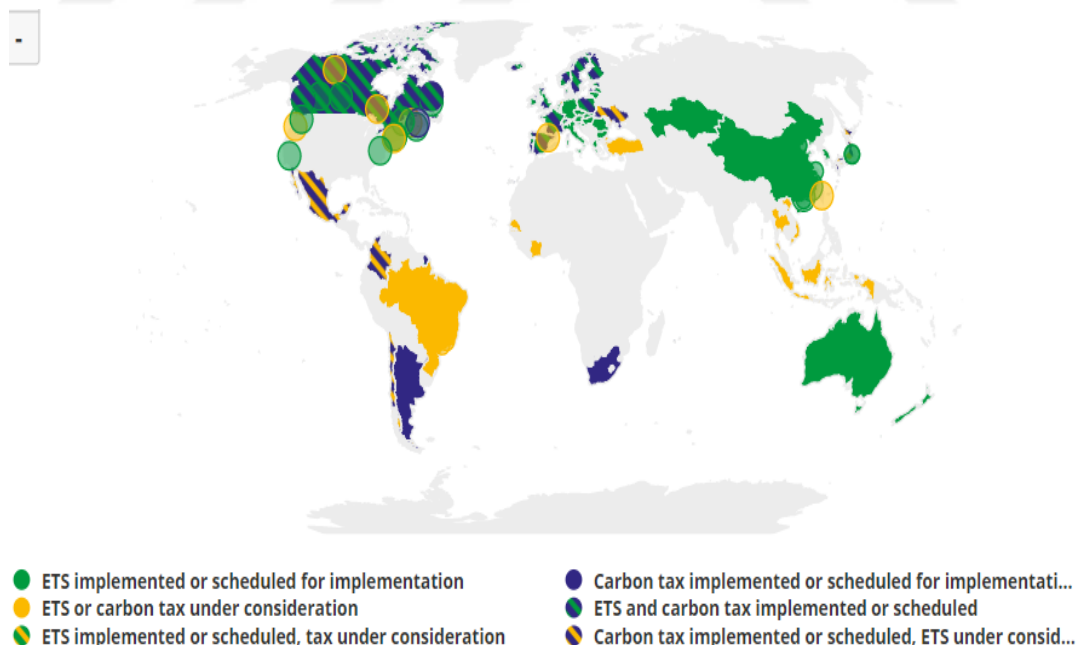
In addition to technical and operational actions, market-based measures are under debate. There are numbers of proposed market-based measures to IMO such as GHG Fund, Leveraged Incentive Scheme, Port State Levy, Vessel Efficiency System and Emission Trading System (IMO, 2016a). GHG emissions are priced under market-based measures (MBM) for two main purposes:1- in-sector reductions by providing incentive for the maritime industry to decrease its fuel consumption and by investing new technologies, 2- out-of-sector decreases by offsetting in other sectors of growing ship emissions(IMO, 2016a). MBMs discussion has been suspended in IMO since

Marine Environment Protection Committee (MEPC) 65 meeting but shipping industry is dealing with GHG emission with MBMs under local governments' strategies.

2.2.3. Other GHG Emission Mitigation Strategies in Shipping

Carbon pricing application brings burden to those parties which are responsible for GHG emission by providing fair ways to find who will pay for the costs of damages from GHG emissions. Setting price for per GHG emission can help to get financial investments required for green technology and market innovation (World Bank, 2020). Current Emission Trading Scheme or taxing are already implemented or scheduled in many countries. Figure 31 illustrates current ETS applications. For EU case, shipping was out of consideration till 2017, however, low-emission mobility strategy indicates that CO₂ emitted at EU ports and during voyages to and from EU ports will be subject to EU ETS as of 2023.

Figure 31: Carbon Pricing Initiatives



Source: World Bank (2019)

Hansson et al (2019) point out that in shipping, carbon tax implementation will increase the fossil fuel's price compared to renewable fuels. Changing fuel ranking a carbon tax above 300\$/t of CO₂-equiv is necessary. Addressing carbon tax to direct emission from ship propulsion provide effective follow up(Hansson *et al.*, 2019). Norwegian NO_x fund provides health structure for tackling with NO_x emission by granting financial support to the industry to implement green technology. NO_x fund has saved NOK14 billion since 2008 and contributed to new technologies of electrification of maritime activities with battery solutions, LNG operations and NO_x cleaning with catalysts, which makes Norway the leading country in terms of green technology (NHO, 2020).

2.3. COMPLIANCE TO EMISSION REGULATIONS IN SHIPPING

Compliance with sulphur emission restrictions depends on the owners and operators of the fuel-use strategy. Emission reduction strategies are chosen based on fuel costs, environmental effects, and investment payback period. (Acciaro, 2014). There are three main sulphur emission reduction strategies for Emission Control Area (ECA) compliance: low sulphur distillates, scrubbers, and liquefied natural gas (LNG) (Gilbert, 2014; Coppola et al., 2016). The three viable alternatives have different aspects for decision making such as the price of the fuels, trading area, regulations, remaining life time of the vessel, time at sea and port (Abadie et al., 2017). These three viable options are explained in the following sections.

2.3.1. Low Sulphur Distillates

Low Sulphur distillates require low capital expenditure as it does not require additional tank, fuels available globally (Kim and Seo, 2019). However, compliance with Tier III NO_x requirements needs additional technical measures. NO_x emitted from ships is originated during combustion of marine diesel engines at high temperature (Brynolf et al. 2014). In order to reduce formation of NO_x, there are numbers of techniques such as exhaust gas recirculation (EGR), adding water during the combustion process or the selective catalytic reduction technique (SCR). SCR

technique is the most promising one as it can be used with various marine fuels (Brynolf et al., 2014).

IMO 2020 regulations are already in force and ‘do nothing’ option of the shipowners are low sulphur distillates. However, reduction on sulphur cap come up with some risks associated with fuels. Fuel availability, the IMO 2020 compliant fuel oil production – blending high sulphur fuel oil (HSFO) with low sulphur fuel oil – will become a challenge for the refineries. Some refineries have not switched to produce low distillates, and blending is the major source of low sulphur distillates that arises as safety risks and stability of the bunker. Compatibility of the different products is another challenge that may cause serious problems on board. Potential increase on bunker cost at short term and impact on operational costs are inevitable. However, Covid19 effect, dramatic fall at Brent oil price at the second quarter of the 2020, compensated this potential price difference.

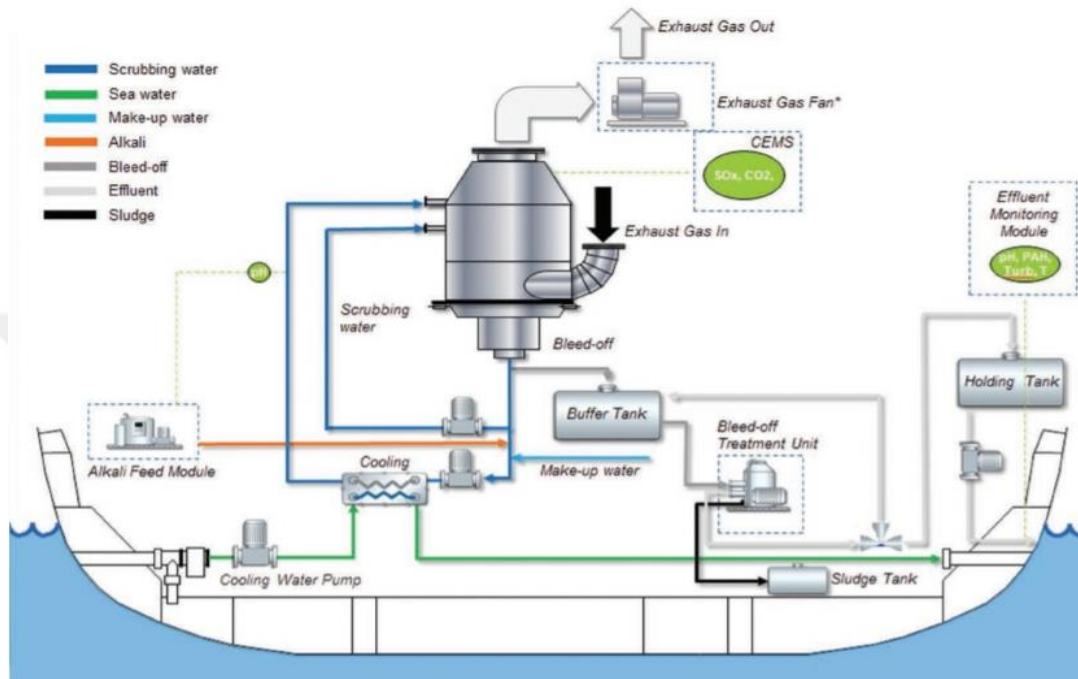
2.3.2. Scrubber

Scrubbers are the other alternatives for sulphur emission compliance. It has advantage that vessels could keep on using HSFO which is expected to be lower price compared to low distillates. Currently 4263 scrubber systems have been installed to vessels and 3536 of them are open type as of June 2020(DNV GL, 2020a). Scrubber system basically absorbs the sulphur oxides in water before releasing into atmosphere. There are three types of scrubbers: open type, close type and hybrid type(Kim and Seo, 2019).

The scrubbers can be retrofitted to existing vessels with reasonable cost subject to space availability and stability constraints. Open type scrubbers are the most economic ones and reduce the SO_x and PM by applying naturally alkaline seawater in the exhaust fumes. The closed loop scrubbers employ clean water and sodium hydroxide solution to reduce SO_x and PM by chemical process. Close-loop scrubbers are more expensive and have problems to deal with waste that is generated during process (Brynolf et al., 2014). Hybrid system uses both types advantages and can employ open system at open sea and close loop system where discharging of scrubber

water is prohibited (Kim and Seo, 2019). Figure 32 illustrates typical close-loop scrubber system.

Figure 32: Close-loop Scrubber



Source: (Wartsila, 2013)

Economic advantage of the open-loop type scrubbers is a question mark if the vessel is serving globally. Treatment of the chemical waste is not allowed in many ports. Some ports around the world have already forbidden to use open-loop scrubbers (IBIA, 2019). From Australia to Pakistan, UAE to some ports in USA are not allowed open type scrubbers. Alternatively ship operators can install close loop or hybrid systems. Another alternative is to switch alternative compliant fuels. Figure 33 illustrates current ports that restricts open-loop systems.

Figure 33: Exhaust Gas Scrubbers Restriction Across the World



Source: (Gard, 2020)

2.3.3. LNG as Marine Fuel

Compliance with sulphur emission restrictions subject to the owners and operators of the fuel-use policy. Emission reduction strategies are chosen based on fuel costs, environmental effects, and investment payback period. (Acciaro, 2014). LNG has significant positive effect for air pollution as it provides complete removal of SO_x and PM, reduction of NO_x up to 85% and reduced CO_2 emission at least 20% (DNV-GL, 2015).

LNG is defined as the cleanest type of natural gas and it contains more than 90% methane. (Kumar et al., 2011). It's colourless, odourless, nontoxic, and corrosive-free. It has a density of 0.41-0.5 kg/l on average. It must be liquefied for transportation due to its extremely low density as gas (Burel et al., 2012). LNG is made by cooling natural gas below the boiling point of methane, which is - 162 degrees Celsius. Liquefaction decreases the amount of gas by over 600 times, and cooling the natural gas allows it to be transported as a cargo by ocean-going vessels (Kumar et al., 2011).

Shell LNG outlook 2019 indicates that more than 70% of energy demand growth will be met by gas and renewables combined with gas supplying more than

40% of the additional demand (Shell, 2019). The report also points out that consumption of LNG in transport has strong growing pace in heavy-duty trucks and buses as well as marine LNG, 143 LNG-fuelled ships in operation (Shell,2019). China is the main driver for increase in LNG demand due to shift from coal to gas as a result of environmental policies that improve air quality (BP, 2019). Environmental awareness is a strong driver for LNG and LNG as ship fuel gets benefit of this despite the barriers as lack of infrastructure, high investment cost or LNG prices (Wang & Notteboom, 2014; Fevre, 2018).

On the other hand, there are several challenges such as lack of infrastructure, and operational standards that prevent faster developments. Though LNG ship fuel is to be used by LNG driven vessels -that is under shipowner discretion; LNG fuel supply is controlled by other stakeholders of shipping as ports, terminals, suppliers etc. One of the biggest obstacle for LNG powered engines is to have a methane slip problem, as methane gas has 25 times higher global warming potential than CO₂ emissions (Brynnolf et al., 2014). Natural gas consists of various components, but the main constituent is methane (85-95%). LNG as alternative marine fuel has advantages for SO_x, NO_x and PM emissions, however, incomplete combustion of methane is a critical point for LNG as marine fuel. Uncontrolled methane slip may eliminate all environmental benefits of LNG marine fuel (Storvik, 2016). The different engine concepts have different methane slip, with the highest methane slip reported for the lean burn dual fuel concept. Otto cycle medium-slow speed LNG fueled engines meet Tier III requirements without additional investment, however, methane slip reduces CO₂ reduction potential and obtained 10 to 20% improvement at CO₂ emission. On the other hand, diesel cycle provides better methane combustion at high pressure engines but needs EGR/SCR for Tier III compliance (DNV GL, 2018a). Storvik (2016) indicates that catalyst oxidation could provide significant reduction on methane slip. However, location of catalysts, high exhaust temperature requirements are challenging. Hybrid solutions are another option to cope with methane slip as the PERFECT project that minimizes the methane slip as 'zero'(DNV GL, 2018b). The project studies electric driven 20,000 TEU ultra large container vessel with an LNG-fuelled combined cycle gas and steam turbine electric power plant that brings viable alternative for long haul shipping. Reducing methane slip is a challenge for dual-fuel

or gas-fuel engines, and LNG marine fuel's positive contribution to environment could be offset by uncontrolled methane slip.

There are two dimensions for future considerations: air pollutants and GHG emission. Shipping industry needs to cope with these two dimensions in long term while picking up the most convenient fuel. Compared to other clean fuel options, LNG supply chain already exists and is open to development at bunkering phase. Strategic partnership of stakeholders such as terminals, and suppliers extend LNG supply chain to marine end users as LNG bunkering supply chain (Wang and Notteboom, 2015)

2.3.4. Alternatives for Decarbonization Targets

IMO Regulations force industry to seek for alternative solutions. EEDI measures require technical solutions and usually applicable to new building vessels. Taking into consideration present fleet and new building orders, compliance will not be very fast. On the other hand, operational measures are related with day-to-day practices of the vessels and can be applied to existing vessels. Fleet wide applications can contribute to overall emission targets significantly (Bouman et al., 2017). On the other hand, DNV-GL study indicates that based on 39% of seaborne trade growth and under present policies, total CO₂ emission levels will be reduced by 27% in 2050 compared to 2008. However, operational and technical measures will not provide sufficient reduction. Targets will be achieved only if carbon neutral fuels keep between 30 to 40% of total energy (DNV GL, 2019).

2.3.4.1. Technical Measures

Technical measures to improve energy efficiency of the vessels brings advantages to reduce GHG emissions. Outstanding measures are using light materials, improving propulsion, bulbous bow design, air lubrication, hull surface coating, waste recovery systems are all utilised to comply with EEDI requirements. Potential fuel saving ranges vary from 0 to 25% (Bouman *et al.*, 2017; ITF, 2018).

Table 7: Main Technological Measures

Measures	Potential Fuel Savings (%)
Light Materials	0-10
Slender Design	10-15
Propulsion improvement devices	1-25
Bulbous bow	2-7
Air lubrication and hull surface	2-9
Heat Recovery	0-4

Source:(ITF, 2018)

Table 7 summarises main technological measures to improve efficiency of the vessels and their potential fuel saving percentages.

2.3.4.2. Operational Measures

Operational measures deal with day-to-day practice of the vessels. These include speed optimization, capacity utilization, voyage optimization and other operational measures such as trim/draft optimization, energy management, optimized maintenance (Bouman et al., 2017).

Table 8: Operational Measures

Operational Measures	CO ₂ Emissions Reduction Potential (%)
Speed	0-60
Ship Size	0-30
Ship-port interface	1
Onshore power	0-3
Voyage Optimization	0.1-48
Capacity utilization (at vessel and fleet level)	5-50
Other measures (Trim/draft, energy management etc)	1-10

Source: (Bouman et al., 2017; ITF, 2018)

Operational measures and their potential CO₂ emission reduction potentials are summarised in Table 8.

2.3.4.3 Alternative Fuels

Alternative fuels are expected to comply with the present and future emission control regulations; however, technical challenges, infrastructure, availability and economic perspectives need to be considered with holistic approach. Moreover, life cycle assessment of the alternative fuels should cover not only downstream but also upstream side that gives realistic approach for environmental performance for the alternative fuel (Gilbert et al., 2018). Apart from LNG, the most viable alternatives are methanol, biofuel, hydrogen, and ammonia. In addition to these fuels, hybrid systems and new technologies such as fuel cells, batteries and wind-assisted propulsion could be promising alternatives in long term.

2.3.4.3.1. Biofuels

Biofuels have significant advantages in terms of renewability, efficiency and sulphur content. However, the development for biofuels compatible with marine engines is still in its infancy. Biodiesels such as HVO (hydrotreated vegetable oil), biomass to liquids (BTL) and liquefied biogas are the most viable options as biofuel. SVO (straight vegetable oil) is suitable for replacing HFO, and LBG can substitute fossil LNG and biodiesel is the best replacement for MDO/MGO (Kesieme *et al.*, 2019). Biofuels are categorized at three levels based on carbon source: The first-generation biofuels are sourced by sugar, starch; the second generation is derived from woody crops, feedstocks and wastes; the third generation is alga-based that is potential for coastal areas. One of the biggest obstacles is the lack of infrastructure. However, biodiesels can be used at MGO/HFO infrastructure and LBG can be facilitated by using existing LNG network. On the other hand, price wise biofuels are expected to be more expensive than fossil fuels and current supply of biofuels is not sufficient to cover shipping fleet (DNV GL, 2019).

2.3.4.3.2. Methanol

Methanol is another viable alternative for future. Methanol could be produced from natural gas, second generation biomass or CO₂. Methanol's SO_x emission is close to zero, and very low NO_x and PM emits that comply with upcoming regulations for EGR or SCR (Alavi, 2018). NG sourced methanol's life cycle assessment for GHG is almost at the same level with HFO. On the other hand, CO₂ captured methane production's GHG is significantly minimised. Moreover, as it is liquid form at room temperature, the methanol does not require additional investment cost for onboard storage or modifications. However, relatively lower energy content of the methanol requires more volume onboard in order to obtain the same energy level compared to conventional fuels. Today methanol is mainly produced from natural gas, and it makes it less competitive for GHG emission and price. Low flash point requires additional safety precautions (Paulauskiene et al., 2019). Global production quantity is another big obstacle in front of the methanol to become primary alternative fuel source for shipping.

2.3.4.3.3. LPG

LPG, as fossil-based fuel, complies with SO_x emission control regulations, and provides up to 17% saving on GHG emission compared to HFO and MGO. Regulatory framework is already in place as subject to IGC code and IGF Code. LPG is available across the world with import and export terminals. Historical trends indicate that LPG is cheaper than Brent oil and at the same level with LNG in USA market. Engine technology is available as four stroke otto cycle, two stroke diesel cycle or gas turbine options. However, it needs EGR and SCR systems to comply with Tier III NO_x standards. Bunkering infrastructure has not been developed yet. LPG requires relatively less CAPEX compared to LNG, even though LPG price is higher than LNG, and payback time has advantages. LPG has advantages as alternative fuel, but the biggest barrier is infrastructure development (DNVGL,2019). Current LPG production is not enough to cover demand for shipping and other industries.

2.3.4.3.4. Hydrogen

Hydrogen has two different pathways to be produced: fossil fuel source through natural gas and renewable hydrogen produced through electrolysis based on renewable wind or solar power. Unlike other fuel alternatives, hydrogen is to be used in fuel cells (FC), while other fuels are to be used in internal combustible engine (ICE). Natural gas pathway does not contribute more to mitigation of GHG emissions and price is also more expensive compared to LNG. Moreover, renewable pathway could be very expensive compared with other alternatives, but provides future proof emission control opportunities (Horvath et al., 2018). Liquid form of hydrogen's energy density and volume to be retained onboard are important obstacles. Moreover, application on large merchant vessels is still not practical. Safety standards need to be improved and infrastructure needs to be developed (Horvath et al., 2018).

2.3.4.3.5. Ammonia

Ammonia as ship fuel is another alternative for marine use. Ammonia with fuel cells is not yet well developed but it can be used in Internal Combustion Engine and positively contributes to GHG emission reduction up to 34.5% (ITF, 2018) (DNGL, 2019). Ammonia can be produced from renewable sources, utilizing electrolysis and tank-to propeller does not emit carbon. NH_3 is already on the market as it is used as agricultural fertilizer. However, safety standards as marine fuel and lack of infrastructure are the main barriers for today. It's highly toxic and corrosive to skin, eyes and lungs. Air mixture could become flammable at 15 to 28 percent by volume (de Vries, 2019). If the production is not based on renewables, improvement in CO₂ emission will not be sufficient. Moreover, renewable base ammonia cost is twice as high as natural-gas based one (ITF, 2018). On the other hand, ammonia can also be used after converting LPG fuelled ships which makes it future proof fuel (DNV GL, 2019).

2.3.4.3.6. New Technologies

New technologies are promising alternative for zero-emission ship propulsion. Energy storage systems, solar panels, and wind propulsion have significant effect to reach 2050 targets. Hybrid systems are the most promising options that provide flexibility(DNV GL, 2019). It's still at infant stage and needs technological, regulatory and safety improvements to become an economically reliable option(Roh et al., 2019)

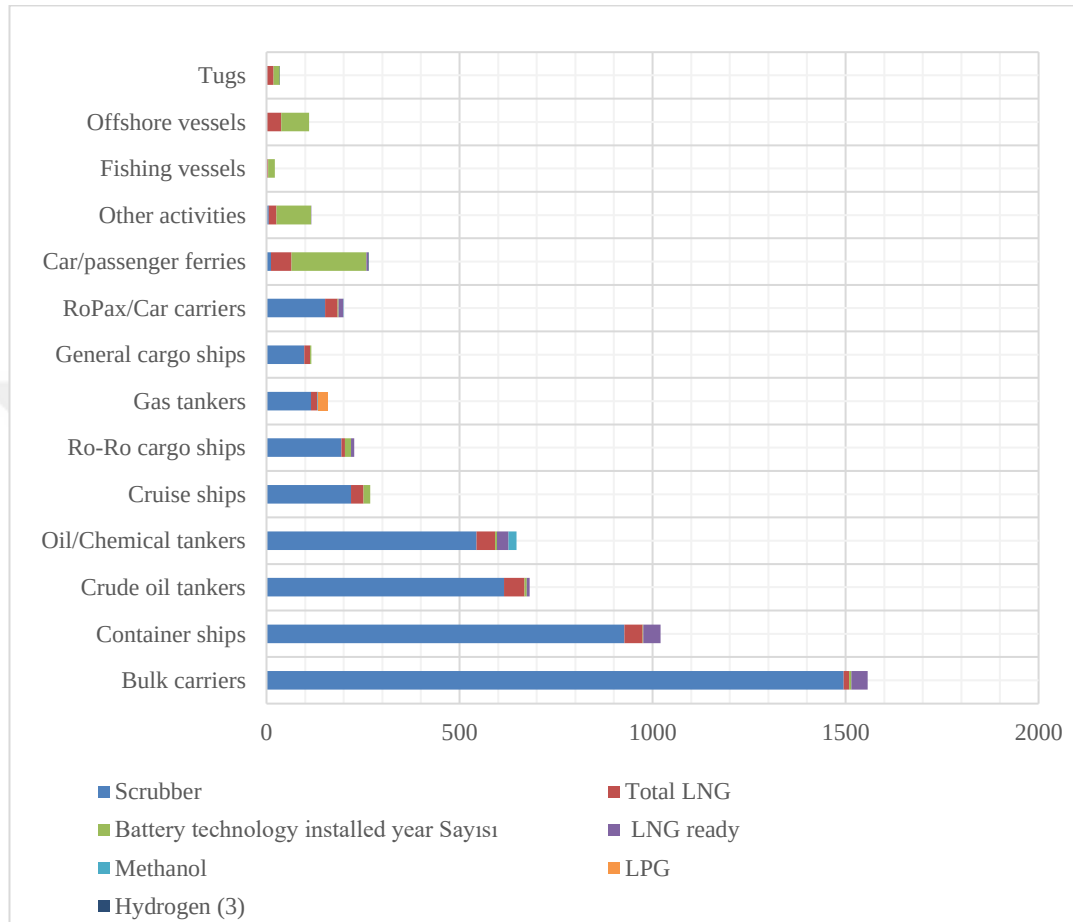
Fuel cells offers multi-fuel flexibility, easy modularization as well as vibration-free and reduced noise pollution. Fuel cell systems convert chemical energy into electrical and thermal energy through electrochemical oxidation. Effective use of LNG and liquefied hydrogen makes fuel cells a promising option. Main drawbacks for fuel cell (FC) are the high investment cost and higher operational cost. The cost of onboard fuel-storage systems can be significant. Safety standards are still needed to be improved (DNV GL, 2019).

Using wind for ship propulsion is not an innovation, however, ambitious 10-30% energy saves at wind assisted, and up to 50% energy savings at hybrid systems are promising for future carbon free ship propulsions. Wind propulsion technologies such as kite, flettner rotors provide partial proposition systems. Application of wind propulsion depends on ship type as it cannot be suited for all type of the vessels (IWSA, 2015).

Figure 34 summarises current appearance of alternative fuels and new technologies in shipping based on DVGL database. Scrubbers are far the most preferred option among all as it has 4379 vessels in operation or in order list and mostly preferred by bulk carriers. Number of the battery driven vessels is 448, but batteries have very low demand by bulk carriers, tanker or cruise vessels which are the largest demand centres, rather , car/passenger ferries are the largest ship types that utilize batteries. 398 LNG powered vessels either in service or on order and preferred by bulk carriers, container vessels, tankers and cruise vessels which makes the biggest demand opportunity among alternative fuels. Moreover, 143 vessels are designed as 'LNG Ready', meaning that, they can easily switch their engines to run by LNG. The number of the vessels fuelled by Methanol, LPG, Hydrogen are 52 as of May 2020. On the other hand, methanol powered vessels are oil/chemical tankers which are already

carrying methanol as cargo, and they could be potential alternatives for oil/chemical tankers.

Figure 34: Current Uptake of Alternative Fuels and New Technologies in Shipping



Source: (DNV GL, 2020b)

Alternative fuels initiative should be improved for carbon-neutral alternatives for commercial shipping in global scale. Funding researches is crucial for further improvement and it could be supported by market-based measures and carbon pricing. LNG as an alternative marine fuel has advantages in terms of availability and infrastructure compared to others, despite methane slip drawback. As it's stressed in DNVGL report, only technical and operational precautions will not be sufficient to accomplish 2050 targets of the IMO. Using alternative fuels which have direct impact on vessels' GHG emissions is inevitable. LNG provides the most feasible alternative, however, world wide availability of LNG supply chain needs to be extended as small/mid scale supply chain in order to be used by final users at sea.

2.4. SMALL-SCALE LNG

LNG supply chain basically comprises four steps: exploration/production, liquefaction, shipping and regasification (Maxwell and Zhu, 2011). The supply chain is shaped by consumer characteristics, location, consumption profile, cost etc. Distance for LNG distribution and LNG transshipment scale are important elements that affect overall supply chain (EMSA, 2017). Scale of the LNG to be handled affects distribution channels not only in operations but also cost and technical issues such as Boil of Gas (EMSA, 2017). While defining the scale of the LNG, there are not exact criteria (EMSA, 2017), however, generally accepted definitions in the industry are summarized in Table 9.

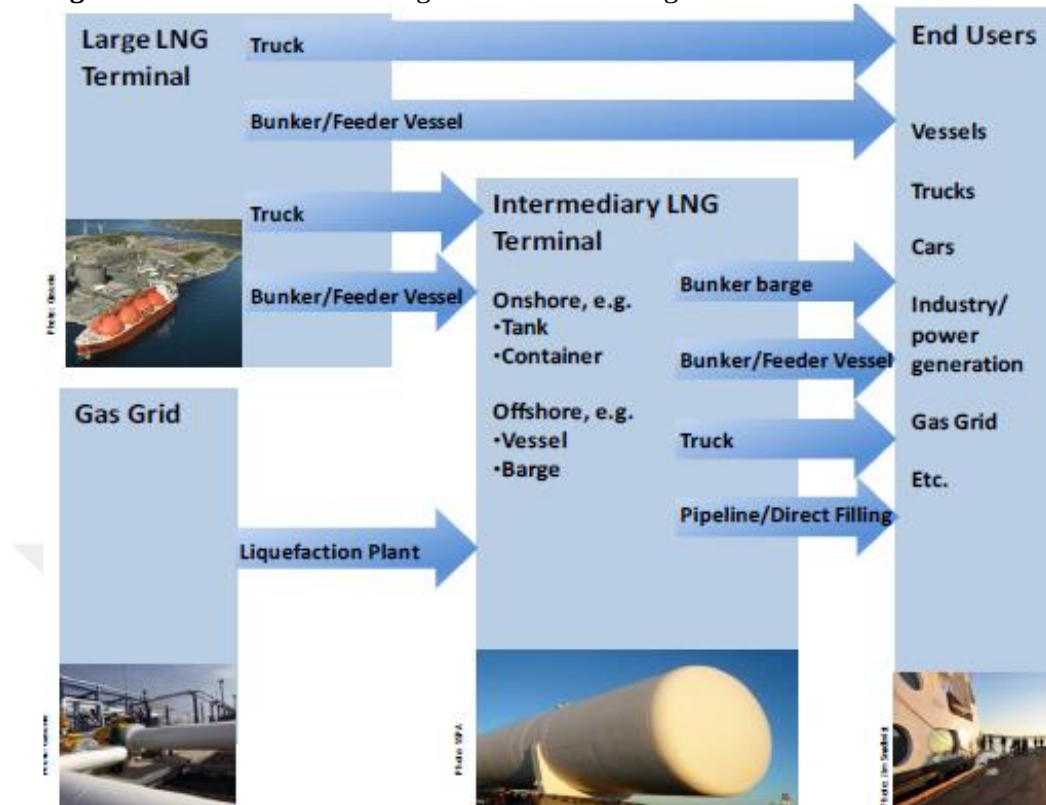
Table 9: Definitions of Large, Medium, Small Scales in Different Activities

Activity	Large Scale	Medium Scale	Small Scale
Onshore Storage Capacity	Import Terminal $\geq 100,000\text{cbm}$	Intermediary Terminal $10,000\text{-}100,000\text{cbm}$	Intermediary Terminal $\leq 10,000\text{cbm}$
Ship size LNG Capacity	LNG Carriers $100,000\text{-}270,000\text{cbm}$	LNG feeder vessels $10,000\text{-}100,000\text{cbm}$	LNG bunker vessels $1,000\text{-}10,000\text{cbm}$ LNG bunker vessels/barges $200\text{-}1,000\text{cbm}$

Source: (DMA, 2012)

LNG supply chain is extended to several steps if it is used as fuel for transportation or industrial use. This so-called ‘Down-Stream LNG Supply Chain’ usually requires small/mid-size LNG distribution. Therefore characteristics, operations or technical issues are not always same for larger scale LNG supply chain (DMA, 2012). Small/Mid-scale LNG delivery involves different stakeholders such as suppliers, terminals, ports, shipowners etc.(EMSA, 2017).

Figure 35: Infrastructure Arrangements for Providing Different End Users with LNG Fuel



Source: (DMA, 2012)

There are several methods to deliver LNG fuel to end users as defined in Figure 35. Delivering LNG fuel to end users can be carried out in different ways depending on logistics, technical and operational issues: Truck to Ship (TTS), Ship to Ship (STS), Terminal (Port) to Ship or Container to Ship. Quantity to be transferred, time constraints, onboard storage capacities, boil-off gas problem are important factors to build supply chain. Moreover, LNG bunkering price or market and lack of infrastructures bring an overall challenge for Small/Mid-scale LNG supply chain (Wang and Notteboom, 2014). LNG bunkering development is effected by these extended supply chain challenges and their optimization to take investment decision (EMSA, 2017).

2.5. LNG BUNKERING

Bunkering is refuelling of bunker which is referred to marine fuel (Vilhelmsen, Lusby and Larsen, 2013). It's an operation to supply necessary fuel to run main and

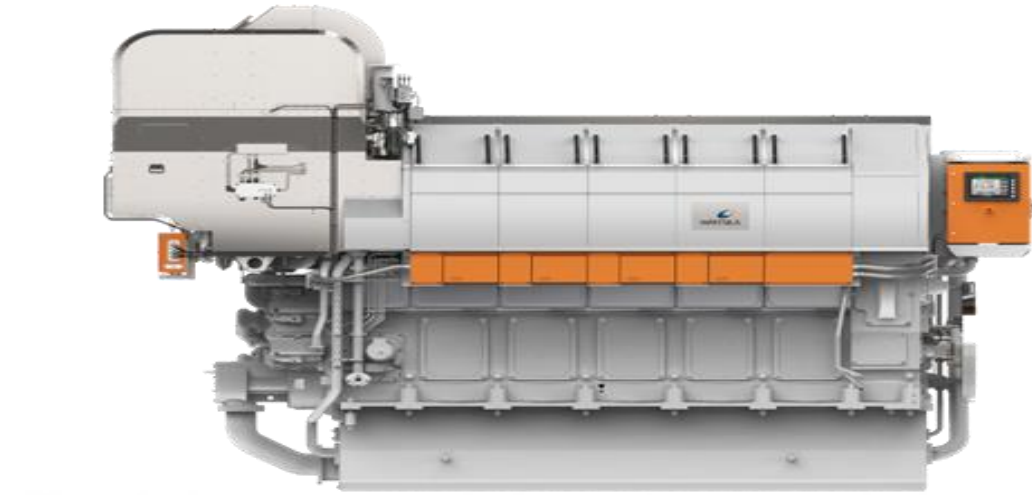
auxiliary engines onboard. LNG is an alternative fuel to conventional marine fuels and require special engine, storage and system designs to be utilized onboard. In line with characteristics and quantity of the LNG to be handled; supply chain design, infrastructure development must be critically reviewed. Technical standards are covered under IGF Code -if it's not under IGC Code- determines standards for gas carriers. European Maritime Safety Agency defines LNG bunkering as an operation where LNG fuel is transferred from a mean of distribution source to LNG fuelled ship. Different stakeholders involved in this process from ship-side are LNG supplier, ports, safety personnel, administrations and policy makers (EMSA, 2017).

2.5.1. LNG Propulsion

LNG has been in use for more than 40 years in marine diesel engines. LNG carriers are already in service with dual-fuel diesel engine options (Burel, Taccani and Zuliani, 2013). They have been examined for many hours and they are reliable option as marine engines. New design option for methane slip problem is in progress, which is the biggest drawback for dual-fuelled engines.

There are four engine types that can be used in marine industry: 1- Pure-gas four stroke (low pressure), 2-dual-fuel four stroke (low pressure), 3-dual fuel two stroke (low-pressure), 4- dual-fuel two stroke (high pressure) (DNV GL, 2019). First two types are convenient for smaller ships at short sea shipping and work with otto cycle. Type three and type four are designed for slow speed and can be used in deep sea shipping with large vessels. All four types have methane slip problem but can comply with emission control regulations. The only exception is for type four which may need EGR or SCR instillation in order to comply with Tier III requirements as it works with diesel (diffusing) principle and NO_x reduction (25%-30%) is much lower than otto type engines. Flexibility of the type two, three and four is an advantage for long-term investment decisions as they are able to switch their fuel from LNG to MGO, liquefied biogas (LBG), synthetic methane, biodiesel or synthetic diesel if deemed necessary (DNV GL, 2019).

Figure 36: Wärtsilä 31DF Model Diesel Engine



Source: (Wärtsilä, 2020)

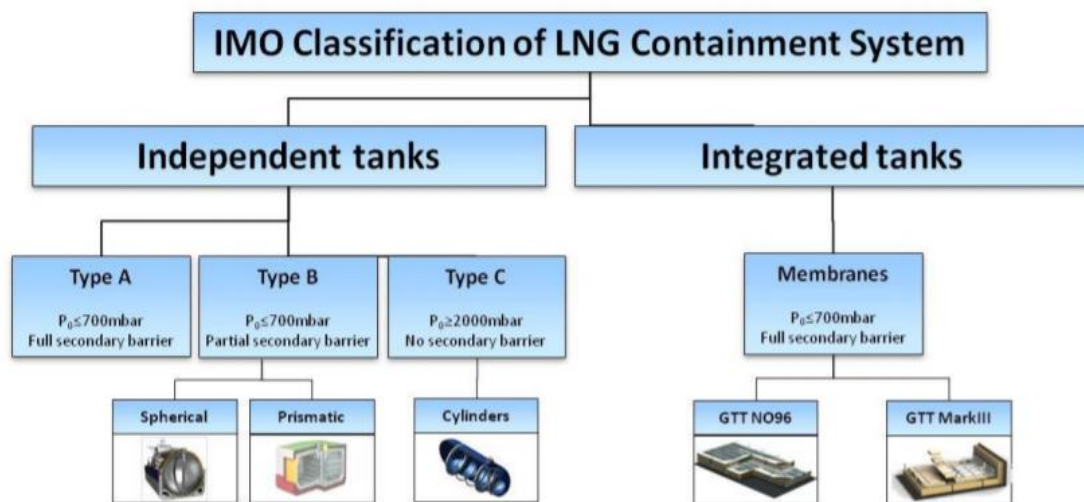
Figure 36 shows Wartsila 31DF model which is recorded as the world's most efficient 4 stroke diesel engine. It can be used as main engine in diesel electric configuration or as an auxiliary engine. It provides optimum performance especially for OSV and drilling vessels (Wärtsilä, 2020). Another model of Wartsila is 50DF is in service and known as one of the first LNG powered ships 'Viking Grace' since 2013. Dual-fuel four stroke engines can operate with both fuels and can switch between fuels without any interruption. MAN, Wartsila and Caterpillar MAK are major manufacturers of the four stroke dual fuel engines (IMO, 2016b).

2.5.2. LNG Storage Onboard

LNG storage onboard is one of the handicaps of the LNG powered ships compared to conventional ships. LNG's density is almost half of the other marine fuels such as HSFO or MGO. In order to provide equivalent energy source from LNG fuel, storage capacity requires three or four times bigger space than conventional fuels. In addition to density, the second reason is temperature of the LNG as it needs to be stored at below -160°C . Therefore, it requires proper insulation, meaning more space to lose from cargo, engine or accommodation space.

IGC Code determines technical design criteria in terms of tank strength and construction for LNG storage onboard. Maximum allowable pressure for tanks is subject to Maximum Allowable Relief Valve Setting (MARVS) onboard. There are two main tank categories in gas carriers: non-self supporting tanks (atmospheric membrane tanks) and self-supporting tanks (actual pressure tanks). The self-supporting type tanks are classified under three segments: Type A, Type B and Type C (GTT, 2015).

Figure 37: IMO Classification of LNG Containment System



Source: (GTT, 2015)

Figure 37 illustrates classification of LNG containment systems according to IMO. LNG bunker vessels and LNG fuelled vessels are usually designed as independent tanks, although there are examples of integrated tanks.

2.5.2.1 Type A

These are prismatic tanks and their vapour pressure should not exceed 0.7barg. As the material strength of the tanks is insufficient for crack propagation, Type A tanks require a complete structural secondary barrier. The second shell could be part of the vessel's inner hull and it is expected to resist the low temperature cargo(IMO, 2016b).

2.5.2.2. Type B

Type B tanks could be prismatic or spherical. These are the examples of Moss-Rosenberg tanks. The design vapor pressure is typically 0.25barg and determining stress levels, fatigue and crack propagation requires detailed tests and analyses. This improved design capability provides opportunity compared to Type A, and Type B tanks need to have only partial second shell. They can be used for longer endurance vessels that provide more space for storage(IMO, 2016b).

2.5.2.3. Type C

Type C tanks could be spherical, cylindrical, or bi-lobe pressure tanks with a design pressure greater than 2 barg. Typical working pressure is less than 10 bars for tanks up to 700cbm. These are designed according to relevant pressure vessel design code and proven as leak proof. Therefore, no secondary barrier is needed. Out of the shell has resistance to low temperature usually with stainless steel and insulated with polystyrene or polyurethane panels on the tank wall (IMO, 2016b).

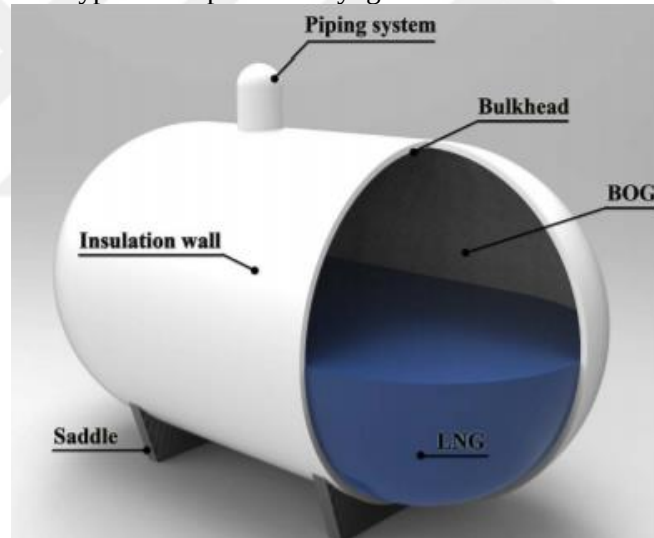
2.5.2.4. Membrane Tank

These are commonly used as membrane containment systems in LNG carrier such as GTT's Mark III and NO96 systems. Membrane tanks are not self-supporting tanks and normally comprise of two independent and liquid tight barriers and two layers of insulation to protect the hull from the low temperatures and to limit boil-off (IMO, 2016b). Membrane tanks are preferred in LNG carriers; however, application on LNG fuelled vessels still has not been preferred. Although, membrane tanks, Type A tank and Type B tanks have advantage of improved insulation, LNG fuelled vessels prefer Type C tanks that they can operate at pressure of 10bar or higher and control boil-off through tank pressure (Draffin, 2013).

2.5.3. Boil-Off Control

LNG is stored under cryogenic condition at approximately -162°C , and all components of the system including piping, valves are designed to reduce heat entry. However, their interaction with cryogenic liquid creates boil-off gas (BOG)(Ryu et al., 2016). In particularly Type C tanks, LNG fuel can produce significant amount of BOG from flashed gas and this could be challenging for LNG fuelled vessel and LNG bunkering vessel for pressure control (Draffin, 2013). Dealing with BOG is the major problem for LNG bunkering vessels because of economic and environmental reasons. LNG bunker barges have large surface-to-volume ratio and, as a result, boil-off rate is high as it is between 0.2% and 0.6% a day(Kim et al., 2019). It's around 0.1% to 0.15% in large LNG carriers.

Figure 38: Sketch of Type C Independent Cryogenic Tank



Source: (Lin et al., 2018)

Figure 38 shows sketch of Type C tank. IGF Code requires minimum holding time for Type C tanks as 15 days; on the other hand, USCG requirement is 21 days. The Code also indicates several methods to handle BOG such as thermal oxidation of vapours, re-liquefaction of vapours, liquefied gas cooling, pressure accumulation, and energy consumption by the ship. Re-liquefaction system requires convenient space to install and consume energy for re-liquefaction process and additional cost. Therefore,

it's not feasible for small scale LNG carriers (Kim et al., 2019). Technical improvements in BOG handling still continue.

2.5.4. LNG Fuelled Ships

Currently 182 LNG fuelled vessels are in service around the world as of May 2020, according to DNVGL data till end of the 2025, 389 LNG fuelled vessels will be in service (DNVGL, 2020). LNG fuel option is possible for all types of vessels from tug boats to cruise vessels. However, cargo space loss is different according to vessel types. While tankers are able to install tanks on deck, car carriers or container vessels usually need to lose some cargo space. Taking into account total life span of about 25 years, retrofit option is possible for existing vessels as well -although it could be much costly than new building. Payback time also depends on mostly LNG price and vessel's trading area.

2.5.4.1. New Building

New LNG fuelled vessel orders not as a number but as a type and size of the ships is promising. There is an increasing demand from cruise ship, oil tanker and container vessel segment. Large container ship operator such as MSC, Hapag Lloyd, CMA-CGM have already invested in dual fuelled vessels (Hapag-Lloyd, 2019; MSC, 2019; CMA-CGM, 2020) . Moreover, in 2020, Samsung Heavy Industry Shipyard received two VLCC LNG fuelled ship orders (Offshore, 2020d), meaning that LNG bunker structure needs to be improved to handle VLCC demand for a single operation.

M/V MSC Gülsün, it's shown in Figure 39 one of the world's largest container ships, is owned by Mediterranean Sea Company (MSC) and she was built in Samsung Heavy Industries (SHI) and it is registered to Panama with DNVGL classification. She has 399.9m length, 61.5m breadth and 16m summer draft which allows 23756 TEU capacity. The vessel is in service with east to west container transportation along with 2000 refrigerated container capacity which allows food, drink and pharmaceutical items' transportation at sea. Apart from her massive size, innovative engineering makes this vessel the lowest carbon footprint by design. The CO₂ emission of the

vessel is 7.49gr to move 1 ton of cargo 1 nm. M/V MSC Gülsün has shore power connection option, bulbous bow, optimised rudder-bulb, exhaust gas economizer for auxiliary engines. The vessel is currently running with tradition marine fuel with MAN D&T 11G95ME-C9.5 engine but it was designed as ‘LNG Ready’. This means that the vessel can switch to duel fuel option when LNG is available and provides better profit margin enroute (MSC, 2019).

Figure 39: M/V MSC GÜLSÜN



Source:(MSC, 2020)

Lloyd List awarded 114000dwt Aframax tanker M/T Gagarin Prospect that is owned by Russian shipowner SCF and operates under Shell charter. It's one of the first LNG fuelled Oil Tanker. SCF owns another 5 Aframax tankers ‘Green Funnel’ series which are chartered to Shell(SCF, 2020). Figure 40 shows M/T Gagarin Prospect underway.

Figure 40: M/T Gagarin Prospect



Source: (SCF, 2020)

Most of the current LNG fuelled vessels are relatively small vessels, and they cannot create sufficient demand for many ports across the world and makes investment decision difficult for bunker suppliers. When the large vessels enter the market, it is expected to create reasonable demand for suppliers.

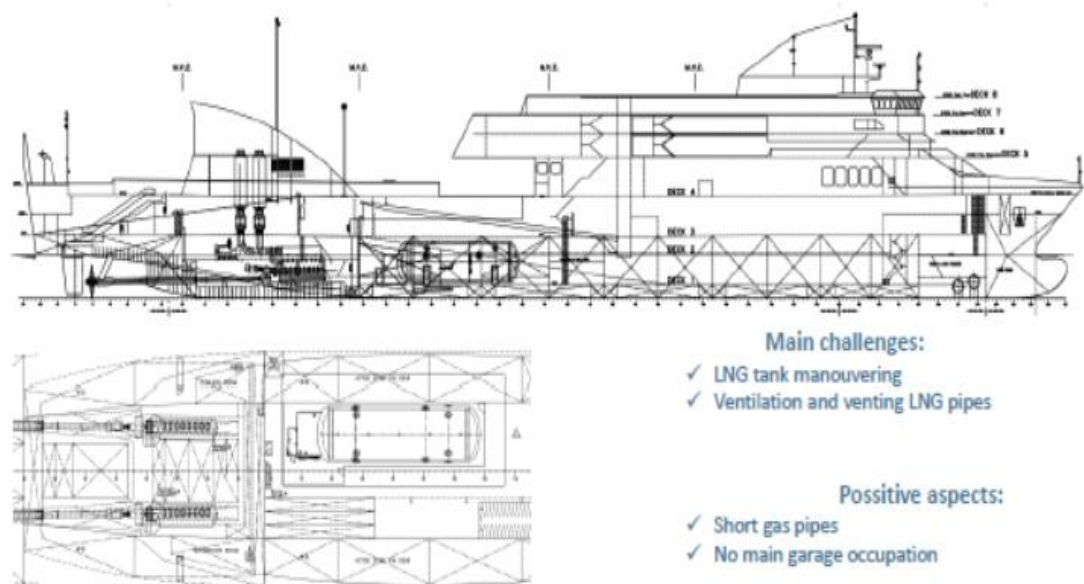
2.5.4.2. Retrofit

Retrofitting option may involve intensive structural work, piping and modification. Converting vessels to LNG fuel type is not usually feasible compared to new buildings while taking into account pay-back time (Shell, 2019a). Hapag-Lloyd, one of the leading container fleet owner, invested in LNG fuelled vessels. 15000TEU capacity M/V Sajir is one of the biggest vessels in Hapag Loyd fleet, determined as pilot vessel and it's under retrofitting process in China to be fuelled by LNG. The 5-year old vessel, already has dual-fuel engine onboard and will be re-designed according to DNVGL's LNG-Ready concept. After conversion, vessel will be able to cut its CO₂ emissions by about 20% and more than 90% SO_x and PM emissions. The biggest challenge is seen as integrating LNG tank into the ship. Unlike smaller vessels, M/V Sajir to be equipped with 6700cbm of LNG capacity by GTT Mark III membrane

tank. Since the tank will be placed in front of the engine room, approximately 300 container capacity will be lost (Riviera, 2019).

Balearia, a Spanish shipping company has already retrofitted two of their ferries into LNG and started the third one. Napoles (Figure 13) was the first ferry converted to LNG fuel in 2018. The ferry has 53 passenger vehicles and 1600 passenger capacity. Retrofitting process involved installation of 200 ton storage tank and dual-fuel engines. Total cost was approximately 14.1million USD. They saved 30% from fuel cost and reduced noise level onboard at the end of the project (Cotenaval, 2019).

Figure 41: Napoles Retrofit Project



Source: (Cotenaval, 2019)

On the other hand, China Guangdong province has started retrofit project which aims to reduce emissions. The project plans to complete 1500 inland vessels conversion and built 19 bunkering facility by 2025. It's calculated that annual demand for LNG as bunker will rise to 400000 tons and will replace oil-based fuels(Offshore, 2020b).

2.5.5. LNG Bunker Vessels

There have been 15 LNG bunker vessels in operation across the world by 2020. 22 new bunker vessels are already on order and expecting to be in service by 2023. 14 other bunker vessels are under discussion. The largest 6 LNG bunker vessels in operation are between 5000cbm and 10000cbm, and other 5 of them have capacity between 1000cbm and 5000cbm. However, in parallel to growing vessels size powered by LNG and potential demand, bunker vessels tank capacity is increasing. 4 LNG bunker vessels over 1000cbm -may be called as LNG feeder vessels are already on order, and 3 others are under discussion(DNVGL, 2020a). LNG bunker vessels are specifically designed for ship-to-ship bunker transfers. Not all of the LNG bunker vessels are driven by own propellers. Pushed tugboats are utilized for some types up to 8000cbm capacity tankers. Another functional design is M/T Oizmendi which is multi-purpose bunkering vessel and has FO, MGO and LNG tanks onboard. She can supply marine fuel at any requested type. The vessel is part of the CORE LNGas Hive project and it is supported by European Commission to foster the use of gas as marine fuel (Offshore, 2018).

M/T Coralius is one of the first LNG bunker vessels specifically designed to conduct LNG ship-to-ship bunkering operations in Europe. The 1A Ice classed vessel was built in Dutch Royal Bodewes shipyard by the joint venture ‘Sirius Veder Gas AB’. The vessel is under long-time charter of SkanGas. The vessel is owned by Sirius Veder GAS AB, which is a joint venture between Sirius Rederi and Anthony Veder. It was built under joint industry project Flexi. It’s a project co-founded by EU under TEN-T and Zero Vision Tool platform. The objective of the project is to build up LNG bunkering infrastructure in the Skagerrak/Kattegat region in collaboration with Skangas Brofjorden Terminal (Sirius, 2017). Figure 42 shows M/T Coralius at Baltic Sea.

Figure 42: M/T CORALIUS



Source:(AnthonyVeder, 2020)

General specifications of M/T Coralius is shown in Table 10. The vessel has advanced manoeuvring capability, 360deg bridge view and high accommodation standards for crew members.

Table 10: General Specifications of M/T CORALIUS

Type	LNG Feeder	Capacity	5800cbm
Built	2017	LOA	99.6m
Temp/bar	-163°C / 4.5 bar g	Tank Type	Type C
Flag	Sweden	Beam	17.95m
Class	BV	Service Speed	13.5 knot

Source: (AnthonyVeder, 2020)

Coralius's tanks were manufactured by TGE. The vessel has bilobe type two LNG tanks which are designed for 4.5bar. The bilobe tanks are separated by bulkhead, therefore 4 independent cargo tanks were generated. Moreover, two compressors with 532cbm/h each and four cargo pumps 250cbm/h each were installed to achieve 1000cbm/h loading/discharging rate. Nitrogen generator was installed. During cargo operation methane slip is zero since the boiler consumes mixture of methane and nitrogen. Block coefficient is relatively low, combined with hull design, and zero methane slip during cargo operations increases environmental performance of the

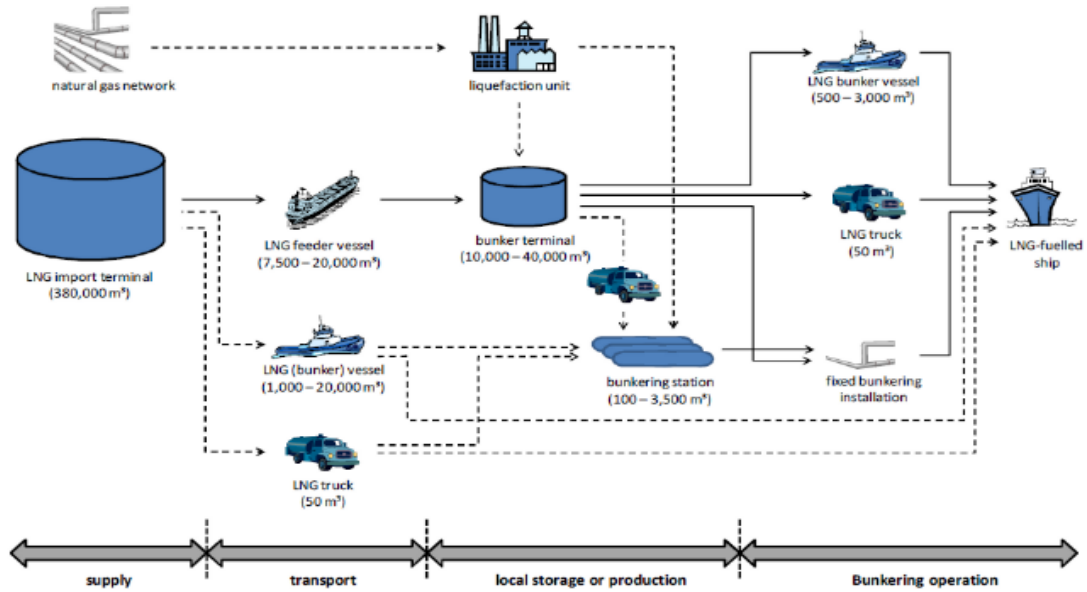
vessel(Sirius, 2017). The manifold arrangements are located at forward and midship section in order to provide operational flexibility. Boil-off gas management is made by subcooling system. In order to conduct safe bunkering operations, hose handling crane unit was placed at manifold area and vessel donned by portable Yokohoma fenders which are easy to handle with onboard cranes and fender-cradle arrangements.

2.6. LNG BUNKERING SUPPLY CHAIN

There are different stakeholders and aspects in small scale supply chain for LNG as marine fuel. Different stakeholders have different priorities in the supply chain mechanism. However, there are several aspects that need to be taken into consideration while designing supply chain such as reliability, safety, security of supply, flexibility, capacity, operational cost and investment cost (IMO, 2016b).

Shipowner will not take LNG as primary fuel source unless they are not convinced of its sufficient availability in the market. Stipulation of LNG as marine fuel is subject to development of the supply chain (Sharples, 2019). From gas phase to LNG receiving terminals working with high volumes, shipowners are not able to cover all supply chain costs from gas phase till the end, rather they may pay only for last steps of the supply chain which is commercially viable. LNG marine fuel requires to use existing supply chain in some context, and bunkering is able to develop where the LNG market already exists for industrial purpose or power generation (Sharples, 2019). Small scale LNG can be produced from pipeline via liquefaction terminal, or can be extended from LNG receiving terminal by ship, truck or pipeline.

Figure 43: Different Supply Routes for The Delivery of LNG as Ship Fuel



Source: (EMSA, 2017)

Figure 43 illustrates potential supply routes for LNG marine fuel. Natural gas in pipeline grid can be liquified in a small/medium scale unit and LNG can be transferred to either satellite terminal or bunker station. Second supply points are LNG import terminals where large scale LNG carriers discharge their cargoes. LNG can be transported by feeder vessels to satellite terminals or with smaller amount can be transferred to bunkering stations by trucks or barges. Bunkering operation takes place at the last step, LNG powered ship can receive the fuel either by bunker barge, truck or direct piping connection in port (EMSA, 2017). The final stage of the delivery follows the same options as conventional fuel supply: Turck to Ship (TTS), Ship to Ship (STS), Pipeline to Ship (PIS), and Container to Ship (CTS).

2.6.1. Truck to Ship (TTS)

Truck alternative is the most feasible option for small deliveries below 200cbm. Trucks' capacities are between 40 cbm and 80cbm that differ according to national transportation regulations. Hose connections sizes can be between 2'' and 6''(DMA, 2012).

Figure 44: Truck to Ship LNG Bunkering



Source: (Offshore, 2020a)

Figure 44 shows typical TTS LNG bunkering operation. TTS has benefit of limited initial investment cost, trucks can also be utilized for industrial purpose as well. Deliveries can be achieved by road in certain distance and relatively faster. Moreover, numbers of the trucks can be connected to vessel via shared manifold and can perform the operation simultaneously to save time. However, on the negative side, location flexibility is limited, receiving vessel needs to be in a quay that trucks can approach. This can also distract cargo or passenger handling (IMO, 2016b).

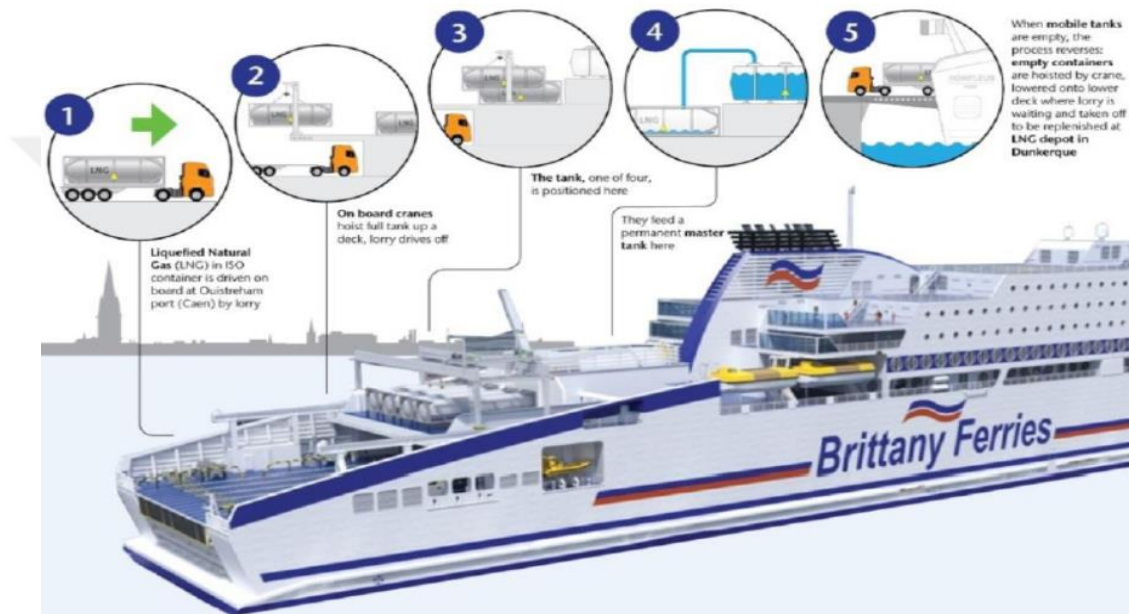
2.6.2. Pipeline to Ship (PTS)

Pipeline to ship bunkering is possible from satellite terminal or receiving terminal to jetty via pipeline. On the negative side, length of the pipeline to jetty is critical as the pipeline could be highly costly and can cause technical challenges as well. This method also has limited flexibility that receiving vessel needs to be moored to fixed position. Therefore, port or berth needs to have stable long-term demand for bunker delivery or must be supported by demand from power generation or industrial use (IMO, 2016b).

2.6.3. Container to Ship (CTS)

The standard ISO container is used for this purpose. That provides flexibility for bunkering. M/F Hanfleur is the first passenger ship fitted with an onboard crane to handle ISO LNG tanks into place.

Figure 45: Brittany Ferries Container to Ship Bunkering



Source: (Brittany, 2019)

ISO Containers are carried to the vessel by trucks. Onboard cranes hoist up the container and it's placed next to other three containers. Four containers (tank) feed the master tank on upper deck. Once the ISO Containers are emptied, containers will be taken off by trucks and new ones will arrive by trucks. Figure 45 summarises the steps of the process (Brittany, 2019).

2.6.4. Ship to Ship (STS)

TTS, PTS and CTS have some limitations for LNG marine fuel delivery in terms of capacity and flexibility. Ship to ship option overcomes these limitations as it is used to be in conventional bunker delivery. It provides flexibility -delivery can be

performed while the vessel moored in port or at designated anchorage area(IMO, 2016b). It copes with capacity and scheduling restrictions of the trucks and provides large amount of bunker at shorter time window with high pumping capacity (DMA, 2012). On the other hand, high initial investment cost for LNG bunker vessel is a crucial obstacle. Below 100cbm volume demands are not practical for LNG bunker barges (DMA, 2012). Nevertheless, development of the LNG marine fuel depends on infrastructure and larger vessels in international shipping require higher volumes and it's only practical by Ship-to-Ship bunkering supply as it's made by conventional fuel supply.

Figure 46: Ship to Ship Bunkering Operation



Source: (Offshore, 2019)

Figure 46 shows a ship-to-ship bunker LNG bunkering operation between M/T Gagarin Prospect and LNG bunker vessel M/T Caridssa in the port of Rotterdam.

2.7. LNG BUNKERING INFRASTRUCTURE

LNG import terminals are critical links in LNG bunkering supply since they offer flexibility and cost advantage compared to pipelines. Potential LNG demand is

subject to available LNG bunkering infrastructure. Recent developments in Singapore and Middle East close the gaps between East to West shipping traffic for the larger vessels at long haul and provide world-wide network for LNG. Figure 47 shows commissioned and planned LNG bunkering infrastructure which have service as bunker to vessel and pipe to vessel. Most of the facilities are located in North Sea and Baltic Area which are leading regions for alternative fuels as well as LNG.

Figure 47: Tank-to-Ship and Ship-to-Ship LNG Bunkering Facilities



Source: (DNVGL, 2020b)

LNG bunkering infrastructure is investigated in detail according to region in the following sections.

2.7.1. Infrastructure in Europe

Baltic Sea and North Sea coasts have already developed LNG bunkering infrastructure, either by port-to-ship, truck-to-ship or ship-to-ship. In addition to existing LNG production plants, Norway has already more than 40 small-scale LNG terminals. EU Directive 2014/94/EU requires that marine ports in core network should be able to provide LNG bunkering by December 2025 and inland ports in core network by 2030. European Union produce funding mechanism such as European Union

Trans-European Transport Network (TEN-T), Marco Polo II, Poseidon Med II projects that support sustainable transportation Europe-wide network of railway, roads, inland waterways, short sea shipping, ports, airports, railroad terminals and maritime shipping (EC, 2018).

As part of the TEN-T project, there are 33 LNG bunkering facilities in EU by 2018(EAFO, 2020). In line with ECA requirements, firstly LNG network has been developed in Baltic Sea and North Sea. Stockholm is the first port in the world to supply LNG bunkering by ship-to-ship (Marinelink, 2013). Major ports such as Rotterdam, Amsterdam, Antwerp, Hamburg, Gothenburg are already giving service either by terminal to ship, ship-to-ship or truck-to-ship.

EU funds also inland water ways Rhine/Meuse-Main-Danube for LNG bunkering infrastructure, bunkering stations and barges powered by LNG (Trimis, 2020).

France provides ship to ship bunkering in Marseilles, Dunkerque and Montoir-de-Bretagne. France LNG network covers Atlantic Coast, English Channel and Mediterranean (EAFO, 2020).

Spain gets benefits from TEN-T funds and has already established 14 LNG bunkering facilities both in Atlantic coast and Mediterranean coast. Ship-to-ship LNG bunkering infrastructure has already been settled in important bunkering hubs of Spain such as Algeciras, Barcelona, Tenerife Huelva. Spain is able to provide LNG bunkering to all ports across Spain at least by trucks (EAFO, 2020)

Following Spain, Italy is also developing a small-scale LNG supply chain. In addition to Oristano LNG terminal, 6 small-scale terminals across to Italy peninsula, Sicily and Sardinia will be established. 7500cbm LNG bunker vessel will be utilized and 30000cbm LNG carrier will replenish satellite terminals across the coast (Edison, 2020).

The Poseidon Med II projects aim to make Greece an international marine bunkering and distribution centre for LNG in Southeast Europe, as well as to adopt LNG as a marine fuel in the Eastern Mediterranean. The projects run under Public Gas Corporation of Greece (DEPA) and connects Greece, Southern Cyprus and Italy. The projects include satellite terminals and LNG bunker barges. Poseidon Med II's budget is approximately 53M Euro and funded by EU (Poseidon, 2020). Moreover, DEPA

signed an agreement with European Investment Bank (EIB) for a LNG bunker barge. The barge will be based in Piraeus and will have a 3,000 cubic meter LNG capacity. She will be the first of its kind in Greece and the Eastern Mediterranean, receiving LNG from the Revithoussa LNG terminal. She will be used to refuel ships in Piraeus and other Greek and foreign ports (Maritime, 2020).

2.7.2. Infrastructure in USA and Canada

Currently there are two ports in USA which provide LNG bunkering supply as Jacksonville, FL and Port Fourchon, LA. Third bunkering facility, Tacoma WA, is under development. Port Canaveral is also planned for LNG fuelled cruise ships and Florida (Parfomak *et al.*, 2019).

Initially, JAXLNG started service by the trucks in 2016 and replaced its service as ship to ship by arrival of bunker barge 'Clean Jacksonville' in 2018. Jacksonville performs the largest LNG bunkering operation in USA. LNG is sourced from Macon, GA. Currently, JAX LNG is constructing a small scale liquefaction plant at port. Port Fourchon gives LNG bunkering service since 2015 in the Gulf of Mexico to LNG powered offshore supply vessels. The port sources LNG from Alabama and Texas and stores them in a terminal. Currently providing truck to ship bunkering, however, two LNG bunkering barges are under construction already, in order to enable ship to ship LNG bunkering operation. Tacoma is the third place in USA, expecting to provide LNG bunkering facility along with liquefaction plant. Tacoma is in the North America ECA zone and vessels trading between Alaska and Washington just stay within this zone during entire journey. Proposed bunkering facility and liquefaction plant's total cost is expected to be 310 million USD. Other potential LNG bunkering facilities are expected to be established in Mexico Gulf and USA west coast in order to serve international shipping trading in USA ports (Parfomak *et al.*, 2019). Figure 48 illustrates current and potential LNG bunkering facilities in the USA.

Figure 48: Existing and Potential LNG Bunkering facilities in the USA



Source: (Parfomak et al., 2019)

Since 2017, British Columbia provides LNG bunkering service to five BC Ferries and two Seaspan cargo ferries. Port of Vancouver launched the first ship-to-ship LNG facility in North America. Furthermore, as a gas rich country, LNG is a viable option for Canadian greenhouse gas reduction mitigation strategies. Vancouver port authority also collaborates with Port of Tomakomai, Japan, for LNG bunkering development (Safety4sea, 2019; Reportlinker, 2020).

2.7.3. Infrastructure in Japan

As a part of strategy to become an LNG hub in Asia, Japan is subsidizing LNG bunkering projects. Currently, the Port of Yokohama is providing truck-to-ship LNG bunkering facility. The first ship to ship LNG bunkering is planned to launch in 2020 by two Japanese consortiums of NYK, K Line, JERA and Tsusho Corporation. The bunker vessels will be in service at Tokyo Bay and Ise and Mikawa bays. Japan Sumitomo Corporation runs another project to start LNG bunkering by the end of 2020. Port of Tomakomai is also considered as LNG bunkering place by using portable containers. In Western Japan, Kyushu and the Setouchi regions are under way

to provide truck-to-ship LNG bunkering facility (Japantimes, 2019; Parfomak et al., 2019)

2.7.4. Infrastructure in South Korea

The Korean government plans to provide LNG bunkering service to secure its competitiveness for international shipping and support domestic shipping operations (Lu et al., 2019). , Gwangyang Port, Busan Port, Pyeongtaek Port, Ulsan and Incheon Port are selected to construct LNG bunkering terminal by Ministry of Maritime Affairs and Fisheries (Park and Park, 2019). Government also subsidies 10% for shipowners who want to invest in LNG powered vessels to be built in Korean shipyards. Korean LNG company is building 18000cbm LNG bunker vessel at Hyundai Mipo Dockyard.

2.7.5. Infrastructure in China

China started to apply Emission Control Area measures within territorial water and inland water ways. Since 1st of January 2020, vessels entering inland waters should use maximum 0.1 sulphur fuel. From 1st January 2022, China will implement the same restriction for its territorial waters. In order to comply with the regulations, China has already started developing infrastructure for LNG bunkering.

China is planning to complete LNG bunkering systems at Yangtze River, Beijing-Hangzhou Canal and Xijiang River by 2025. By the end of the 2018, China had 163 new built LNG powered vessels and 117 retrofit vessels, mainly in Yangtze River, Beijing-Hangzhou CANA, Pearl River and Huangpu River. 21 LNG bunkering stations have been built and only 5 of them are in operation with total capacity of 68.4 million tons (Qiaoyu, 2019). Figure 49 illustrates coastal LNG bunkering network in China.

Figure 49: Coastal LNG Bunkering Network in China



Source: (Qiaoyu, 2019)

The largest 7 ports of the world out of ten are located in China. In order to keep competitiveness of the ports, China planned to establish 4 international LNG bunkering centres: Bohai Sea, Yangtze River Delta, Pearl River Delta, and Hainan. China's first 14000cbm LNG bunkering vessel has been in service since May 2018. Moreover, two LNG powered vessels are under construction. Vessels capacities are 6000 and 12000cbm and fit for feeder service between LNG storage tanks, as well as ship-to-ship bunkering operations with large carriers. China aims to reach 5 million tons LNG marine fuel capacity by 2030 (Qiaoyu, 2019).

2.7.6. Infrastructure in Singapore

Singapore is the largest bunkering hub in the world and provides broad range of fuels for international shipping. It's announced 4.5million USD to be subsidised for the construction of two LNG bunkering vessel (Parfomak *et al.*, 2019). According to MPA's pilot program in LNG bunkering, as of May 2020, the first LNG bunkering barge of Singapore launched for Fuel LNG which is joint venture between Keppel

Offshore& Marine and Shell Eastern Petroleum. The bunker barge will be operated by Kline (MPA, 2017).

By December 2019, Pavilion Energy Singapore and Total Marine Fuels have initialed an agreement to jointly develop LNG bunker supply chain in Singapore. The agreement includes long term agreement use of the 12000cbm GTT Mark III membrane type LNG bunker vessel's sharing. Pavilion Energy performed Singapore's first ship-to-ship LNG bunkering operation in May 2019 by reloading 2000cbm LNG marine fuel from small scale tankers to commercial vessels (Marinefuels, 2019).

Singapore has signed a memorandum of understanding with 10 partners which include Chinese Port of Ningbo Zhoushan, Port of Rotterdam, Norwegian Maritime Authority, Japan Ministry of Transport, and Ulsan Port Authority (Parfomak *et al.*, 2019). LNG bunkering facility in Singapore is a game changer for LNG marine fuel's world-wide development. As the largest bunkering hub of the world, Singapore, closes the gap between Esat and West international shipping route.

2.7.7. Infrastructure in Other Regions

Joint venture of Total and AES developed infrastructure in Panama Colon LNG Terminal and Dominik Republic Andres LNG Terminal. Panama terminal allows reload for small scale vessels minimum capacity of 3000cbm and truck loading. Andres terminal is able to reload small scale vessels minimum 10000 cbm (Pfeuty, 2019). In South America, there are nine operating LNG terminals and six terminals are in development stage that have potential for LNG bunkering development in the near future (Parfomak *et al.*, 2019).

Total run a 'well to wheel' project in Oman that involves upstream to LNG bunker vessel delivery. In Sohar Port, 1Mtpa capacity onshore liquefaction plant is planned to build and will source the gas from Oman's Greater Barik region (Pfeuty, 2019). In December 2018, Abu Dhabi based Adnoc and Japan's Inpex signed an agreement for LNG bunkering development. Moreover, in September 2019, Shell and Qatar Petroleum signed a deal to establish a global LNG bunkering venture (PE, 2020).

Truck-to-ship LNG bunker service is already available in Australia. Australia McGowan government takes initiative to create LNG bunkering hub in Pilbara where

there is a LNG production centre. Australia's first ship to ship bunkering licence was executed to Woodside Energy at Port Hedland and Dampier by the Pilbara Ports Authority in May 2020 (Manifoldtimes, 2020).

2.8. LNG BUNKERING SAFETY

Risks associated with LNG marine fuel is different from conventional marine fuels like MGO and HFO. The most important hazard of the LNG is its flammability. Flammable vapour will be formed if LNG is released at normal ambient temperature and pressure. The release may cause a fire or explosion if the vapour is in flammable range which is between 5 and 15 percent by volume in air for methane. Therefore, release of the LNG should be prevented at all stages of the supply chain (ABS, 2014). LNG as a cryogenic fluid causes frost burn when it comes to contact with the human skin. LNG spill also causes brittle fracture damage at normal shipbuilding steel, as it has the extremely cold temperature. Since the main content of the LNG is methane, breathing in large concentrations may cause asphyxiation (Vandebroek and Berghmans, 2012).

The transfer of the LNG from one transport mode to another may cause leakage, release or other hazards in the supply chain. Therefore, the risks and hazards associated with LNG transfer should be evaluated with the risk assessment. There are two main approaches in risk assessment as qualitative and quantitative. A qualitative risk assessment evaluates the risk according to identified hazards and consequences, and then confirm suitability of operation according to the settled safety procedures. In case of new LNG bunkering operation in a port area, more detailed quantitative risk assessment is required (ABS, 2014). These cases include, if cargo handling is conducted in parallel to bunkering or passengers will be present on board during bunkering operation. There are two methods to define safety designs: deterministic and probabilistic approach. In the deterministic approach, maximum credible accidental release is based on bunkering system which takes into account hose dimensions, flow rate, temperature, pressure and ESD system. In the probabilistic approach, cumulative consequences of potential various leakage scenarios are reviewed by the use of event tree model. Heat radiation exposure contours around the

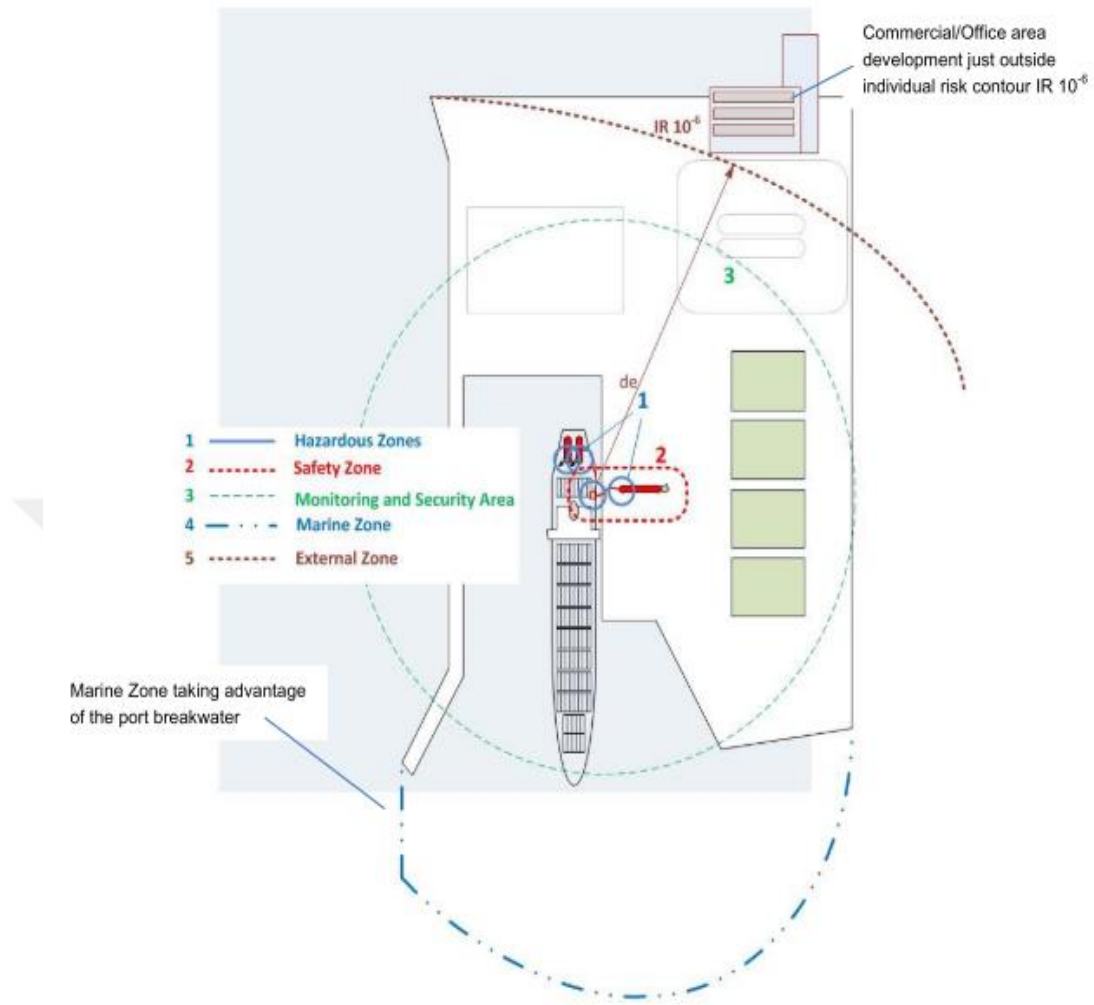
bunkering site must be assessed for LNG dispersion, vapour cloud modelling, and fire calculations.

2.8.1. Safety and Security Zone

One of the important results of the risk assessments of LNG bunkering is to determine safety zone for operation. The safety zone's aim is to define an area into which only designated personnel with appropriate safety equipment and training qualifications are permitted to enter. The size of the zone is determined according to some criteria, risk assessment and local regulations. In addition to safety zone, security zone should be established around bunkering facility (IMO, 2016b). The geometry of the ships and the state of cargo shipment, it is argued, are important criteria for defining a safety zone since the local environment has a direct effect on gas congestion. (Park et al., 2018). The purpose of the security zone is to keep bunkering operation clear from other activities such as vessel traffic, cargo operation, as well as equipment that has risk to interfere with LNG bunkering system or equipment (ABS, 2014).

There are other zones identified in the LNG bunkering literature in addition to the protection and security zones. A hazardous zone is a three-dimensional environment in which a potentially flammable atmosphere can occur at any time. Marine zone is designated area where shipping traffic may impact LNG bunkering operation. External zone is to define the distance where public may be present such as commercial/office area according to regulatory regimes. Figure 50 illustrates control zones.

Figure 50: Control Zones



Source: (EMSA, 2017)

2.8.2. Simultaneous Operation (SIMOPS)

SIMOPS is defined by USCG CG-OES policy letter as “two or more operations occurring simultaneously, one of which involves LNG bunkering operations, and the combination of which may present safety, environmental and security concerns” (EMSA, 2017:339). It may be required when ship owner/operators wish to perform other operations such as cargo handling, passenger transfer, waste disposal, maintenance, ballast operations etc. during LNG bunkering. SIMOPS is a critical stage for LNG bunkering development, otherwise vessels’ turnaround time will increase at port.

The risk assessment is the first step for the SIMOPS. At planning stage, relevant elements for different SIMOPS scenarios should be determined and also should be indicated in approved LNG bunker management plan. The quantitative risk assessment is also required along with qualitative risk assessment (ABS, 2014). Port of Rotterdam took initiative and started performing SIMOPS under certain berths and criteria (Voulon, 2019).

2.9. REGULATORY FRAMEWORK

Regulatory framework in LNG bunkering has different layers from international perspective to local port regulations. Internationally the main environmental instrument is MARPOL. MARPOL Annex VI sets the regulations for emission controls in international context. As LNG brings viable alternative to stricter emission regulations, it has been considered as marine fuel. However, flash point of the LNG is lower than 60degC, and it cannot be considered as fuel according to SOLAS. Therefore, IMO first recommended Resolution MSC.285(86) based on the rules developed in Norway by Norwegian Maritime Authority and DNV along with IGC Code which already provides guidance for gas carriers. After this initial stage, IMO adopted IGF Code and it came into force on 1st of January 2017.

The International Code of Safety for Ships using Gas or Other Low Flashpoint Fuels (IGF Code) set standards for cargo ships over 500gt and passenger ships using natural gas as fuel. It contains design, construction, arrangement safety and operational criteria for subject vessels. The code provides guidance for safety, related safeguards, control mechanism and operational procedures. IGC Code, MARPOL, SOLAS, STCW Code and Conventions are other international regulatory body enforcements.

At the second stage, countries' regulations and directives take place. European Union set standards based on these regulations and directives such as EU Sulphur Directive, EU Port Regulations, EU Alternative fuel Directive (EMSA, 2017). In USA, the Coast Guard and the Federal Energy Regulatory Commission have jurisdiction over LNG storage, infrastructure and bunkering operations along with US federal agencies (Parfomak *et al.*, 2019)

Industrial standards such as ISO (International Standardization Organization), EN (European Standard), Equipment standardisation need to be followed. ISO/TS 18683:2015 is a technical specification guidance that describes the properties of LNG, the risk assessment process, the safety hazards and LNG bunkering system's functional requirements (ABS,2014). Moreover, ISO TC67 and TC8 sub-committees on petroleum, petrochemical and natural gas industries of materials, equipment and offshore structures, as well as Ships and Marine Technology, related with LNG as fuel, small scale development and bunkering have been published (EMSA, 2017).

Flag administrations are primary responsible authorities to enforce international and national regulations regarding LNG bunkering systems, procedures and operations. Classification societies take substantial role to design and construct an LNG bunkering system. The classification societies, while implementing, reviewing their own standards, designs and constructions, should also need to comply with international and national standards set by IMO and Flag Administrations.

The classification societies such as BV, ABS, Lloyd Register, DNGL provide main supportive and best practice guidance for the LNG marine fuel. IAPH (International Association of Ports and Harbours), SGMF (The Society for Gas as a Marine Fuel), IACS (International Association of Classification Society) support LNG marine fuel and bunkering's technical standards and operational best practices and implications. Industrial best practices which are prepared by SIGTTO (Society of International Gas Tanker and Terminal Operators), OCIMF (Oil Companies International Marine Forum) are important references that need to be followed and strictly implemented in order to perform operations at the highest industrial standards. The other regulatory framework may include local requirements, specific to the related port authority.

2.10. HUMAN RESOURCES AND COMPETENCY

Many accidents in marine industry are related with human errors(Stokes *et al.*, 2013; OCIMF, 2018). Quality and experience of the staff is critical for many industries which handle hazardous cargoes. Their reaction to unexpected events, emergencies or just how they handle the routine operations directly affect efficiency of the operation

(SGMF, 2019). LNG is a cryogenic liquid and associated with several risks such as fire, BLEVE (Boiling Liquid Expanding Vapour Explosion), asphyxiation, cryogenic burns and cracking of metal structures (Stokes et al., 2013). In addition to toxic effects, at severe conditions, incidents could lead to fire, loss of vessels and life in the vicinity. Therefore, crew competency is critical in marine operations.

Competency is defined as *‘the combination of skills, knowledge and behaviours that a person brings to a position that enables them to perform their tasks efficiently, safely and effectively’* (OCIMF, 2018:iii). As the human element is a key success factor for safe LNG handling operations, it’s crucial for crew members to have the necessary competency for bunkering, maintenance, or emergency procedures in order to assure safe and efficient operations (EMSA 2017). OCIMF (2018) points out six elements for crew competency: Team working, communication and influencing, situation awareness, decision making, results focus and leadership and managerial skills. The training requirements of LNG carrier are defined at STCW under IGC Code requirements. However, LNG fuelled vessels are not necessarily LNG carrier, apart from fuel tanks. Therefore, IMO introduced International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels (IGF Code) which defines and provides international standards for the vessels operating with gas or low-flashpoint liquids as fuel (IMO, 2020c). IMO has covered this training requirements with model course 7.13 Basic Training for Masters, Officers, Ratings and Other Personnel on Ships Subject to the IGF Code and model course 7.14 Advanced Training for Masters, Officers, Ratings and Other Personnel on Ships Subject to The IGF Code. The model courses aim to meet mandatory minimum standards of competence for seafarers who are responsible to handle operations subject to IGF Code requirements. However, LNG bunkering operations may be conducted by truck to ship or terminal to ship operations. Training for road tanker operators and terminal staff is a must as well (SGMF, 2019). In addition to IMO model courses, providing minimum international standards for LNG marine fuel handling, SGMF, DNVGL, Wartsila and other industrial actors provide guidance for training and simulation activities that cover industrial requirements at highest level.

2.11. COMMERCIAL ASPECT OF LNG BUNKERING

LNG bunkering commercial aspect is vital for new supply chain development. LNG bunkering price, contracts, and quality of LNG bunker are discussed in the following sections.

2.11.1. LNG Bunkering Price for End-Users

LNG fuel prices, like natural gas pipeline sales, are usually gas-indexed or oil indexed. It means that they are connected with hubs such as TTF (Netherlands Title Transfer Facility), or Brent crude oil. LNG bunker price structure consist of two components: LNG market value and logistics. It can be defined as follows:

$$\text{LNG Price} = \text{Alpha} * \text{Index} + \text{Add-on}$$

Index is a gas benchmark such as TTF, Henry Hub (HH), the Platts LNG Japan Korea Marker or UK National Balance Point (NBP). Add-on is the logistics cost. LNG processes are usually expressed by energy content. They depend on the market and it's expressed as megawatt hour (MWh) or British thermal unit (MMBtu). If the price is taken as calorific value, it should be stated as either a gross calorific value (GCV), or a net calorific value (NCV).

Alpha in the formula represents a factor usually ranging between 1.03 and 1.15 and it's assumed to include the supplier's trade margin and the fuel cost resulted from boil-off gas. Add-on logistics cost could be more detailed for transparency. It includes terminal loading cost, port dues, distribution and service charge. In addition to these details, also currency of the gas indexed price is important as HH, TTF, NBP USE different currencies.

As the index value is LNG price and free from bunkering, LNG bunkering price is subject to logistics cost. Three important elements determine the final cost: The transport mode, the amount of LNG to be bunkered and the distance to the main terminal. There are three main different LNG bunkering delivery types, truck-to-ships (TTS), ship-to-ship (STS), pipeline-to-ship (PTS).

Bunker supply cost has two main parts: 1- price of the LNG marine fuel at the import hub, 2-infrastructure cost of storage and transhipment from a hub to the ship. Bunkering method has significant effect on the infrastructure cost. Table 11 shows overview of cost distribution according to supply mode. Investment cost includes LNG

bunkering equipment, bunkering vessel, license cost, safety measures, training and installation of quay in some cases. Operational costs include bunker vessel's operation costs and transshipment costs from import terminal (Faber *et al.*, 2015).

Table 11: Cost of LNG Bunkering per Bunkering Method

	Ship-to-ship bunkering	Truck-to-ship bunkering	LNG terminal to ship bunkering via pipeline	LNG terminal to ship bunkering via bunker vessel
Investment cost	LNG bunkering equipment	LNG bunkering equipment	LNG bunkering equipment	LNG bunkering equipment
	Bunkering vessel	Tank trucks including filling stations	Land based (storage) tanks	Bunkering vessels
	Licence cost/safety measures/Training of personnel	Licence cost/safety measures/Training of personnel	Licence cost/safety measures/Training of personnel	Licence cost/safety measures/Training of personnel
	Installation of quay (optional)	Installation of quay (optional)	Installation of quay (optional)	Installation of quay (optional)
				Land based (storage) tanks
Operational cost	Operational costs of bunker vessel	Operational costs of truck	Operational costs of pipeline	Operational costs of bunker vessel
	LNG terminal take-out fee Transshipment costs from import hub	LNG terminal take-out fee Transshipment costs from import hub	LNG terminal take-out fee Transshipment costs from import hub	LNG terminal take-out fee Transshipment costs from import hub

Source: (Faber et al., 2015)

Table 12 summarises investment and operating cost distribution of ship-to-ship scenario. Ship-to-ship option requires high capital expenditure as building a LNG

bunker vessel is highly costly. Operational expenditures are also much higher than truck option. However, ship-to-ship option provides flexibility for suppliers and bunker can be delivered either at port or anchorage area, in large quantity and much faster.

Table 12: Investment and Operating Cost Scenario for Ship-to Ship Option

Type of Investment	Unit	Price
Investment costs LNG bunkering ships	EUR	
1000 cbm		20 million
3000 cbm		28 million
4000 cbm		32 million
10000 cbm		41 million
Operational costs LNG bunkering ship	EUR/year	
1000 cbm		1,8 million
3000 cbm		2,4 million
4000 cbm		2,5 million
10000 cbm		3,2 million
Engineering services (documentation, supervision)	% of total investment cost	6
Transport cost of bunker vessel from LNG import harbour to receiving vessel	EUR/t HFO	530/t
Transshipment cost from import hub (per million m3 at 1% price surcharge)	EUR	2 million
LNG Terminal take-out fee	EUR	8/m3
Safety/wage technical personnel/evaporation LNG		Unknown

Source: (Faber *et al.*, 2015)

LNG bunker price for end user is subject to these costs associated with these investments and operational costs. Inevitably, high CAPEX requirement to be reflected to end users. Therefore, LNG bunker fuel advantage is subject to another variable in equation, LNG market price. Relation of LNG price and MGO or VLSFO prices are important criteria for LNG marine fuel option.

2.11.2. LNG Bunkering Contracts

Custody transfer occurs anytime when there is a change of ownership in the supply chain. Seller and buyer define the amount and quality of the products in order to determine accurate value for transaction. If the third party supplier takes place in logistics chain, distributor does not own the LNG, but has obligation to assure that LNG's quantity and quality remains within specifications(SGMF, 2019).

2.11.2.1. Quantity of LNG

Conventional marine fuels transactions are sold by volume and paid by mass. Unlike conventional fuels, LNG has different content which depends on the source of the natural gas. Table 13 shows two distinctive LNG sources from Indonesia and Australia. Although the same volume of LNG is transferred, there is a significant difference in energy content which is the vital consideration for any energy sources. If the LNG is to be used in road by trucks, the transaction still can be made according to volume and mass as the quantity is much smaller and always distributed from the same import terminal or liquefaction terminal by certain standards. However, for the marine fuel sources, as the ship may receive LNG from different regions with different standards, using energy content is inevitable (Koutsourakis, 2019).

Table 13: LNG as Volume, Mass and Energy

Location	Volume transferred m ³	LNG density kg/m ³	Mass transferred kg	Energy content MJ/Nm ³	Gas/Liquid Ratio Nm ³ / m ³	Energy Transferred 10 ⁶ MJ
Australia	1,000	467.35	467,350	45.32	562.46	25.490
Indonesia	1,000	431.22	431,220	41.00	581.47	23.840
Difference	-	7.7%	7.7%	9.5%	-3.4%	6.5%

Source: (Koutsourakis, 2019)

Quantity of LNG transferred is usually carried out by mass flow systems. In bulk LNG, it's also carried out by tank measurement before and after the operation by tank radar systems. In case vapour return line is connected for Boil-off Gas

management, two flows meter is connected in order to measure liquid LNG and gaseous BOG.

2.11.2.2. Quality of LNG

The second important parameter for LNG bunkering contracts is the quality of the LNG. LNG as marine fuel's environmental impact is subject to LNG composition and type of the engine. Three criteria are important for gas composition: Calorific Value, Methane Number and Wobbe Number (SGMF, 2019).

Calorific Value

Calorific value, in other words heat content is subject to hydrocarbons' carbon atoms. The more carbon atom gives out more heat per molecule during combustion compared with methane. LNG for industrial use is priced as Gross Calorific Value as it's a benefit taken for condensing water vapour formed during combustion. However, for marine fuel use it is sold as Net Calorific Value, heat of vaporisation of the water is subtracted. The difference is about 10% and it may be taken as constant to convert vice versa. However, calculation methods may change from country to country (SGMF, 2019).

Wobbe Number

It's a flow parameter and indicates the amount of heat flow through a burner nozzle at certain size in a certain period. Same Wobbe Number for different fuels meaning that the same amount of heat is delivered (SGMF, 2019)

Methane Number

Knock resistance of gaseous fuel is defined as Methane Number in Otto cycle engines. It's usually determined by test engine and a scale from 0 to 100. However, there are different methods to calculate methane number and may give different results for the same LNG source. Methane number varies according to the source of the LNG and the components as well. Table 14 shows how methane number is changing according to the calculation methods and the components (Koutsourakis, 2019).

Table 14: Methane Number Based on Different Calculation Method

Methane	87.4	90.4	99.8	70
Ethane	8.6	5.2	0.1	15
Propane	2.4	2.8	0	10
Butane	0.05	1.5	0.1	3.5
Heavier HC's	0.02	0.02	0	0.6
Nitrogen	0.35	0.07	0.1	0.9
Calculated Methane Number				
CARB	75	70	98	47
PrEN16726	72	70	97	50
AVL	75	70	98	51
PKI	75	70	98	51
MWM	72	70	98	50

Source: (Koutsourakis, 2019)

As methane number scaled from 0 to 100, there are certain ranges of MN that works effectively in different types of the engines. While North America sourced LNG's methane numbers in the 75 to 89 range, Asia Pacific sourced LNG usually has 68 to 89 Methane numbers. The expected minimum methane number is 70 for effective engine performance(SGMF, 2019).

Table 15: Impacts of Methane Number

	High MN	Low MN
Knocking resistance	Higher	Lower
Efficiency	Lower	Higher
NOx emissions	Lower	Higher
Loading performance	Slower	Faster
Energy content	Lower	Higher

Source: (Koutsourakis, 2019)

Table 15 shows how methane number has impact on knocking resistance, efficiency, NOx emissions, loading performance over engine. In addition, lower methane number contains higher energy content (Koutsourakis, 2019).

2.12. EXISTING LITERATURE IN LNG SUPPLY CHAIN, SMALL-SCALE LNG SUPPLY CHAIN AND LNG BUNKERING

Literature review is conducted to help to generate and refine research ideas and to evaluate and draw a picture of the current literature (Tranfield, Denyer and Smart, 2003). The principle of the performing literature review is to gain comprehensive overview for the LNG bunkering supply chain and to identify research gaps. LNG bunkering industrial practices are relatively new. Therefore, firstly LNG supply chain literature was reviewed parallel to motivation of the research which aims to propose model for LNG bunkering utilization, capacity, fleet composition scheduling and supply chain model.

There are numerous articles which aim to optimize LNG supply chain and network design. LNG transportation is mainly carried out by large LNG carriers, supply chain is usually modelled in maritime transportation context. The supply chain modelling is mainly classified under three problems: 1-Inventory routing problem, 2-location routing problem, 3-fleet size and vehicle routing problem. In some articles these problems are investigated as sub-problems or as integrated problems at the different stages -part of the overall objective. The methodologies utilized to solve these problems are usually mathematical modelling and simulation.

Inventory routing problem has been investigated in the literature with different perspectives but mathematical modelling has been utilized as the main method to solve the problem (Grønhaug and Christiansen, 2010, Rakke et al., 2011, Uggen et al., 2013, Goel et al., 2015, Cho et al., 2018). Location routing problem has been explored by mathematical modelling methodology by Gucma et al.(2018), Bittante et al (2017b), Zarei and Amin-Nasri (2019). Fleet sizing and vehicle routing problem was explored by simulation (Halvorsen-Weare et al., 2013, Park and Park, 2019) and mathematical modelling (Bittante et al., 2017c, Koza et al., 2017). On the other hand, some researchers utilized both mathematical modelling and simulation methods according to their specific problem (Otamendi and Doncel, 2012; Fagerholt et al., 2010; Zhang et al., 2019). Table 16 summarises LNG supply chain literature in maritime transportation context with problem definition, objective and employed methodology in order to solve a scientific problem.

Table 16: Literature Review of LNG Supply Chain Optimisation

Year	Author	Problem and Objective	Method
2008	Özelkan, D'Ambrosio and Teng	Optimizing liquefied natural gas terminal design for effective supply-chain operations, storage capacity, vessel docking capacity and throughput for LNG Terminal	Mixed integer programming model
2010	Grønhaug and Christiansen	SC optimization for LNG, Inventory Routing Problem, Maritime transportation, arc-flow and path flow problem design.	Mixed integer programming, LP relaxation
2010	Fagerholt et al.	Short-term routing and scheduling problem are solved with optimization based decision support systems along with Monte Carlo simulation as decision support in maritime transport.	Monte Carlo simulation and optimization.
2010	Fodstad et al.	Vessel routing and scheduling at tactical level with profit maximization taking into account entire LNG supply chain	Mixed Integer Programming
2010	Borraz-Sánchez	NG pipeline optimization	NLP, MINLP
2011	Rakke et al.	Inventory routing , maritime transportation LNG	Rolling horizon heuristic MIP
2012	Lee et al.	LNG receiving terminal cost optimization	Dynamic Simulation
2012	Otamendi and Doncel	LNG Supply chain optimization including ships' arrival, regasification, transportation and distribution.	Simulation optimization, discrete-event methods
2012	Goel et al.	LNG supply chain, inventory routing problem, ship scheduling.	Mixed Integer Programming, arc-flow formulation.
2013	Uggen et al.	Maritime Inventory Routing Problem in LNG supply chain	MILP, heuristic approach, fixed and relax time decomposition
2013	Halvorsen-Weare et al.	LNG maritime transportation, ship routing and scheduling problem under uncertainty.	Simulation, Math programming
2013	Berle et al.	LNG Maritime transportation, taking into account risk assessment and inventory routing problem.	Monte Carlo simulation, heuristic based planning
2013	Jankowski and Przywarty	Defining LNG Supply Chain stakeholders in South Baltic Sea Region	Review

Table 16: Literature Review of LNG Supply Chain Optimisation Continue

Year	Author	Problem and Objective	Method
2015a	Jokinen et al.	Small scale LNG SC optimization, includes maritime inventory routing problem and capacitated vehicle routing problem.	Mixed Integer Linear Programming
2015	Goel et al.	LNG inventory routing problem and scheduling.	Discrete optimization MIP, Constraint programming
2015	Aymelek et al.	Network design problem, LNG Bunkering network optimization for liner shipping.	Mathematical Modelling
2015	Azadeh et al.	Natural Gas Supply Chain modelling in well, refinery, compressor station, city gas gate station and customers level.	Multi period fuzzy linear programming
2016	Artana et al.	Optimization of LNG Supply Chain problem with decision variables such as plant capacity, vessel size, number of vessels, round trips and regasification capacity of the receiving terminal.	AHP, MILP
2016	Tanguy and Napoli	Maritime network modelling, maritime supply chain of energy.	Graph Theory and Network modelling
2016	Mutlu et al.	Annual delivery planning problem in LNG supply chain, large-scale optimization	Mixed Integer Programming
2016	Androulaki and Psarras	Natural Gas supply chain alternatives for Greece	Math Prog, Simulation, Expert view
2016	Bittante et al.	LNG SC in the Baltic Region, location routing problem, fleet size and mix vehicle routing problem.	Mixed Integer Linear Programming
2016	Schneider and Vis	Maritime Location Decision for LNG Bunkering, maritime flow capturing facility location model	Math Modelling
2016	Al-Haidous et al.	LNG annual delivery plan, maritime transportation,	Mixed Integer Programming, Arc-flow model
2017	Andersson et al.	LNG Annual delivery program problem	Mixed Integer Programming
2017a	Li et al.	Vessel Routing problem, coordination of inland waterways and large ports.	Constraint Programming, Benders decomposition
2017	Geng et al.	Maritime transportation risk, LNG importation portfolio, political risk and emergency management.	Non-dominated sorting genetic algorithm-II

Table 16: Literature Review of LNG Supply Chain Optimisation Continue

Year	Author	Problem and Objective	Method
2017	Shaikh et al.	Natural gas import scheme for China, energy security, LNG and piping gas.	Mathematical Programming
2017	Koza et al.	Maritime transportation, tanker fleet sizing problem, LNG as fuel in liner shipping.	Mixed Integer Programming
2017	Zhang et al.	LNG importing optimization problem. LNG Import Strategy taking into account the cost, the country risk, shipping risk.	Multi objective Programming, Simulated Annealing Algorithm, software implementation
2017a	Bittante et al.	Optimal design small-scale LNG supply chain, two dimensional spatial problem includes two-echelon location routing problem. Taking into account LNG deliveries to satellite terminals and truck deliveries to customers.	Mixed Integer Linear Programming
2017	Bittante et al.	Multi-period optimization for LNG supply chain, vehicle routing problem, fleet-size and mix-vehicle routing problem.	Mixed Integer Linear Programming
2017	Kahveci	LNG Inventory routing problem,	Mixed Integer Linear Programming
2018a	Bittante et al.	Small scale LNG SC Optimization, strategic maritime transportation problem includes fleet size and mix vehicle routing problem.	Mixed Integer Linear Programming
2018	Ahn	Optimisation of small-scale LNG SC in Spain, truck distribution.	Mixed Integer Linear Programming, Network optimization, Regression
2018	Strantzali et al.	Small-scale LNG supply, electric production in Greece.	Multicriteria analysis, PROMETHEE
2018	Gucma et al.	LNG Bunkering distribution, location routing problem.	Mathematical Programming
2018	Paulauskas et al.	LNG Bunkering Station Location Optimization, optimal bunkering network creation problem.	Graph Theory
2018	Deluster et al.	Small-scale LNG supply chain in Europe, two-echelon capacitated location routing problem.	Mixed Integer Programming
2018	Cho et al.	Maritime transportation, LNG Inventory Routing Problem under uncertainty, weather conditions	Two stage, Stochastic mixed integer programming

Table 16: Literature Review of LNG Supply Chain Optimisation Continue

Year	Author	Problem and Objective	Method
2018a	Mikolajková et al.	Optimal fuel distribution network, network layout, gas quantities to be delivered to customers by pipeline, truck, storage locations and sizes.	Mixed Integer Linear Programming
2018	Msakni and Haouari	Maritime transportation, LNG Supply chain, short-term delivery problem	Mixed integer programming, Column generation, heuristic
2019	Park and Park	LNG Bunkering Terminal facility, TTS-STS bunker deliveries estimation for 2025 and 2030.	Simulation Modelling
2019	Kusumaningtyas	Determining optimal locations for LNG bunkering, facility location and inventory problem.	Mathematical programming, deterministic optimisation, robust optimization
2019	Lu et al.	Maritime transport, Location Selection of an LNG bunkering port in Korea	Consistent Fuzzy Preference Relation , Interview
2019	Zarei and Amin-Naseri	Integrated natural gas supply chain optimization, location allocation and capacity expansion problem.	Mixed Integer Linear Programming
2019	Zhang et al.	Optimal Design and operation for supply chain systems includes transportation, storage and processing.	Multi-simulation MILP model based on Monte Carlo sampling
2019	Mikolajková-Alifov et al.	Optimal Gas supply for customers by pipeline, trucks.	Mixed Integer Linear Programming

Source: Author

LNG supply chain has different dynamics compared to small/mid scale LNG supply chain as well as LNG bunkering. Therefore, as the motivation of the study is LNG bunkering supply chain modelling, literature was reviewed more specifically in this framework. For this purpose, literature review was conducted through Dokuz Eylul University Library Search Engine that scans 50 data base which include international and national data sources such as Web of Science, ScienceDirect, EbscoHost, Scopus, Springer and Ulakbim. Advanced search option was used in Boolean mode. Boolean logic describes relationships between terms functioned by ‘and’, ‘or’ and ‘not’ (EBSCO, 2019). The review was not restricted with ‘available in collection’ option and ‘adopt to equivalent topics’ box was clicked. The search

timeline was restricted from January 2008 till December 2019. The first literature was searched by ‘LNG Bunkering’ keywords in order to gain general insight to this relatively new topic. Then search was conducted as ‘LNG fuelled Ship’ as it indicates same issue with shipowner perspectives rather than supplier or port approach. As the main purpose is to investigate LNG Bunkering supply chain, the search was conducted with ‘Small/Mid-Scale Supply Chain’ key words. It was found that there is only limited number of researches carried out in this field. The number of the related articles is given in Table 17.

Table 17: Key Words and Results

Key Words	Number of Related Documents	Journal Articles/ Proceeding Papers
LNG Bunkering	297	76
LNG Ship Fuel or Marine Fuel or Bunkering	545	184
LNG Bunkering + Supply Chain	9	5
Small Scale LNG + Supply Chain	17	8
Medium Scale LNG + Supply Chain	1	1

Source: Author

LNG bunkering supply chain problem is a relatively new subject in the literature. LNG fuel option for shipping has been discussed with different perspectives in the literature. Port operation side is also investigated by different research. However, entire network design of LNG bunkering supply chain with different stakeholders’ perspective is very limited.

LNG bunkering operation brings ship and port dynamics side by side. The same perspective is observed within the literature review. Some studies propose LNG bunkering handling terminal or jetty design alternatives (Yun et al., 2015; Fan et al., 2018; Kim et al., 2018a; Lee et al., 2018; Wang, Ji and Yun, 2018), some others operational efficiency (Ekanem Attah and Bucknall, 2015; Zhenkang et al., 2015; Perera and Mo, 2016). Dual-fuel engines, gas leakage and ‘Boil-off Gas’ are crucial aspects of LNG as ship fuel and revealed in the literature accordingly (El-Gohary, 2012; Liang, 2012; Fu et al., 2016; Ryu et al., 2016; Mrzljak et al., 2017; Grotle and Æsøy, 2018; Kim et al., 2018b, 2019; Shao, Lee and Kang, 2019; Jeong et al., 2019; Roh et al., 2019).

Another important factor has been seen as safety of LNG handling for bunkering, where safety zones, simultaneous operations, collision risk, gas leakage, onboard safety systems and hazardous consequences are discussed (Lee, Seo and Chang, 2015; Pagonis et al., 2016; Jeong et al., 2017; Sun, Guo and Pareek, 2017; Jeong et al., 2018; Jeong, Suk Lee and Zhou, 2017; Junhao et al., 2017; Li et al., 2017; Choi et al., 2018; Park et al., 2018; Stokes et al., 2018).

Regulatory discussions are relatively fewer than other perspectives (Wang and Notteboom, 2015; Xu et al., 2015, 2017; Wan et al., 2018). Economic framework and demand is widely discussed, along with comparative analyses of other alternative fuels evaluating through different methods and variables (Soundararajan and Han, 2014; Moreno-Gutiérrez et al., 2015; Peksen, 2015; Aronietis et al., 2016; Abadie et al., 2017; Eise Fokkema et al., 2017; Lindstad et al., 2017; Yoo, 2017; Abadie and Goicoechea, 2019). However, most articles were published regarding LNG as fuel concerns air pollution, GHG, emission control, life cycle assessment, technical, economical assessment (Elgohary et al., 2015; Moreno-Gutiérrez et al., 2015; Thomson et al., 2015; Ling-Chin and Roskilly, 2016; Bouman et al., 2017; Y. Zhang et al., 2017; Ge and Wang, 2017; Lindstad et al., 2017; Gilbert et al., 2018; Horvath et al., 2018; Feenstra et al., 2019).

Some articles bring broader approaches to LNG bunkering. Wang & Notteboom, (2014) carry out systematic review of present reports, papers, articles, presentations and it provides a holistic approach to the challenges of LNG fuel propulsion. Another study of Wang & Notteboom, (2015c) explore the LNG bunkering development with port perspective, however the study is limited with only North Europe ports within ECA area.

Only few articles in literature investigate supply chain viewpoint of LNG bunkering. Aymelek et al. (2015), covers up challenges of LNG bunkering and proposes a network model for deep sea liner shipping. Jafarzadeh et al. (2017), system engineering approach explores technical aspects of LNG fuelled systems, significantly contributes to the decision making process while taking into account operation, safety and economic perspective. However, the study is limited with fishing vessels and Norway case. Calderón et al. (2016) explores the LNG bunkering development by port perspective and investigate safety standards, logistics and financial aspects. Gucma et

al(Gucma, Båk and Chłopińska, 2019) propose a model of LNG distribution concept based on location-routing problem (LRP).

Current literature related with Small/Mid Scale LNG and LNG Bunkering supply chain is very limited. Few articles have been explored.

Jokinen et al (2015) presents small-scale LNG supply chain optimization at Finland coasts. The study has two dimensions: maritime routing problem and capacitated vehicle routing problem. As its objective is to minimize the cost, the research provides optimum solution for satellite port location and fleet size. The research also explores feasibility under different LNG price scenarios while taking into account ship and truck utilization. It was assumed that current FO demand will be replaced by LNG. The problem was solved by MILP formulation with thirty days' time horizon.

Artana et al (2016) investigates small-scale supply chain problem in Indonesia. The first objective is to find the best location for satellite terminal that is sorted by AHP method -taking into account four qualitative criteria and fourteen sub-criteria. The second step, the objective function was set as minimizing cost while considering storage tank capacity, vessels size, number of trips, receiving and regasification capacity by Gradually Reduced Gradient Method.

Strantzali et al (2017) presents small-scale LNG supply chain for four populated islands electricity production that power plants run by LNG. The authors developed an Additive Value Model tool to examine small-scale LNG supply alternatives using PROMETHEE method that asses pairwise comparison and provides ranking of examined alternatives. Current electricity demand was taken as reference to calculate LNG demand at each island.

Bittante et al. (2017a) propose a model for small-scale LNG supply chain optimization at tactical and strategic aspect. The model solves LNG distribution problem including convenient ports, size of the satellite terminals, optimal fleet and routing for maritime transport as well as truck deployment in order to compensate inland LNG demand. Bittante et al. (2017b) model includes multi period decision support at strategic and tactical aspect. The objective function was formulated to minimize simultaneously investment and operational costs. The model proposes optimum location of satellite terminals, number and size of the ships to be deployed,

number of trucks per port, maritime routing and road connections. However, some operational factors such as boil-off gas, terminal time windows have not been included in the model.

Bittante et al. (2018) aims to propose solution at strategic level. The model presents optimal solution for size and number of fleet, maritime routes, the number of the voyages for each ship while taking into account uncertainty of demand, price of LNG at Caribbean Region.

Ahn (2018), proposes a model for Spain small scale LNG supply chain. MILP method was used to minimize the total cost. Regression model was used to forecast small-scale LNG demand and fuel price. The model provides optimal capacity for truck utilization while taking into account seasonality.

It was observed that all articles -except Strantzali et al. (2017), used mathematical modelling in particular Mixed Linear Integer Programming (MILP), only Artana et al (2016) solves the problem with non-linear formulation and uses Generalized Reduced Gradient (GRG). Artana et al. (2016) study is also differentiated from the other articles as they used AHP method to determine the best locations for satellite terminals. Jokinen et al.'s (2015) approach claims that incorporating with 'shipping strategy' makes model free from scheduling variables and keeps it more simple to solve. Bittante et al. (2016), (2017a), (2017b), Jokinen et al (2015), and Ahn (2018) took into account both sea and shore side of the supply chains, on the other hand, Bittante (2018), Artana (2016), Strantzali (2017) just optimized maritime transportation. All the researches were based on case study that propose a model for local small-scale supply chain problems. In all papers, the objective functions were formulated to calculate minimum cost. There are limited number of the study in small-scale LNG supply chain. Besides, five articles out of eight belong to the same working group. The problems were solved with deterministic approach and MILP formulation. MILP enables to solve realistic problems within reasonable time period if some operational issues such as boil-off loss, scheduling are neglected (Bittante et al, 2017b). Hoff et al (2010) states that in larger scale maritime transportation problems were solved by heuristic approach.

The findings are summarized in Table 18. The related literature was narrowed to nine articles. Problem and objectives of the researches are highlighted and methodologies that are used to solve scientific problems are defined.

Table 18: Summary of Mid/Small Scale Supply Chain Literature

Year	Author	Problem and Objective	Methodology
2015	Jokinen, Pettersson, & Saxén	Regional supply from a large-scale regasification terminal to end-users can be carried out by a combination of ship and truck transports utilizing satellite terminals along a coastline. Minimizing fuel procurement cost. Finland case study.	Mathematical modelling, MILP
2016	Bittante, Jokinen, Krooks, Pettersson, & Saxén	Gulf of Bothnia LNG supply chain problem with deterministic approach. It solves multiple vehicles, multiple visit problem at the tactical and strategic level.	Mathematical modelling, MILP
2016	Artana, Putranta, Arief, & Madeariana	Selecting best location for satellite LNG terminal and LNG routing from Batam to West Kalimantan, and minimizing investment cost for supply chain.	AHP, Mathematical Modelling, Gradually Reduced Gradient Method
2017a	Bittante, Pettersson, & Saxén	Designing supply chain from supply terminal to satellite terminal at coast of Finland and Sweden by ship and truck. Objective is to minimize overall cost taking into account operational cost, investment and fuel price.	Mathematical modelling, MILP
2017b	Bittante A., Jokinen, Krooks, Pettersson, & Saxén	Regional supply of LNG to satellite terminals across Bothnia Gulf including by ship and trucks. Demand was fixed at certain time horizon at receiving side and split delivery was allowed. Determining location of satellite terminals, fleet capacity and routing were optimized with minimizing fuel operation and investment cost. Multi-period formulation was used.	Mathematical modelling, MILP
2018	Bittante A., Pettersson, & Saxén	Fleet Size and Mix Vehicle Problem- (FSMVR), multiple depots and split load was performed. Minimizing fuel procurement cost at Caribbean Region.	Mathematical modelling, MILP

Table 18: Summary of Mid/Small Scale Supply Chain Literature Continue

Year	Author	Problem and Objective	Methodology
2018	Ahn S.	Spain small-scale LNG supply chain optimization, seasonality taken into account, objective is to minimization of total cost.	Mathematical modelling, MILP, Regression, Forecasting
2018	Strantzali, Aravossis, Livanos, & Chrysanthopoulos	Selecting best supply schedule from import terminal to Greek Island, covering annual fuel demands.	Multicriteria analysis, additive value model, PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation), Simos Approach
2018	Deluster et al.	Small-scale LNG supply chain in Europe, two-echelon capacitated location routing problem.	Mixed Integer Programming

Source: Author

LNG Bunkering at mid/small scale LNG capacity has different dynamics than large scale LNG supply chain, it requires extended utilization, capacity control, infrastructure and high capital expenditure for investment. Mid/Small scale LNG supply chain has very limited attraction from researchers. Only limited numbers of articles are available on this topic. It is observed that mathematical modelling has been used in all articles to sort out the problem. Mixed Integer Linear Programming is the main modelling method for small-scale supply chain problems.

Planning horizon in maritime transportation literature is classified in three levels: Strategic, Tactical and Operational problems (Christiansen et al., 2007). The problems under strategic planning horizon are related with the network and transportation systems design, fleet size, type, number of the vessels and capacity, port-terminal location, size and design, and shipping market selection. Tactical problems involve adjustment of fleet size and capacity, fleet deployment for specific routes, ship routing and scheduling, berth and crane scheduling, ship management, and container management. Operational level problems include speed selection, ship loading/discharging and weather routing (Christiansen et al., 2007).

Strategic long-term decisions usually involve some tactical and operational information, so that, three category overlaps on many occasions. Designing optimum fleet is one of the strategic decisions for shipowners or charterers. It includes the

number, size and capacity of the ships. Minimizing variable and fixed costs of fleet size is the objective function of a strategic problem; however, it involves routing and scheduling decisions that contain tactical and operational level planning as well.

There are many uncertain factors in maritime industry; derived demand from economic activities, time lag between demand and corresponding available supply and operational uncertainties. Therefore, it's important to consider robustness in optimization models to encourage trust. Uncertainty and robustness are handled with different approaches such as simulation, re-optimization for different scenarios, deterministic models that are used penalties and stochastic optimization models. As it was seen in small scale LNG supply chain literature, deterministic models with different scenarios are the most commonly used solution methods.

2.13. SUMMARY

In this chapter small-scale LNG and LNG bunkering literature reviewed through articles and sectoral reports. LNG as marine fuel is a strong alternative to comply with emission control regulations which are implemented by the IMO. LNG completely removes SOx and PM. It also provides significant reduction on NOx and reduce CO2 emission about 20%. The ship size and terminal storage capacity below 10000 cbm is defined as small-scale LNG. Using LNG as transportation fuel requires extended steps from larger LNG supply chain and its characteristics are different from conventional LNG supply chain. Handling the LNG at small-scale come up with some technical constraints, operational difficulties, safety issues and new commercial approaches. Human element and regulatory framework are other dimensions need to be sorted for LNG bunkering development. Supply chain for small-scale LNG has not been settled across the world, yet. In the literature, studies are limited in terms of small-scale LNG supply chain and LNG bunkering as well. As this research aim to propose a model for LNG bunkering in Turkey, Chapter III has been utilised to specifically investigate Turkey's current energy overview as well as natural gas and LNG structure.

CHAPTER III

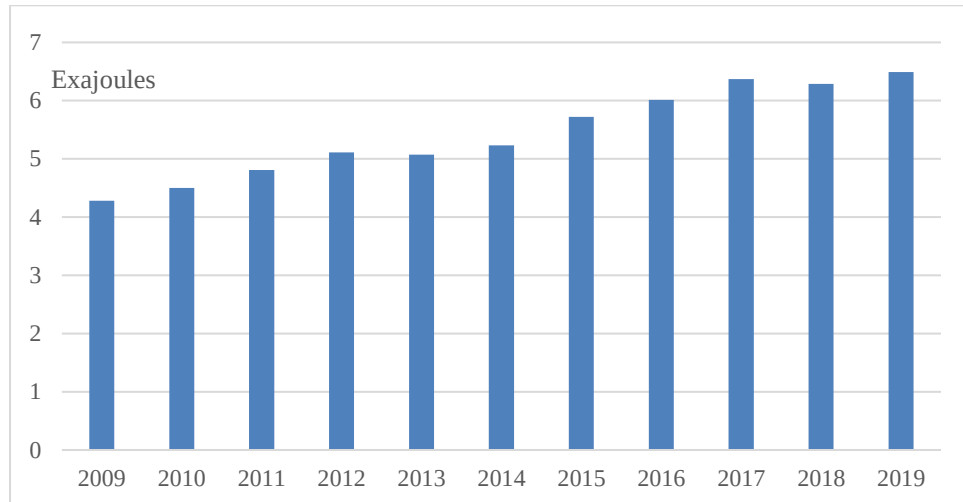
NATURAL GAS AND LNG IN TURKEY

3.1. TURKEY'S ENERGY OVERVIEW

Turkey's growing economic trend requires sustainable energy sources. Parallel to economic and population growth, 5.5% annual increase has been observed in electricity demand since 2002 (Toklu and Gerengi, 2019). As the energy dependent country, growing energy demand creates significant challenge for Turkey (Erşen and Çelikpala, 2019). Growth in population, urbanisation, industrialisation and economy is critical for sustainable projection (Kırlı and Fahrioglu, 2019). Availability of resources at affordable price and sustainability provide ground for Turkey's energy security (Bilgin, 2015; Öge, 2019). Sustainable energy security is the main concern for Turkey so making strategic plans for energy policies priorities this as the first objective (MENR, 2019a). Therefore, diversification of supply is critical for Turkey's energy policies (Öge, 2019).

Turkey's energy mix is dominated by fossil fuels and its share in energy supply is approximately 85% (Kırlı and Fahrioglu, 2019; Sigma, 2020). Due to lack of fossil fuel sources, Turkey is a highly import-dependent country for energy which involves gas, oil, and coal 99.6%, 94.32%, 97.3% respectively. This dependency has significant effect on country's trade deficit. Energy imports in 2019 was 41.18 billion dollars and it takes 20,3% of the country's total import expenditure (Sigma, 2020). Turkey's energy consumption increased more than 50% from 100 million tonnes oil equivalent to 153 million tonnes oil equivalent between 2008 and 2018 (BP, 2019). As it is indicated in Figure 51, at the end of the 2019, consumption reached to 6.49 exajoule, following gradual increases over the years.

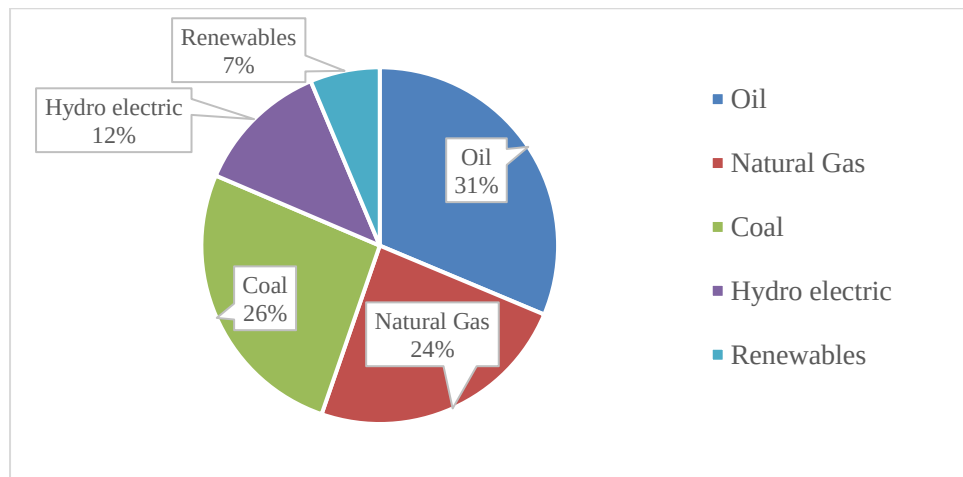
Figure 51: Turkey's Energy Consumption trend as Exajoules



Source: Author, compiled from (BP, 2020c)

Oil takes the first place as primary energy sources among other alternatives with 31,28%. The second energy source is coal and takes 26%. Natural gas's share is 24% and other energy sources, renewables and hydro-electric followed natural gas with 12% and 7% respectively. Figure 52 summarises Turkey's primary energy sources distribution in 2019.

Figure 52: Turkey's Primary Energy Sources by 2019

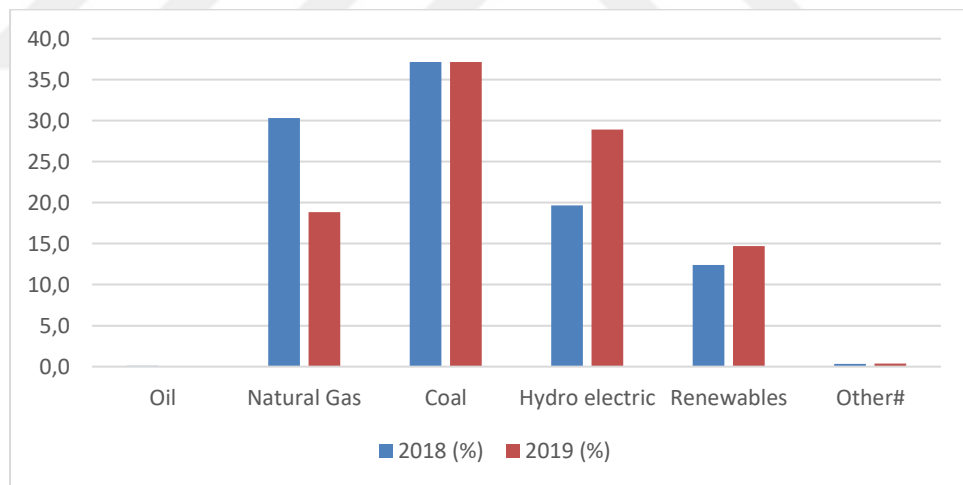


Source: Author, compiled from (BP, 2020c)

Natural gas takes a critical part in Turkey's energy strategy. It's share in power generation is 24%, despite significant decrease from 2018 to 2019 (Figure 53). In

addition to power generation; heating and industrial use of the natural gas increased rapidly and now it is accounted for more consumption than power generation (Topuz, 2019). Oil became primary energy sources according to 2019 data. Oil production is very limited in Turkey and it is imported by pipeline and maritime transport (Toklu and Gerengi, 2019). Coal is the second prime energy source according to 2019 data. It's mainly used for electric generations and takes the highest percentage (BP, 2020c). Industrial sectors such as cement, iron and steel mainly use coal as energy source (Toklu and Gerengi, 2019). Offshore and onshore wind power, and solar energy sources have potential to grow up. Subject to investments and related photovoltaics (PV) panels and wind turbines are incentivized for domestic production (Toklu and Gerengi, 2019). Renewable energy-based power generation increased 19.4% in 2019 and reached to 45.3 terawatt-hours (BP, 2020). From hydropower perspective, Turkey is using only 30% of its potential mainly that could be utilized by small-scale hydro projects (Kaygusuz, 2019).

Figure 53: Power Generation by Sources



Source: : Author, compiled from (BP, 2020c)

Turkey's energy demand is an urgent issue and diversification is also needed for energy security. Turkey's energy generation has been supported to use domestic sources in order to reduce natural gas dependency (Rzayeva, 2018). Nuclear, coal and renewable energy sources get support in order to sustain shift from hydro-carbon based energy mixed to more diversified structure (Bilgin, 2015). Feed-in tariff and capacity

mechanism have been put in service for power plants using domestic coal (Toklu and Gerengi, 2019) . As legislation changed in February 2020, Renewable Energy Resource Area (RERA) investments have been encouraged by ministry under the support mechanism (CME, 2020). As the part of the diversification in energy source; two nuclear power plants are under construction in Turkey; Akkuyu and Sinop, with 35 and 34 billion kWh capacities respectively (MENR, 2016).

Turkey, despite the energy dependency, aim to become an energy hub between Europe and Asia (MENR, 2019a). This ambition is supported by Turkey's geographical position which located between energy sources in Middle East, Central Asia, Russian and energy consumers in Europe. World's proven 72% of oil and gas reserves are found in neighbourhood of Turkey -Russia, Middle East, Caspian and as well as Eastern Mediterranean. Moreover, Istanbul and Çanakkale Straits through which approximately 3% of global oil supply is shipped, brings Turkey to a key geopolitical role (Erşen and Çelikpala, 2019).

Bilgin (2015) argues that geopolitical advantage is not the only base for Turkey's energy strategy, rather, market characteristics, economic concerns, and trade opportunities are important motivators for Turkey's strategy (Bilgin, 2015). Two important frameworks of Turkey's energy strategy are to encourage private sector involvement and market liberalisation (Bilgin, 2015; Rzaeva, 2018; Erşen and Çelikpala, 2019). Turkey has LNG import terminals, FSRUs, and numerous pipelines and interconnections between Asia and Europe as gas infrastructure (Topuz, 2019). However, Öge (2019) argues that Turkey has not benefitted from its geopolitical position in terms of pipeline transit due to contractual obligations. Turkey's current natural gas infrastructure and market dynamics are discussed in following sections.

3.2. NATURAL GAS AND LNG INFRASTRUCTURE

Natural gas infrastructure has been developed by BOTAS (Petroleum Pipeline Company) which was established in August 1974 for crude oil transportation through pipeline. In 1987, BOTAS started natural gas trade and transportation. It was aimed to meet increasing energy demand of Turkey and to control air pollution in the cities. BOTAS was the only gas supplier in Turkey till 2007. By 2017, BOTAS had supplied

approximately 80% of the natural gas consumption in Turkey. National gas grid reached to 15907 km by 2018. Since 2007, BOTAS has also been giving services for private companies.

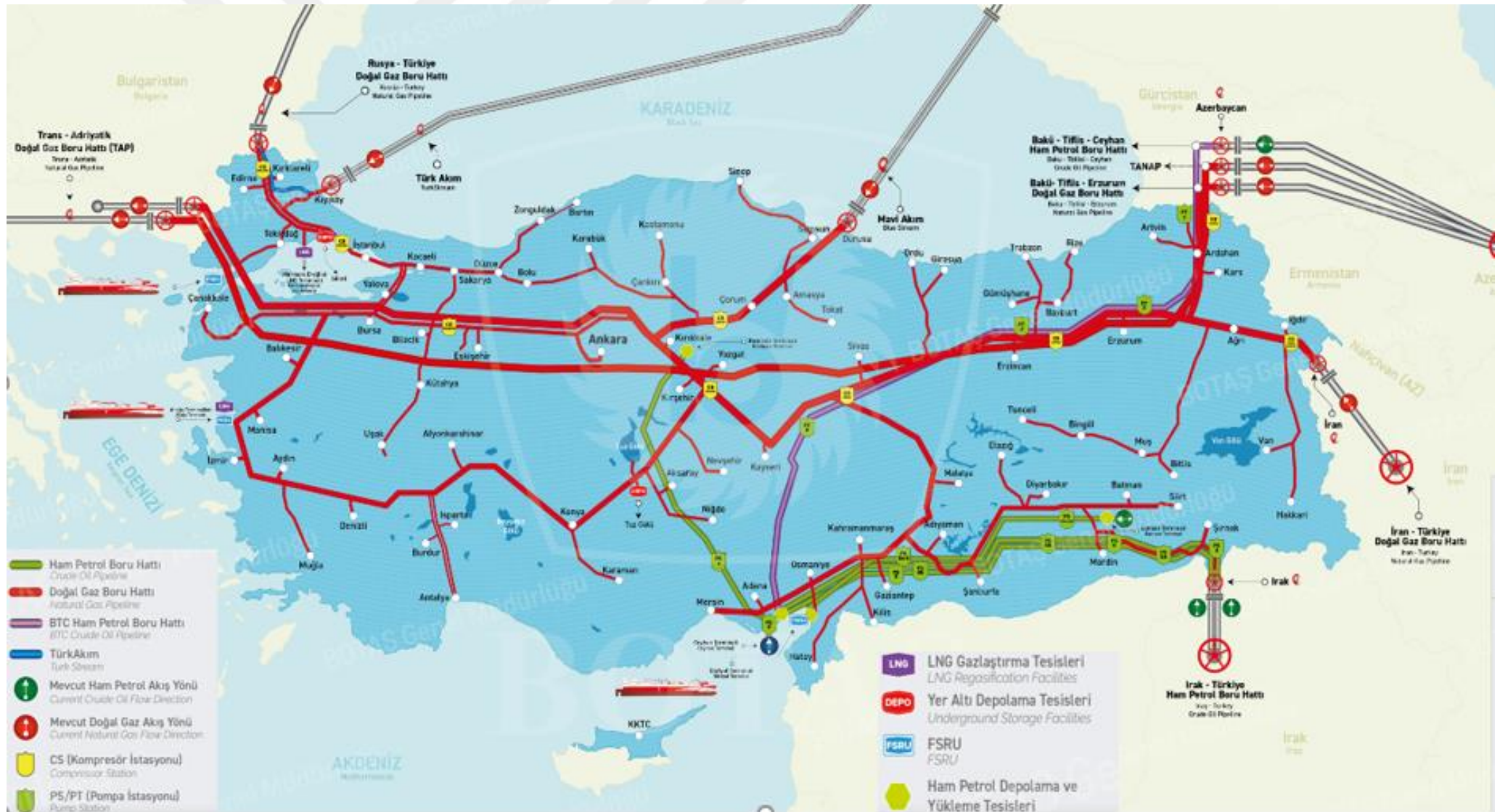
Turkey has significant international and national natural gas network. International pipelines are Russia-Turkey West Line, Blue Stream, Eastern Anatolia Transmission Line (Iran-Turkey), Baku-Tblisi-Erzurum Pipeline, Turkey-Greece Gas Interconnection (ITG), Trans-Anatolia (TANAP), and Turkstream Gas Pipeline (MENR, no date). There are also planned and existing natural gas storage projects in Kuzey Marmara and Tuz Gölü. Natural Gas grid is also supported by LNG import terminals and FSRUs in Marmara Ereğlisi BOTAS, Ege Gaz Aliğa, FSRU Aliğa and FSRU Dortyol (MENR, 2020a). Turkey's natural gas and oil pipeline are illustrated in Figure 54.

3.2.1. Marmara Ereğlisi Import Terminal

Marmara Ereğlisi LNG Terminal is located in the north of Marmara Sea. Construction of Marmara Ereğlisi LNG import terminal was started in 1989 and put into service in 1994. There are four functions of the terminal: 1- Receiving and unloading of the LNG carriers, 2- Storage, 2- Regasification and sending-out the gas to national grid, 4- Loading LNG to trucks. The terminal has a 37 million Sm³/day gasification capacity (BOTAS, 2020b).

Marmara Ereğlisi Import Terminal primarily receives LNG from Algerian Company Sonatrach and Nigerian LNLNG company as part of long-term import agreements. Terminal also receives LNG from spot markets. Imported LNG is regasified and distributed through national grid.

Figure 54: Natural Gas and Oil Pipelines in Turkey



Source: (BOTAS, 2020a)

3.2.1.1. LNG Tanks

The terminal consists of three LNG storage tanks and each has a capacity of 85000cbm. Tank type is double containment, the inner tank is made up for 9% nickel steel and the outer tank is carbon steel. The gap between the inner and the outer tank is filled with perlite expanded bead insulation. Each tank is surrounded by concrete bund walls. Tank design pressure is 150mbar (gauge) and maximum working pressure is 125 mbar (gauge) (BOTAS, 2019)

3.2.1.2. LNG Pumps

There are two types of pump: Low pressure and High pressure. Each of the tanks has 300cbm/h capacity, well mounted low pressure pumps at 12.8barg rating point. High pressure pumps are centrifugal type and they have 330cbm/h capacity at rating point 108.63barg. High pressure pumps are employed to transfer LNG from re-condenser to the vaporizers. In order to meet pipeline pressure requirements, these high pressure pumps are utilized to increase the LNG pressure to 82 barg (BOTAS, 2019).

3.2.1.3. Vaporizers

The terminal is equipped with five open rack type heat exchangers, four of them have design capacity of 228300 Nm³/h and one 342250 Nm³/h. LNG is vaporized through circulation of the sea water that is discharged from the eight warm sea water pumps. There are also six sea water pumps as the jetty-shore side of the terminal as back-up.

There are also four submerged combustion type vaporizers (SMV) each of has 124600 Nm³/h capacity. These pumps provide supportive vaporisation capacity when sea water vaporizers are out of order during maintenance and in case of low sea water temperature that cause shortfall in vaporisation capacity. These pumps can also be run simultaneously with sea water vaporisers to increase send-out capacity to 667000 Nm³/h (BOTAS, 2019).

3.2.1.4. Compressors and Re-condenser

In order to handle boil-off gas, compressors are employed. Two boil-off gas compressors with capacity of 7130Nm³/h, two ship unloading compressors at 18300 Nm³/h capacity. In addition to these compressors there are two pipeline compressors with capacity of 7130 and 9600 Nm³/h. These are utilized to take suction gas from BOG Compressors discharge 10.9Bbag and compressing it around 78barg to discharge 6'' line. Moreover, one blower with a capacity of 22360 Nm³/h is in the system in order to provide returning of the gas during discharging of the ship(BOTAS, 2019). There is one re-condenser unit in order to re-condense the BOG generated in the storage tanks during regular send-out and ship discharging operation(BOTAS, 2019). Some technical specifications of the terminal are summarised in Table 19.

Table 19: Terminal Specifications

Max Loaded Displacement	180000 t
Maximum LOA	440m
Maximum Draft	13m
Maximum Beam	No limitation
Flow Rate	3633 cbm LNG/h max
Specific Gravity	0.42 to 0.50
Temperature	-164deg C / -159degC
Pressure	5 barg
Return Gas Flow Rate	29800 Nm ³ /h max
Return Gas Temperature	-157 deg C to + 25 deg C
Return Gas Pressure	0 to 0.8 barg (operation)/ 12barg (design)

Source: (BOTAS, 2019)

2.2.1.5. Terminal's Marine Operations

The terminal is designed to handle the vessels from 40000cbm to 210000-270000bm Q-Flex, Q-Max LNG carriers. Peak flowrate of the terminals is 1370000 Nm³/h (12 billion Nm³/year). There are three docks mounted with ball bearing swivel

joints marine unloading arms (16'') and one vapour return line (12'') on the terminal. Terminal is equipped with 12'',14'',16'' reducers.

3.2.2. EGE GAZ LNG Terminal

EGEGAZ LNG Terminal is located in Aliğa/Izmir on Aegean Sea Coast and founded in 1998 under Çolakoglu Group. It's the first private LNG terminal and the first LNG tanker called in 2006. There are two full containment LNG tanks and each of them has 140000cbm capacity. Regasification and send-out capacity is 1660000 Sm³/h. The terminal is able to handle LNG vessels up to Q-Max size with unloading capacity 11000 m³/h. The terminal regasifies the LNG and sends it out to national grid and also directly loads to trucks as LNG (EgeGaz, 2020).

3.2.3. Floating Storage Regasification Unit (FSRU)

There are two FSRU Unit in service at the moment, in Aliğa and Dört Yol. However, new FSRU project has been planned for Saros Gulf (Tpic, 2019). Floating Storage & Regasification Unit has ability to receive LNG from LNG carriers through ship-to-ship operations, store in their tanks and regasifies the liquid natural gas by utilizing vaporizer units. Regasified natural gas is sent out to the national grid.

3.2.3.1. ETKI Aliğa FSRU

Etki LNG Terminal is a deep-water marine terminal, located in Aliğa. The first FSRU of Turkey is moored in Aliğa Etki LNG Terminal. FSRU Neptune in 2017 with capacity of 145130 cbm and was able to receive Q-Flex LNG carriers up to 217000cbm. In 2019, FSRU Neptune was replaced by FSRU Turquoise, - which has 166631 cbm capacity (ETKI, 2020). The vessel is moored at terminal jetty with vessel's conventional mooring systems. The design of mooring arrangement allows two vessels to be moored in double-banked configuration. Terminal specifications are summarised in Table 20.

Table 20: ETKI LNG Terminal Jetty

Max Loaded Displacement	142995 t Q-Flex
Maximum Allowable LOA	345m
Length of Berth	415m
Minimum Water Depth	17m
Max Allowable Draft	14m
Salinity	1022 -1025
Minimum Under Keel Clearance	3m

Source: (ETKI, 2020)

FSRU – Turquoise P technical specifications are summarised in Table 21. The vessel was built in Hyundai and owned by Kalyon 50%, Kolin 30% and Onal 20%.

Table 21: FSRU – TURQUOISE P

Ship Type	FSRU
Year Built	2019
Containment system	Membrane Type - GTT MARK III
Cargo capacity	166 631 m ³
Regas capacity	750 mmscf/d
Classification	BV
Flag	PANAMA
Engine	Wärtsila-Hyundai DFDE
Speed	18 knots
LOA	294,28 m
Breadth moulded	46 m
Summer draught	12,519 m
Gross Tonnage	109 777
Net Tonnage	36 075

Source: (ETKI, 2020)

3.2.3.2. FSRU ERTUĞRUL GAZİ

FSRU Ertuğrul Gazi is the FSRU owned by Turkey. It has been delivered to Turkey in April 2021 and located in BOTAS Dörtyol. The vessel was built in South Korea (BOTAS 2021).

Table 22: FSRU Ertuğrul Gazi

Length	295.00 m
Beam	46.00 m
LNG Storage Capacity	170,000 m ³
Regasification Capacity	28 million Sm ³

Source: (BOTAS, 2021)

Some technical specifications of FSRU Ertuğrul Gazi are indicated in Table 22.

3.2.4. Natural Gas Pipelines in Turkey

Pipeline projects require long-term sustainability and they are constrained by economic variables such as profitability and cost effectiveness. As the energy security is vital for all nations, pipeline security involves supply, demand and transit security (Öge, 2019). Turkey has an ideal geographical position as a transit hub which can be provided by pipeline networks. There are numerous pipeline projects in Turkey as international and national grid. These are Blue-Stream, West Line, East Line from Tebriz-Dogubeyazıt, South Caucasus pipeline from Azerbaijan via Georgia, Turkey-Greece interconnection, and TANAP (MENR, 2020b).

3.2.4.1. Russian Turkey Natural Gas Pipeline (West Line)

West Line pipeline imports started in 1987. The pipeline enters Turkey from Bulgaria border. The line is 845km long and follows Hamitabat, Ambarlı, Istanbul, Izmit, Bursa, Eskişehir and Ankara. Malkoçlar metering station is located in Bulgarian border and has capacity of 14 billion cbm per year (MENR, 2019b).

3.2.4.2. Blue Stream Gas Pipeline

Natural gas is exported from the Russian Federation under a 25-year natural gas purchase-sale deal signed by BOTAS and Gazexport in December 1997. The agreement is for 16 billion cbm of natural gas supply per year. Pipeline consists of three parts: 1- On the Russian territory 370 km, 2- Black Sea passage 390 km and 3- Turkey territory 501 km starting from Samsun. In Turkey side, pipeline reaches to

Ankara via Amasya, Çorum and Kırıkkale and meet main line in Polatlı. The pipeline has been in service since 2003 (MENR, 2019b).

3.2.4.3. Eastern Anatolian Natural Gas Main Transmission Line (Iran-Turkey)

The agreement between Iran and Turkey was signed in August 1996 in order to supply 10 billion cbm per year. Total length of the pipeline is approximately 1491 km and lay over Dogubeyazit, Erzurum, Sivas, Kayseri and Seydisehir along with Kayseri branch. The gas purchase was started from Iran 2001 in (MENR, 2019b).

3.2.4.4. Baku-Tbilisi-Erzurum Natural Gas Pipeline (BTE)

The pipeline will transport natural gas from Azerbaijan's Shah Deniz field in the Caspian Sea to Turkey. The two governments signed an agreement in 2001 to supply Turkey with 6.6 billion cubic meters of Azerbaijani natural gas per year. The pipeline is approximately 980 km long, and gas flow began in July 2007. The project was extended with Shah Deniz field Phase 2 Projects in Georgia and Azerbaijan, and the first gas flow was started on June 2018(MENR, 2019b).

3.2.4.5. Turkey-Greece Natural Gas Interconnection (ITG)

The South European Gas Ring's first phase was established under the European Union's INOGATE (Interstate Oil and Gas Transport to Europe) program. The pipeline links the natural gas networks of Greece and Turkey, allowing natural gas to be transported between the two countries. The first supply was started in 2007. (MENR, 2019b).

3.2.4.6. Trans- Anatolia Natural Gas Pipeline (TANAP) Project

TANAP project was signed between Turkey, Azerbaijan and Shah Deniz Consortium. The agreement includes 6 billion cbm supply of natural gas. The project

also includes 10 billion cbm Azeri natural gas transportation to Europe via Turkey. For this purpose, Shah Deniz Phase II, South Caucasus Pipeline Expansion (SCPX) project, TANAP and the Trans Adriatic Pipeline projects have merged. Turkey has 19% share in Shah Deniz Phase II project and SCPX through TPAO and 30% in TANAP project through BOTAS.

TANAP consists of a 1850km long pipeline with 16 billion cbm per year initial capacity and has been planned to reach 32 billion cbm per year capacity from Georgia to Greece. In addition to BOTAS's 30% share in the TANAP project, remaining shares belong to SOCAR and BP as 58% and 12% respectively. The first gas flow started in June 2018 and supply to Europe is planned for 2020 (MENR, 2019b).

3.2.4.7. TurkStream Gas Pipeline Project

The agreement was signed between Russian Federation and Turkey in October 2016. The project has capacity of 31.5 billion cbm per year in two lines -15.75cbm each. The pipeline lies through Black Sea and reaches to receiving terminal in Turkey's Black Sea coast. One of the pipelines is planned to deliver Russian gas to Turkey's national grid, other line is planned to deliver Russian gas to Europe. Offshore sides of the pipelines are constructed by Russia. One of the pipelines on shore side has been constructed by BOTAS and the second line which is planned to deliver gas to Europe, has been constructed by a company in which countries have 50% share. Turkey aims to increase energy security via this project against disruption in 14cbm capacity West Line which comes from Russia to Turkey via third countries (MENR, 2019b). Unlike West-Line, the project provides uninterrupted connection between Russia and Turkey and by-passes Ukraine, which has a geopolitical tension with Russia (Erşen and Çelikpala, 2019).

3.2.5. Underground Natural Gas Storage in Turkey

Turkey has a balance on supply and demand of the natural gas annual demand. However, increases in demand during winter time, along with the sourced countries or

countries en-route may cause periodical imbalances. In order to cope with this problem and seasonality in demand, Turkey uses storage tanks.

North Marmara Natural Gas Underground Storage plant in Silivri has 2.84 billion Sm^3 capacity. As a part of enlarging project (Phase II), storage capacity will increase to 4.6 billion Sm^3 . The project is planned to complete in January 2021.

Another project is Tuz Gölü (Salt Lake) Natural Gas Storage Project which has 1.20 billion Sm^3 storage and 40 million Sm^3 / day withdrawal capacity was completed in February 2017. The project will be extended with new investments up to 5.4 billion Sm^3 storage and 80 million Sm^3 / day withdrawal capacity by 2023(MENR, 2020a).

3.2.6. LNG Infrastructure in the Region

In addition to Turkey's LNG import terminals, Greece also has an LNG terminal nearby Athens, Revithoussa. It's located on the Revithoussa island in the Pachi Gulf, 45 kilometers West of Athens. It is the only facility in Greece that collects LNG cargoes, temporarily stores and regasifies LNG, and supplies natural gas to the entire country. The capacity of the terminal is 225,000 cbm, with a regasification capacity of 1250 cbm/h and a sustained daily send out rate of 1250 cbm/h (DESFA, 2020). It's marked as blue dot in Figure 55.

Greece also planned a FSRU to be located in Alexandroupolis. It will be 17.6 km southwest of the Port of Alexandroupolis with capacity of 170,000 cbm. The send out capacity will be 5.5 billion cbm/year. The FSRU will be connected to National Natural Gas System of Greece via 28km pipeline. Regasified LNG will be transferred to Greece, Bulgaria, Romania, Serbia, North Macedonia, Hungary and Ukraine (DESFA, 2018). It's marked as yellow dot in North of Aegean Sea in Figure 55.

South Cyprus has two important LNG projects: Vasilikos large-scale LNG production facility and Cyprus FSRU (GIE, 2021). The FSRU will be permanently anchored in Vasilikos Bay, about 1.3 km off the coast of Limassol, and will link directly to the neighboring Vasilikos power station, Cyprus' largest power plant. The former LNG carrier will be converted to FSRU which will be capable to handle the vessels ranging from 120,000 cbm to 217,000 cbm. The project will be carried out under joint venture agreement of Natural Gas Infrastructure Company of Cyprus

(ETFYA), China Petroleum Pipeline, Metron, Hudong-Zhonghua Shipbuilding, and Wilhelmsen Ship Management (Offshore, 2020c). The project finance is obtained through The European Bank for Reconstruction and Development (EBRD) is to provide a €80 million. In addition, the European Union is providing a €101 million grant through the Connecting Europe Facility, with the remaining project costs being covered by a €150 million loan from the European Investment Bank (EIB) and a €43 million equity contribution from the Cyprus Electricity Authority (EAC)(Offshore, 2020c). Export terminal is also planned at same area subject to East Mediterranean natural gas reserves.

Figure 55: East Mediterranean and Black Sea LNG Terminals



Source: (GIE, 2021)

In Black Sea, there are two planned projects. The first one is planned as FSRU in Yuzhny (Odessa) and other one is planned in Constanța as small-scale LNG facility which provides ship fuel (GIE, 2021). However, these projects are subject to Turkey's decision over LNG tanker's passage through Turkish Straits.

3.3. NATURAL GAS MARKET OVERVIEW IN TURKEY

Natural gas takes third place as Turkey's primary energy source following petroleum and coal. Natural gas market activities in Turkey involve import, distribution, storage, wholesale, export, transmission, compressed natural gas (CNG) distribution and transmission. By the end of 2019, natural gas market reached to 45685.34 Sm³ total supply (production and import) and 46048.18 Sm³ total demand (domestic sales and exports) volume (EMRA, 2020a). Natural gas market overview is summarised in Table 23.

Table 23: Natural Gas Market Overview by Years (million Sm³)

	2016	2017	2018	2019	Difference % (2018-2019)
Import	46,352.17	55,249.95	50,282.05	45,211.47	-10.08
Production	367.28	354.15	428.17	473.87	10.67
Export	674.68	630.67	673.29	762.68	13.28
Consumption	46,395.06	53,857.14	49,204.14	45,285.50	-7.96
End of Period Stock	1,700.25	2,948.37	3,167.23	3,095.44	-2.27

Source:(EMRA, 2020a)

From 2018 to 2019, production volume increased approximately 10% and import volume decreased almost in the same level. Although Turkey is dependant to natural gas imports, natural gas exports increased 13.28% from 2018 to 2019. Production rate has also increased to the highest level since 2014. On the other hand, natural gas consumption decreased for three years in a row.

Table 24: Amount of Consumed Natural Gas by Sectors (Million Sm³)

Sectors	2018	2019	% of 2019
Conversion sectors	18,191.64	11,258.00	24.86
Energy Sectors	1,735.04	1,986.82	4.39
Transportation Sectors	430.5	411.06	0.91
Industry Sectors	11,993.23	12,424.04	27.43
Service Sectors	3,995.64	4,606.06	10.17
Household	12,625.17	14,396.42	31.79
Other Sectors	232.93	203.10	0.45
Total	49,204.14	45,285.50	100

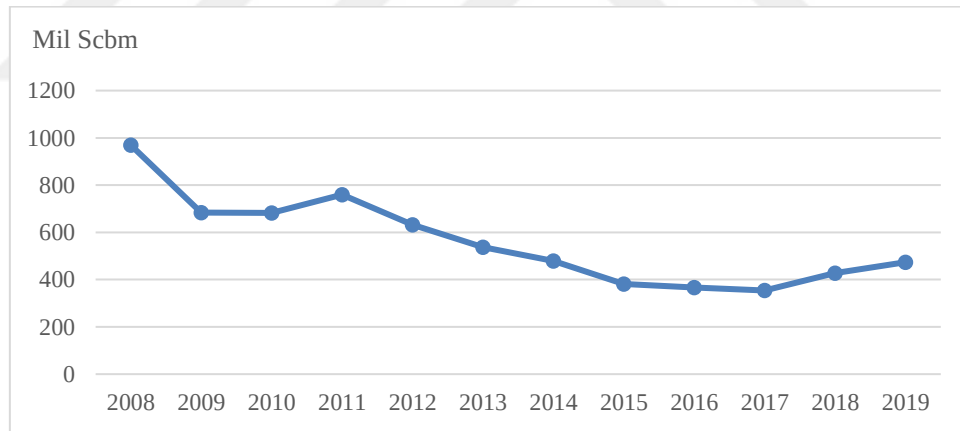
Source: Author, EPDK, 2020

Distribution of the consumption through sector is indicated in Table 24. Household consumptions take the first place and followed by industrial use as 27% and conversion sectors mainly producing electricity as 24,86%. Transportation sector takes less than 1% share according to 2019 data.

3.3.1. Natural Gas Production in Turkey

Natural gas production and exploration activities are licensed by the General Directorate of Petroleum Affairs. Currently, there are eight companies which have permission for production and exploration activities in Turkey. Although there has been a slight increase in production for the last two years, total production volume has decreased to about 50% compared to that in 2008. Figure 56 illustrates production trend of the natural gas.

Figure 56: Production of Natural Gas between 2008-2019



Source: (EMRA, 2020a)

Tekirdağ and İstanbul are the main centres for the natural gas production and represents approximately 83% of the total production. Türkiye Petrolleri Anonim Ortaklığı (TPAO) takes the biggest share in production and performs 83% of the total production according to 2019 data(EMRA, 2020a).

3.3.2. Natural Gas Imports

Turkey carries out natural gas imports via pipelines and LNG import points. Pipeline imports are received from Russia, Iran and Azerbaijan with long term purchase agreements, long term LNG agreements and LNG spot markets. Table 25 summarises Turkey's natural gas imports between 2009 and 2020. Russia takes an important part in Turkey's natural gas imports, while taking over 50% share over the years, in 2019 it reduced to the lowest level as 33.61%. These differences were compensated by increases in Azerbaijan gas imports from 14% to 21%. Total natural gas imports have decreased by 10% and lowered dependency to Russian natural gas. However, this reduction on Russian gas quantity is not reflected in country's budget due to 'take or pay' obligations. Iran, first time in 2019, takes the third place as natural gas imported country with share of 17.11%.

Table 25: Amount of Imported Natural Gas by Source Country (Million Sm³)

	Russia	Iran	Azerbaijan	Algeria	Nigeria	Other**	Total	Change
Year	(%)	(%)	(%)	(%)	(%)	(%)	Amount	
2009	54.3	14.6	13.8	12.5	2.52	2.18	35.856	-4
2010	46.2	20.4	11.9	10.3	3.13	8.09	38.036	6.08
2011	57.9	18.7	8.67	9.47	2.84	2.44	43.874	15.35
2012	57.7	17.9	7.3	8.88	2.88	5.37	45.922	4.67
2013	57.9	19.3	9.38	8.65	2.81	1.97	45.269	-1.42
2014	54.8	18.1	12.3	8.48	2.87	3.43	49.262	8.82
2015	55.3	16.2	12.7	8.09	2.56	5.15	48.427	-1.7
2016	52.9	16.6	13.9	9.24	2.63	4.58	46.352	-4.28
2017	51.9	16.7	11.8	8.36	2.43	8.7	55.250	19.2
2018	47.0	15.6	14.9	8.99	3.32	10.2	50.282	-8.99
2019	33.6	17.1	21.2	12.6	3.88	11.6	45.211	-10.1

* Others represent the countries of imported spot LNG

Source: EMRA, 2020

The pipelines are main natural gas sources of Turkey, however, LNG investments, FSRUs are changing pipeline gas/ LNG balance positively to LNG side. LNG share increased from 12.92% to 28% from 2013 to 2019. In 2019, pipeline imports reached the lowest volume since 2010. Table 26 shows import quantities of natural gas imported by gas type.

Table 26: Import Quantities of Natural Gas Imported by Gas Type (Million Sm³)

Gas Type	Pipeline Gas		LNG		TOTAL
Year	Amount	Share (%)	Amount	Share (%)	Amount
2013	39,419.44	87.08	5,849.54	12.92	45,268.98
2014	41,981.41	85.22	7,280.87	14.78	49,262.28
2015	40,778.11	84.21	7,648.96	15.79	48,427.08
2016	38,724.48	83.54	7,627.68	16.46	46,352.17
2017	44,484.67	80.52	10,765.28	19.48	55,249.95
2018	39,032.13	77.63	11,249.92	22.37	50,282.05
2019	32,517.40	71.92	12,694.07	28.08	45,211.47

Source: (EMRA, 2020a)

Table 27 indicates entry points of natural gas to Turkey. Durusu has the highest volume for natural gas import points which receives Blue Stream gas from Russia. Gurbulak receives Iranian gas and Azerbaijan gas through Türkgözü and TANAP points.

Table 27: Imported Natural Gas' Entering Point of the System in 2019 (Million Sm³)

Entry Points	Amount of Imported Natural Gas	Share (%)
Durusu	10,874.95	24.05
Gürbulak	7,736.29	17.11
Türkgözü	6,676.39	14.77
Marmara Ereğlisi LNG Terminal	5,576.64	12.33
Malkoçlar	4,321.42	9.56
Ege Gaz Aliğa LNG Terminal	3,192.89	7.06
Etki Lng Terminal	3,048.99	6.74
Tanap Seyitgazi	2,908.35	6.43
Dörtyol FSRU Terminal	875.55	1.94
Total	4,211.47	100.00

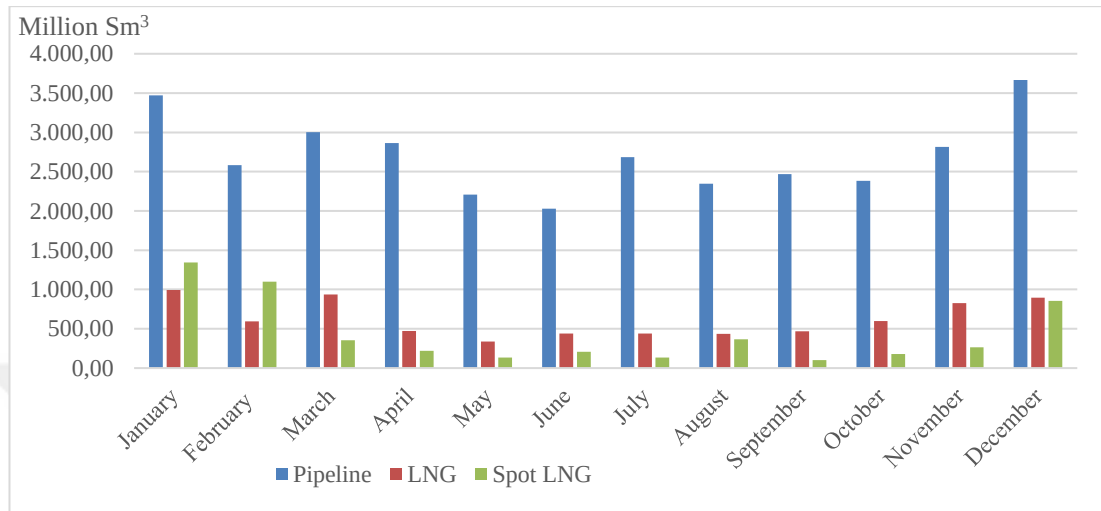
Source: EMRA, 2020

Turkey's LNG Imports

Turkey has signed long term LNG purchase agreement with Algeria and Nigeria and started imports in 1994 and in 1999 respectively. The aim was to increase security and provide supply flexibility. However, Russia/Ukraine gas crises and Russia/Turkey jet fighter shut down crisis reveal that Turkey needs more flexibility in gas supply in order to secure energy supply. Currently there are four facilities for LNG imports: Marmara Ereğlisi BOTAŞ, Ege Gaz A.Ş, Etki LNG FSRU and BOTAS

Dörtyol FSRU. LNG share in total natural gas imports have gradually been increasing since 2013 and reached to highest volume and share at the end of 2019 (EPDK, 2020).

Figure 57: Long Term Natural Gas Imports and LNG Spot Market Breakdown in 2019



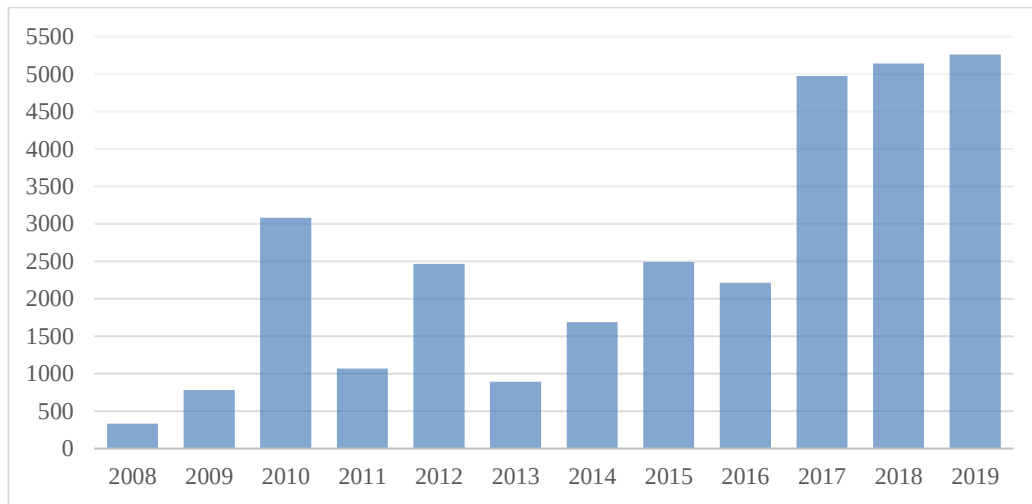
Source:(EMRA, 2020a)

According to EMRA 2019 report, LNG spot imports take % 11.63 share and the rest of the supply is performed under long-term contracts either through pipelines or as LNG. Despite the seasonality, spot imports continued throughout the year in 2019. In January and February, spot LNG imports exceeded long-term contracted LNG imports parallel to increase in household consumptions. Long term natural gas imports and LNG spot market breakdown in 2019 is illustrated in Figure 57.

Long term LNG imports are received from Algeria and Nigeria. According to 2019 data, Algerian imports take 73,05%. There is a significant increase in Algerian based LNG imports as it reached to 5678.36 M Sm³, which means a 25% increase compared to the 2018 volume. Nigerian imports increased as well, however, it remained modest compared to Algeria and took 1756.13 M Sm³ with 5.29% increase compared to that in the previous year.

On the other hand, spot imports are taking an important part and balancing pipeline-based natural gas demand. In 2019, Spot LNG volume reached to 5259.58 M Sm³, representing 11.63% of total natural gas supply. Figure 58 illustrates the change spot LNG import volume over the years.

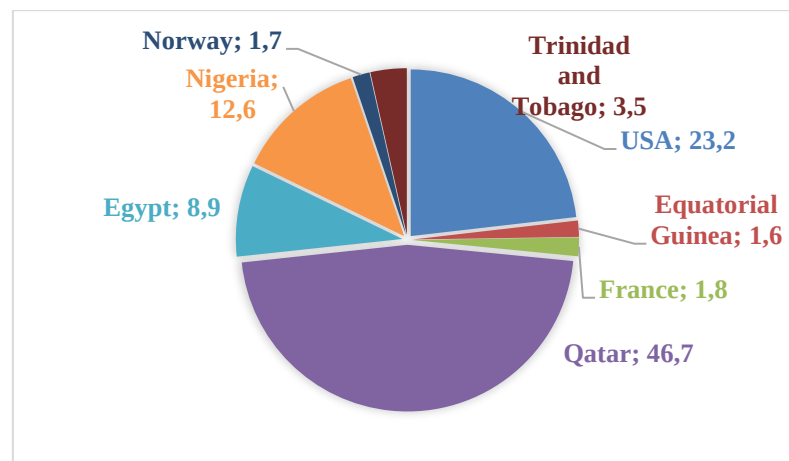
Figure 58: Spot LNG Imports – Million Sm³



Source: EMRA, 2020

Turkey receives spot LNG from various countries. In 2019, imports were provided from eight different countries. However, Qatar takes major part in spot imports and takes over 46% share. USA takes the second place with 23% and followed by Nigeria with 13%. Other countries take less than 10%. Figure 59 shows distribution of spot LNG imports.

Figure 59: Spot LNG Imports by Country



Source: EMRA, 2020

There are 52 companies licensed to import natural gas. However, over the years only EGE GAZ and BOTAS have performed spot imports. Moreover, EgeGaz share is just 6% and BOTAS position is more dominant in the market and private companies

are not able to compete with BOTAS. Breakdown of the spot imports by company is illustrated in Table 28.

Table 28: Spot LNG Shares from 2008 to 2019

Years	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
BOTAŞ	100	91.53	62.33	86.17	97.2	75.38	94.64	89.21	88.6	89.6	94.9	94.41
EGEGAZ	-	8.46	37.66	13.83	2.8	24.62	5.36	10.79	11.89	10.76	5.1	5.59

Source: (EMRA, 2020a)

3.3.3 Natural Gas and LNG Storage

In parallel to recent investments in underground storage and LNG, a significant increase has been observed in capacity. LNG Stock volume has been increased in the last years due to ETKİ FSRU and Dörtöyl FSRU terminals. FSRU units send out the LNG either to trucks as LNG, or to the national grids after the regasification process. In 2019, 12007.39 Million Sm³ was sent out to transmission network and 508.85 Million Sm³ was delivered to trucks (EMRA, 2020).

3.3.4. Natural Gas Contracts

Turkey's energy consumption has high seasonality behaviours and winter time demand surges bring about challenges for gas supply as household consumption takes the biggest share. In order to cope with this problem, FSRUs are utilized as well as TANAP and TurkStream projects (Rzayeva, 2018).

Turkey's long-term contracts with suppliers are critical in terms of pricing and obligations. 'Take or Pay' clause exists in all long-term contracts of Turkey (Rzayeva, 2018). As a receiver country, Turkey should either secure future gas demands or pay for the gas not used. Increasing demand for natural gas is not at a convenient level to receive all the contracted volume. Volatile demand and physical restrictions are bottlenecks of the contracts. Restrictive destination clauses is a burden and lifting this clause may trigger the market and allows bigger volumes to trade (Topuz, 2019). However, in 2021 Russian West Line, Nigeria LNG and Azerbaijan agreements will be ended. Moreover, the biggest single agreement with Russia, Blue Stream, will be ended in 2028. Table 29 summarises the Turkey's active natural gas agreements.

Table 29: Natural Gas Import Agreements of Turkey

Agreement	Company	Date	Came into Force	Duration	Quantity (billion m ³ / year)	End of Agreement
Nigeria (LNG)	BOTAS	1995	1999	22	1,2	2021
Iran	BOTAS	1996	2001	25	10	2026
Algeria (LNG)	BOTAS	1988	1994	30	4	2024
Russia (Blue Stream)	BOTAS	1997	2003	25	16	2028
Russia (West Line)	BOTAS	1998	1998	23	4	2021
Russia (West Line)	Private	1998	1998	23	4	2021
Russia (West Line)	Private	2012	2012	23	1	2035
Russia (West Line)	Private	2012	2012	30	5	2042
Azerbaijan TANAP	BOTAS	2013	2018	20	6	2033
Azerbaijan	BOTAS	2001	2006	15	6,6	2021

Source: Author, data compiled from (Petform, 2018; Topuz, 2019)

3.4. REGULATORY FRAMEWORK FOR NATURAL GAS AND LNG

Ministry of Energy and Natural Resources is the main responsible body for Turkey's energy policies, including analysing and planning. In addition to these base activities, the ministry also supervises the market interests, production, exploration, transmission and distribution of natural sources of Turkey.

Energy Market Regulatory Authority (EMRA) was established in 2001 and its function is to regulate and supervise downstream energy markets with autonomous structures. The main purposes are to provide transparent energy markets and competitive environment in order to sustain sufficient and good quality, low cost and environment- friendly energy markets. EMRA regulates natural gas, electricity, petroleum, and LPG markets. EMRA set standards for the market, issue licences, enforces and implements legislations and applies fines if necessary to ensure competitive market structure. EMRA in natural gas market, regulates natural gas import, transmission, distribution, storage, licensing; investigates the markets, develops and implements secondary regulations; arranges tariffs and investigates the applications in the market (EMRA, 2018).

General Directorate of Petroleum Affairs (GDPA) is under the MENR and responsible for licencing exploration and exploitation of petroleum and natural gas reserves. Ministry of Environment and Urban Planning (MEUP) conducts

investigations, sets standards for environmental protection, and imposes sanctions if necessary. Ministry of Family, Labour and Social Security (MLFS) supervises occupational health and safety precautions that need to be taken in workplaces. MLFS also carries out investigations and imposes sanctions if deemed necessary (Westlaw, 2019).

Regulatory framework for natural gas is set by The Turkish Petroleum Law No.6941, the Natural Gas Market Law No. 4646 and related regulations, guidance and announcements. Organized wholesale Natural Gas Market Operating Procedures and Principles are under Official Gazette number 30189 and Organized Wholesale Natural Gas Sales Market Regulation is set under Official gazette 300024. Organized Wholesale Natural Gas Sales Market (OTSP) started running on 1st September 2018 and Turkey put in service natural gas trade and allowed users of natural gas transmission systems to trade and to eliminate their imbalances. Energy Exchange Istanbul (EXIST) was established for this purpose in 2015 and licensed by EPDK in order to publish and analyse data for transparent, reliable energy market. This is also a part of Turkey's ambition to become a natural gas hub (EPIAS, 2020).

Pipeline transmission of the natural gas is conducted by BOTAS under 4646 Natural Gas Market Law. However, by the numbered 24918 Natural Gas Market Transmission Network Operating Instructions, third parties have access to transmission network under certain regulations.

Natural Gas and LNG Licenses

There are thirteen different types of licences issued by EMRA, covering whole supply chain, transmission, distribution and storage. Natural gas, CNG and LNG are also licenced in different types. The number of the total licences and the number of the active licences are summarised in Table 30. While all distribution of the natural gas and LNG storage licences are active, it's not the case for the rest of the activities. For example, active wholesale licences take less than half of the total licences.

Table 30: Number of the Licenses in Natural Gas Market

License Type	Number of License	Number of Active License
Import License (Long Term)	18	16*
Export License (SPOT LNG)	52	12*
Transmission License (Pipeline)	1	1
Transmission License (LNG)	14	9
Storage License (LNG)	4	4
Storage License (Underground)	4	1
Wholesale License	41	20
Wholesale License (Production)	10	8
CNG License (Transmission-Distribution)	41	23
CNG License (Sale)	38	32
CNG License (Oto CNG)	16	15
Export License	17	2
Distribution License	72	72
Total	328	216

*Includes the one performing domestic wholesale according to their export licence

Source: (EMRA, 2020a)

By the end of 2019, there are 18 long-term licences for long term imports. Out of BOTAS there are 6 companies with 8 licences which are Shell, Kibar, Batı Hattı, Akfel and Bosphorus Gaz. According to 2019 data, there are 52 spot LNG export licences, but only EGEgaz and BOTAS performed spot LNG exports. Remaining 50 licence holder company have not involved in any activities.

Table 31: Annual Transmitted LNG Amount by Companies (Million Sm³)

Company	Total
İpra Enerji Anonim Şirketi	211.60
Ultrans Taşımacılık Sanayi Ve Ticaret Ltd. Şti	147.98
Omv Gaz İletim Anonim Şirketi	118.19
Aygaz Doğal Gaz İletim A.Ş	79.31
Habel Sinai Ve Tibbi Gazlar İstihsal Endüstrisi A.Ş	63.33
Ventes Lojistik Anonim Şirketi	10.80
Enerji Grup İletim Nakliyat Ve Taşımacılık Anonim Şirketi	10.35
Ak-Can Doğal Gaz İletim Ltd. Şti	8.24
Tutan Doğalgaz Akaryakıt Taşımacılık Depolama Ticaret Ltd. Şti	4.43
Reysaş Enerji Ve Akaryakıt Dağıtım A.Ş	1.10
Total	655.33

Source: (EMRA, 2020a)

Transmission operation could be performed by LNG transportation vehicles other than the national transmission grid, according to the law, if an EMRA license is issued.. In 2019, 799.52 million Sm³ of LNG was carried by 9 transmission (LNG) licensees. Annual transmitted LNG amounts are given in Table 31.

3.5. SUMMARY

Turkey is an energy dependant country and growing energy demand generates significant challenge for Turkey. Energy security is another important dimension that Turkey should diversify energy sources. Natural gas takes important part in Turkey's energy sources and in power generation. Dependency to pipeline natural gas supply from three countries could jeopardise the energy security of Turkey. LNG is another alternative to reduce pipeline natural gas dependency and it's share in natural gas imports are gradually increasing in parallel to new FSRUs. First three chapters provide insight for LNG supply chain, LNG bunkering and Turkey's natural gas overview. In light of these literature review, the next chapter is organised to explain methodology of the research.

CHAPTER IV

METHODOLOGY

4.1. RESEARCH METHODOLOGY

The methodology is the theory that guides how the study should be conducted, while the method is the technique or process that is used to collect and analyse the data (Saunders et al., 2019). It's the base of the research and allows the researcher to organize the work, understand the limitations of the research and helps to discover alternatives and different approaches (Saunders et al., 2009). Research design which is referred to plan to conduct a research involves three main components: philosophy, selected strategies and research methods (Cresswell, 2009). Understanding philosophical issues are very critical for the researcher (Easterby-Smith et al., 2015). Basic issues of epistemology need to be understood by the researcher in order to have a clear sense of his reflexive role in research method. It also assists research design by allowing the researcher to consider what type of evidence is needed, how it will be interpreted, and how this will provide adequate answers to relevant research questions. Easterby-Smith et al (2015) also argue that knowledge of philosophy can help the researcher to recognize the relevant research design and limitations of particular approaches. Moreover, knowledge of philosophy assists the researcher in identifying, developing, and implementing research designs that are in accordance with the knowledge framework (Easterby-Smith et al., 2015).

Ontology and epistemology cause debates among philosophers. While ontology is the nature of the reality and existence, epistemology is about the theory of knowledge (Saunders et al., 2019). Natural scientists and social scientists usually have different ontological and epistemological assumptions in order to develop their research methodology (Easterby-Smith et al., 2015). Table 32 summarises the terms ontology, epistemology, methodology, method and techniques according to Easterby-Smith et. al. (2015).

Table 32: Ontology, Epistemology, Methodology, Methods and Techniques

Term	Explanation
Ontology	Philosophical assumptions about the nature of reality
Epistemology	A general set of assumptions about the ways of inquiring in the nature of the world
Methodology	A combination of techniques used to inquire into specific situation
Methods and Techniques	Individual techniques, for data collection, analysis etc.

Source: (Easterby-Smith et al., 2015)

Research philosophy and research paradigm are sometimes used interchangeably in management research in order to describe the assumptions of researchers made in their work (Saunders et al., 2019). Different approaches for paradigm and philosophy have been followed in the research methods literature (Cresswell, 2009; Teddlie and Tashakkori, 2009; Easterby-Smith et al., 2015; Saunders et al., 2019). Keeping in mind this philosophical discussion, Saunders et al.'s (2019) approach has been followed to clarify the research design. Five management philosophies have been discussed in the literature with ontological, epistemological and typical methods to be employed from the such points of view as: positivism, critical realism, interpretivism, postmodernism and pragmatism (Saunders et al., 2019).

The idea of positivism argues that the social world exists externally and objective methods could be utilized to measure properties, rather than being inferred subjectively through sensation, reflection or intuition (Easterby-Smith et al., 2015). Epistemologically observable and measurable facts as scientific methods constitute acceptable knowledge achieved through deductive, and highly structured quantitative methods of analysis (Saunders et al., 2019). Critical realism reconciles the real world and casual mechanism through critical approach (Golicic and Davis, 2012). Critical realism constitutes knowledge with historical casual explanation as contribution and the facts are social constructions. The researcher is as objective as possible and can employ range of methods and data types to fit related subject (Saunders et al., 2019). Interpretivism is usually combined with social constructivism (Cresswell, 2009). The

reality is complex and socially constructed with culture and language. Knowledge is constituted over narratives, stories, perceptions and interpretations. Typically inductive approach is used with qualitative methods of analysis (Saunders, Lewis and Thornhill Adrian, 2019). Postmodernism is appropriate to study organizational dynamics and change as it emphasises on the invisible elements and process of organizations (Easterby-Smith et al., 2015). Saunders et al. (2019) argue that 'truth' and 'knowledge' is decided by dominant ideologies. Typically, deconstructive methods are employed with qualitative methods of analysis. Unlike positivism, pragmatism arises out of actions, situations and consequences and there is 'what works' and solutions to problems (Cresswell, 2009). However, Denzin (2012) argues that 'what works' is not the point, rather, the pragmatist focus is on the consequences of action and it's not combining the methodologies. By considering theories, principles, and ideas in terms of reasoning, behaviour, and practical implications, objectivism and subjectivism, facts and values, true and rigorous knowledge can be reconciled. In pragmatic worldview, researcher may utilize all approaches in order to understand the problem (Cresswell, 2009). The research problem does not lead to utilize one particular type of knowledge, rather, it requires different types of knowledge and methods to understand the problem and answer the research questions. Providing epistemological and ontological clarification, pragmatist view confirms that there are many different ways of interpreting the world and undertaking the research (Feilzer, 2010; Saunders et al., 2019). The study aims to explore relatively new issue for maritime transportation, new marine fuel application in Turkey and aims to contribute to practical solutions that inform the future practice in LNG marine fuel field. Therefore, this research is prepared with the pragmatic research philosophy which enables researcher to fulfil the research objectives.

A research project involves a theory, it may be explicitly in the design of the research or not. As the research is concerned with theory testing or theory building, there are two main approaches to the reasoning to be adopted: deductive or inductive (Saunders et al., 2019). Deductive reasoning derives conclusion from a set of theory-derived premises (Saunders et al., 2019), conversely, in inductive reasoning, known premises are used to generate untested conclusions that build theory. Deductive approach uses data collection to evaluate hypotheses related to the existing theory; in

contrary; data collection is used in the inductive approach to investigate phenomena, recognise patterns, and develop a conceptual structure. Small-scale LNG supply chain and LNG bunkering research requires exploratory study in order to define concepts and explore phenomenon. However, this approach is not satisfactory to achieve research objectives as it requires data to test and evaluate LNG bunkering implications deductively. As neither deductive approach nor inductive approach are able to answer the research questions alone; abductive approach was used in order to explore small-scale LNG supply chain, LNG bunkering and to model LNG bunkering in Turkey. Abductive reasoning follows a pragmatist perspective and allows researcher to explore a phenomenon, identify themes, draw a conceptual framework and test this with subsequent data collection (Mitchell, 2018). Data have been collected through semi-structured interviews and participant observation used to explore the phenomenon and identify the themes. Then, the defined themes have been checked through additional data collection by regression, mathematical model in order to update, clarify and refine the model.

Mixed methods research has been defined as third path alternative to qualitative and quantitative research (Johnson and Onwuegbuzie, 2007; Feilzer, 2010) and it is mostly associated with pragmatist approach and employs both narrative and numeric data for analysis (Teddle and Tashakkori, 2009). There are different types of mixed methods research. Johnson & Onwuegbuzie (2007) classify mixed methods generally in three parts: qualitative dominant, equal status and quantitative dominant. Sounders et al. (2019) classify mixed methods in four types:

- 1- concurrent, qualitative and quantitative works in parallel,
- 2- sequential exploratory, qualitative methods follow quantitative methods,
- 3- quantitative methods follow qualitative methods,
- 4- sequential multi-phase, qualitative methods followed by quantitative and again qualitative methods.

Teddle and Tashakkori (2009) clarify sequential mixed methods as fully integrated mixed methods and partially integrated mixed methods. This research employs different methods at different stages of the study, and then integrates the findings, therefore it could be classified as fully integrated mixed methods research. Teddle and Tashakkori (2009) describe *development* purpose mixed-method study as

equally weighted methods implemented sequentially. Results for each phase of the analysis can be stated separately, with a general discussion concluding the research findings. Supply chain problems require synchronising numerous activities within the network. The disciplines that are part of the supply chain theory such as logistics, transportation, operation primarily follow positivist paradigm and utilize quantitative methods (Golicic and Davis, 2012). Although diversity in research methods leads to more robust outcomes, logistics and supply chain management research has been criticised over absence of diversity in methodology. Utilizing additional methods leads more appropriate reasoning for theory generation and investigation in this field (Golicic and Davis, 2012). Taking into account these critics in supply chain management and logistics literature, combination of qualitative and quantitative methods has been employed in this study. At the first stage, qualitative methods involving semi-structured interviews and participant observations have been used for exploratory part of the phenomenon. At the second stage, quantitative methods involving regression analysis, forecasting and mathematical modelling methods have been employed for explanatory part of the research. The third stage involves expert views as semi-structured interviews. The final stages integrates different methodological outcomes in order to the answer research questions.

This combination of the methodologies for the same phenomenon is broadly defined as 'triangulation' (Denzin, 2012). Jick (1979) argues that triangulation may be used not only to examine the same phenomenon from different perspectives, but also improves our understanding by new and deeper dimensions. Moving between data sets which are provided by different approach, then integrated interpretation is possible by triangulation (Jick, 1979). Nolan and Behi (1995) point out that triangulation can take various forms: method, data, investigator or theoretical (Nolan and Behi, 1995). In methodological triangulation there are three approaches defined by Jick (1979) as within method, between method and holistic. Within method employs two or more variations of the same methods. Between method utilizes different but complementary methods such as semi-structured interviews and questionnaires. Holistic triangulation uses both within and between methods, as it has been used in this research (Nolan & Behi, 1995). On the other hand, there are critics about triangulation strategy in the literature. While adopting different epistemological approaches the researcher may

refuse to accept validity of any methods, and may lead to confusing, imprecise piece of work which is not reliable or valid. Another critics about triangulation is its being expensive in terms of time and money. Researcher's skill could be the third barrier as the research requires different skills to cope with the problem (Nolan and Behi, 1995). The research is required to utilize both qualitative and quantitative methods in sequential process. At the first stage, small-scale LNG and LNG bunkering is investigated through qualitative methods that is the most suitable method to explore new phenomenon and gain understanding. At the second stage, quantitative methods are used in order to analyse Turkey's bunkering dynamics and to forecast Turkey's bunker sales. Mathematical model with MILP method is used to reach minimum cost objective function while determining optimum number of barges and sizes. At the third stage, findings of qualitative and quantitative methods have been evaluated with expert views and methodological triangulation has been performed.

The study aims to propose a model for LNG bunkering in Turkey. Case study collects different forms of data sets as qualitative and quantitative in order to gain more complete understanding of the case (Guetterman and Fetters, 2018). In several contexts, the case study is used as a research strategy to contribute to knowledge of individual, community, organisational, and social phenomena (Yin, 2003). Yin (2003) argues that the case study methods allow researchers to keep holistic and meaningful characteristics of real-life events such as life cycles, organisational and managerial process and the maturation of industries. The case studies may be both descriptive and explanatory and usually attached to pragmatic research tool which facilitates thoroughly understanding complexity of problem as well as supporting decision making (Scholz and Tietje, 2002). How and why questions are more explanatory in nature and often lead to case studies (Denktas Sakar, 2010), because, these questions deal with operational links that need to be outlined over time (Yin, 2003). Yin (2003) classifies case study design in four segments: single-case (holistic), single case (embedded), multiple-case (holistic), multiple-case (embedded). Prime difference between holistic and embedded case studies is holistic case study is designed over qualitative approach, themes and hypothesis are remained as subordinate to the understanding of the case. On the other hand, embedded case studies consist of more than one unit, or object and qualitative methods are not the only option and allows

qualitative and quantitative data and strategies of knowledge integration (Scholz and Tietje, 2002). Another design characteristic of the case study is single case versus multiple case. As the study aims to investigate Turkey LNG bunkering model, single case model has been chosen. Qualitative methods such as semi-structured interviews, participant observation and quantitative methods such as regression, mathematical modelling have been utilized to understand the problem. Therefore, single-embedded case study has been determined as research strategy.

The research involves a specific phenomenon at a specific time. Although the study consists of forecasting, evaluation is made based on existing historical time series data and case study is based on interviews conducted over a particular period of time. Consequently, time horizon has been chosen as cross-sectional.

Research design is summarised in Table 33. The research is conducted with pragmatism and employed abduction with triangulation strategy. Development purpose, fully integrated mixed methods is used in overall research design taking into account different stages of the research. LNG bunkering in Turkey is the case study which utilize qualitative and quantitative methods at single-embedded structure. Primary and secondary data sources are used to explore the phenomenon along with explanatory and descriptive research approach.

Table 33: Research Design

Research Criteria	Tool
Research Philosophy	Pragmatism
Research Approach	Includes inductive and deductive approaches, abduction is employed with triangulation strategy
Methodological Choice	Qualitative and quantitative methods, development purpose fully integrated mixed-methods
Research Strategy	Single-embedded Case Study
Time Horizon	Cross-sectional
Techniques and Procedures	Semi-structured interviews, participant observation, multiple regression, forecasting, mathematical modelling and secondary data as industrial reports, websites.

Source: Author, adapted from Saunders et al. (2019)

4.1.1. Sampling Technique

By considering only data from a subgroup rather than all possible cases or components, sampling techniques allow you to minimize the amount of data you need to collect. Some research questions would necessitate sample data that will enable you to statistically generalize about all of the cases from which your sample was drawn. There are two types of sampling technique: probability and non-probability (Saunders et al., 2019). Probability sampling is usually associated with survey research strategies. The chance, or likelihood, of each case being chosen from the target population is known with probability samples, and it is normally equal for all cases. This ensures that you can answer research questions and meet goals that include statistical estimation of the target population's characteristics from the sample. However, since the probability of each case being chosen from the target population is unknown in non-probability samples, it is difficult to answer the study questions or meet the goals that include statistical inferences about the population's characteristics (Saunders et al., 2019). Purposive sampling occurs when a researcher has a clear understanding of what sample units are needed based on the study's objectives, and then approaches possible sample participants to see if they meet the requirements. Those who comply are employed, while those who do not are dismissed (Easterby-Smith et al., 2015). In the small-scale supply chain literature, stakeholders have been categorised. Therefore, in order to fulfil these requirements of the research objectives, purposive sampling strategy has been used for semi-structured interviews. This research explores relatively new topic in maritime industry and there are limited numbers of the expert in this field. Reaching out the experts was a costly and difficult task; however, global LNG bunkering summit provided opportunity to employ purposive sampling method.

4.1.2. Underpinning Theory of Research

Developing supply chain management requires complete understanding of the entire supply chain in terms of both their management and operation (Janvier-James, 2011). The supply chain is a meta-organization made up of separate companies that have established inter-organizational partnerships and synchronized business

processes across the individual firms' borders (Halldorsson et al., 2007). Supply chain literature review reveals that there is not an accepted general supply chain theory (Halldorsson et al., 2007; Caniëls and Romijn, 2008; Carter and Rogers, 2008; Janvier-James, 2011; MacCarthy et al., 2016). Literature review in LNG supply chain shows that various theories are used in order to explain, describe and predict organisational behaviours in the supply chain such as Transaction Cost Economics, Agency Theory, Resource Based view, Resource Dependency Theory, Network Theory and Relation Exchange Theory (Fayezi and Zomorodi, 2016).

The study explores relatively new supply chain development at small scale for LNG. It is essential to use a combination of organizational theories that provide a framework for the study in order to effectively investigate relatively new phenomena and draw a reliable picture. MacCarthy et al.(2016) argue that economic considerations are substantial determinants of the supply chain parameters in terms of establishing shape, size, configuration, operation and coordination (MacCarthy *et al.*, 2016). The study is conducted with pragmatic research philosophy that enables to utilises TCE theory (Williamson, 2008).

Basic constitution of *transaction cost economics* (TCE) theory is to coordinate a transaction between a buyer and a seller within a market mechanism that results in ex-ante and ex-post transaction cost (Tsay et al., 2018). TCE origin dates back to 1930s with significant economic contribution made by Coase (1931) and Commons (1934). While Llewellyn (1931) was adding legal insight (1931), organization theory perspective was offered by Barnard (1934) (Williamson, 1989). In TCE theory, a company should lower total transaction costs by collaborating with external partners (Halldorsson et al., 2007). TCE also adopts contractual approach to economic organization study (Williamson, 1989). Williamson (2010) argues that TCE is an interdisciplinary project rooting from *economics, organisation theory* and *law (mainly contract law)*. Small-scale LNG development in Turkey encompasses all these three pillars of the theory.

Williamson (2010) points out that translation of economic concepts into accurate mathematics (or diagrams, or words) and ensuring that more logical operations are correctly conducted and tested are all part of getting it right. One of these additional logical operations, particularly in the public policy arena (but also

more broadly), is to determine if putative 'inefficiencies' withstand comparative institutional scrutiny. The parties to such transactions have an incentive to eliminate inefficiencies because any show of inefficiency simultaneously represents an opportunity for mutual benefit (in cost-effective degree). The most feasible option and cost minimisation objective of Turkey's LNG bunkering supply chain are the significant inputs at the second stage of the study.

Human actors, the value of organized adaptation, and repeated intertemporal regularities are all part of TCE's *organization theory*. (Williamson, 2010). Williamson (1996) classifies human actors as part of *asset specificity*. Other asset specificities are described as site specificity, successive locations and transportation costs in between; physical assets specificities, dedicated assets which are discrete investments, capital and temporal specificity (Williamson, 1996). Small-scale LNG and LNG bunkering problem, as part of the objective function, utilizes discrete decision variable as bunker barge selection criteria, and calculates transportation cost between potential locations. Adoption is a critical problem of an economic organization (Williamson, 2010). TCE assesses markets and hierarchies with combined perspectives in order to assure *coordinated adoption*. Autonomous adaptations in the *market* and coordinated adaptations of conscious, deliberate and purposeful kind which are achieved through *hierarchy* are both important according to characteristics of the transactions. Small-scale LNG, as a new market, follows the same pattern and uses both modes of the adaptation as market gets mature. Williamson (2010:16) points out that *intertemporal regularity* is provided by the Fundamental Transformation which refers 'to the transformation of a large numbers bidding competition at the outset into a small numbers supply relation during contract implementation and at contract renewal intervals for transactions that are supported by significant investments in transaction specific assets'. Although time dimension of the TCE is defined as *static* (Fayezi and Zomorodi, 2016), intertemporal transformations are the base form of the *dynamics* (Williamson, 2010). *Contract law* aspect is another instrument in the TCE for governance (Williamson, 1989). The traditional view of a contract as a set of legal rules is thus replaced by the more flexible idea of a "contract as framework." Whereas a contract is a framework for hybrid transactions, administration is used to realize

organized adaptations of the aware, deliberate, and purposeful kind (Williamson, 2010).

As LNG supply chain is highly vertically integrated for the different stage of the supply chain (Zubairu, 2019), TCE explains contractual governance between LNG supply chain stakeholders and associates with different transactions (Williamson, 2010). TCE involves contractual obligations and distribution of transaction costs throughout the supply chain (Fayezi and Zomorodi, 2016). Small-scale LNG contractual supply chain is governed by contractual agreement usually in long term, however, it might be arguable when the market is matured. TCE in supply chain implication is widely acceptable (Fayezi and Zomorodi, 2016), and provided theoretical ground for small-scale LNG supply chain and LNG bunkering model in Turkey. However, due to limitations of TCE not being able to provide dynamic network relation concept, the research requires additional theoretical underpinning in order to conceptualise the research model.

The performance of a firm is subject to effective relations with direct business partners and how these partners cooperate with their own business partners (Halldorsson et al., 2007). The Network Theory (NT) provides these inter-organisational interactions in a network context (Fayezi and Zomorodi, 2016). Knoppen & Christiaanse (2007) argue that interactions between firms is a significant contributor for development of new resources. Resources are important because resource structure determines the structure of the supply chain and motivate the supply chain development. Direct communication, building trust through long term relations leads to customisation throughout the supply chain which meet individual requirements. Social exchange process reinforces mutual trust (Halldorsson et al., 2007). The link between firms is provided by two types of interaction. The first one is exchange process which includes information, goods and services, and social process. The adaptation process, which includes personal, technological, legal, logistical, and administrative elements, is the second (Halldorsson et al. 2007). Connections of firms reflects exchange relationships and, if applicable, the underlying contract. Numerous connection types can be considered when modelling exchange relationships, but the existence of contracts and various flow types such as content flows, knowledge flows, and financial flows are the most important (Hearnshaw and Wilson, 2013).

NT underpins small-scale supply chain network development. Actors in small-scale LNG supply chain are linked through their activity and resource portfolios. Literature review findings indicate that collaboration between stakeholders is necessary for further development in new established supply chain network (Urciuoli et al., 2014; Seo et al., 2016). Exchange and adaption process in LNG bunkering requires mutual trust and it provides theoretical ground for the research and also is confirmed by the findings at the first stage of the study.

Table 34: Theoretical Framework for Small-Scale LNG Supply Chain

Characteristics	Theoretical framework of Transaction Cost T.	Theoretical framework of Network T	Theoretical framework applied to small-scale LNG supply chain
Behavioural assumptions	Bounded rationality Opportunism	Bounded rationality Trust	Personal trust, information sharing, win-win situation (NT)
Problem Orientation	Efficient governance structure: why do firms exist?	Dyadic relationships embedded in networks	Hybrid governance between markets and hierarchies. Collaboration among the actors. (TCE, NT)
Time dimension	Static	Dynamic	Long-term contracts for new components (TCE)
Unit of analysis	Transaction attributes	Inter-firm relations	Relationship between buyer and its suppliers (NT)
Nature of relations	Market failures	Access to heterogeneous resources	Strategic partnership for co-development components (TCE)
Primary domain of interest	Exchange and transaction	Exchange and adaptation process	Investment specific assets, personal contacts, sharing of information (TCE, NT)

Source: Author, adopted from (Halldorsson *et al.*, 2007)

Table 34 explains theoretical framework of the study. Characteristics of the TCE and NT theories underpin different components of the small-scale LNG supply

chain study. Developing new supply chain with high CAPEX requires openness and trust between the stakeholders which leads to best possible results from collaboration as behavioural component of the theory. Collaboration and mutual adjustments precede efficiency for the logistics systems (Halldorsson et al., 2007). Problem orientation is assured through hybrid market and hierarchies governance. However, collaboration of the parties is necessary as well. Long-term contracts for new development of new components are required in small-scale LNG supply chain development, parties could only take risks or investment decision if they can foresee the future. Relationship between buyers and sellers is required. Network Theory provides ground for small-scale LNG supply chain as a unit of analysis. Joint investments or strategic partnerships are essential as safeguards against market failures. Primary domain of interest is assured via exchange and transaction. This could be grounded to both theories, training programs, exchanging of employees as well as sharing information and mutual adaptation. The study encompasses two theories to explore the phenomenon and achieve the research objectives.

4.2. METHODS OF DATA COLLECTION

Various data collection techniques are used in different stages of the research. Following the literature review, semi-structured interviews, participant observation, multiple regression, forecasting, mathematical modelling have been employed. Details of the data collection methods, reasons to utilise these methods, weakness and strengths are explained below.

4.2.1. Semi-Structured Interviews

The literature covering LNG bunkering, LNG Supply Chain, Small/Mid-Scale LNG has been reviewed in order to see the LNG bunkering supply chain development. The subject is discussed in the literature with different perspectives. Analysing the literature revealed six main themes: Safety, Operation Challenges, Technical Challenges, Regulatory Framework, Commercial Factors, and Sustainability perspectives as inputs of the supply chain. The interviews help researchers to collect

valid and reliable data that are relevant to the research questions. There are different typologies in the literature to categorize interviews; commonly, interviews are classified as structured, semi-structured, and in-depth (unstructured)(Saunders, Lewis and Thornhill, 2009). While structured interviews are designed to identify general patterns in descriptive studies, unstructured interviews help to explore new insights. On the other hand, in the semi-structured interviews, the researcher has lists of themes and questions that may vary for different respondents. Some questions may differ according to the flow of the interview or could be focused on specific points according to the context and provides flexibility for the researcher to explore the new phenomena. This approach in semi-structured interviews allows researchers to conduct an exploratory and explanatory study. Semi-structured interviews help to understand variables in small-scale LNG supply chain, LNG bunkering and reveals the relation of the variables. Therefore, as this study aims to explore a relatively new concept in the industry, a semi-structured interview method has been employed.

The researchers prepare a list of themes and questions to be covered; however, this could be varied from interview to interview. Additional questions could be asked according to the flow of the interview in order to explore the research questions and the objectives. The exploratory study is particularly used to understand the problem and provides insight into the phenomenon. It creates casual relationships between variables and explains the relations (Saunders, Lewis and Thornhill, 2009). Therefore, open-ended questions have been preferred in order to reveal and understand the ‘what’ and ‘how’ but also exploring the ‘why’ for LNG bunkering development as it allows us to make exploratory and explanatory research.

The interviews were planned to be conducted through the leading experts in the industry during the LNG Bunkering Summit 2019 in Amsterdam between 29-31 January. Twelve out of twenty interviews were conducted face-to-face during the summit and in following days. One interview was conducted via online meeting tool in the following week and the remaining interviews were conducted by e-mail. However, all e-mail participants have been met during the summit, and agreed to respond by e-mail due to time constraint. Company profiles, organizations, company reports, or other publications related to LNG bunkering along with company representatives’ profiles were investigated in order to be prepared for a possible

interview opportunity, demonstrate credibility and to encourage the interviewees for more detailed data. The purposive sampling strategy was used with a maximum variation approach as a sampling method in order to reach the research objectives, which requires different perspectives in the supply chain as it was categorised as suppliers, shippers, regulatory bodies, and technical service providers (Mack *et al.*, 2002). Samples were selected deliberately in accordance with the research objectives with convenience sampling approach. The size of the samples was restricted in line with theoretical saturation till data collection generated no new insight. The themes of the interview were given to the participants in advance to promote validity and reliability as the participant was allowed to be prepared or gather related information before the interview.

Rigor of the study is achieved through (Wallendorf & Belk (1989) protocol. Before each interview, some terms such as the aim/scope of the research, the researchers' background were explained to establish *credibility*. At the end of the interviews, a brief summary was made in order to test the researcher's understanding. The interviewee was able to evaluate the researcher's understanding and correct it if deemed necessary. The coding of the interviews was compared with an expert who carried out coding separately using MAXQDA18 and evaluated it based on statistical data. The participants were selected on purpose to represent different stakeholders, titles, and companies in order to assure *transferability*. In order to achieve *confirmability*, the researcher made clear his own background and position in advance against potential bias. The coding and theme creating processes were clarified and the findings were linked to the conclusion. The research was conducted in compliance with ethical principles through which the participants' consent was gained; their views were represented as accurately as possible; the names and company details were kept *confidential* so as to assure the *integrity* of the research.

The participants were informed regarding the voice recording in advance and permission was granted. In some cases, it was declined to speak over the recorder and only notes were taken. A mobile phone interview application was used for recording, and notes were taken during the interviews. Six of the interviews were declined as well, due to the length of the meeting or due to some technical reasons. Finally, twenty interviews were clarified, which included six suppliers, five shipowners, five technical

service providers, and four interviews represent regulatory bodies from ports, flag, and classification society. All participants were already in the LNG bunkering business as different stakeholders and experts in this field with titles of one Chairman, one Vice President, one Chief Operating Officer, one Chief Financial Officer, six Directors, nine Managers, and one Senior Safety Advisor. All the participants represent the companies that are already in LNG bunkering business. Table 35 shows the details of the semi-structured interview.

Table 35: List of Semi-Structured Interviews with International Experts

No	Title	Function	Interview	Region
R101	Director	Shipowner	Face to face	Global
R102	Chairman	Supplier	Face to face	Global
R103	Business Development Manager	TSP	Face to face	Europe
R104	Director	TSP	Face to face	Europe
R105	Chief Operating Officer	RB	Face to face	Europe
R106	Vice President	Shipowner	Face to face	Global
R107	Senior Manager	Supplier	Face to face	Europe
R108	Technical Manager	RB	email	Global
R109	Business Development Manager	Supplier	Face to face	Europe
R100	Chief Financial Officer	Supplier	email	Europe/Far East
R111	Director	Supplier	email	Europe
R112	Terminal Assessor	Supplier	Face to face	USA
R113	Business Development Manager	TSP	email	USA
R114	LNG Assistant Manager	Shipowner	email	Far East
R115	Director	TSP	Face to face	USA
R116	Business Development Manager	Shipowner	Face to face	Global
R117	Senior Safety Advisor	RB	email	Europe
R118	Director	Shipowner	email	Canada
R119	Director	RB	Online	Far East
R120	Director	Supplier	Face to face	Europe

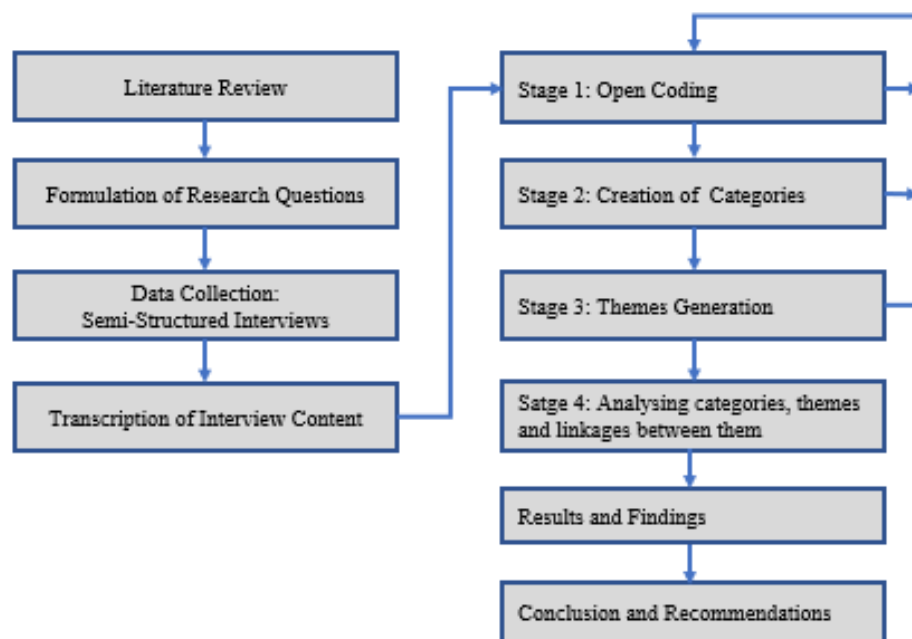
Source: Author

Shipowners' representatives run container fleet, ferryboats, LNG vessels, and tankers. The participant covered under the regulatory body, represents one of the leading ports in shipping. Truck-to-ship and ship-to-ship operations are currently conducted, and simultaneous operations have just started. The port develops regulatory content and sets standards in order to perform safe and effective LNG bunkering operations. The second port respondent represents one of the busiest ports in Europe

for Ro/Ro shipping, container, and LNG handling. The port also provides ship-to-ship LNG bunkering facility. Classification society representative already has LNG fuelled vessels under their service. The suppliers are either major oil representatives taking part in every stage of the supply chain, or conventional bunker supplier who have recently invested in LNG bunkering, or LNG suppliers who have recently started to provide marine fuel. Technical service providers represent engine manufacturers, safety equipment manufacturers for gas systems and infrastructure developers for gas supplies. LNG bunkering operations are very limited across the world, and it's still only possible at specific locations. The dedicated LNG bunkering summit has provided the opportunity to reach out to senior-level experts in this newly developing field.

Face-to-face interviews, online interview, notes taken during interviews were transcribed. To analyse this primary data obtained from the interviews, MAXQDA 18.1.1 Software was used. The qualitative data were coded on software. The study was conducted in four stages: 1-Open Coding, 2- Creating categories, 3- Generating themes, 4-Comparing the themes, analysing, and integrating them (Vaismoradi et al., 2016). Following these four stages, MAXQDA descriptive statistics were analysed. Flowchart of the semi-structured interviews illustrated in Figure 60.

Figure 60: Flowchart of the Research Method for Semi-Structured Interviews



Source: Author

The first stage of the study following literature review Face-to-face interviews, online interview, notes taken during interviews were transcribed. To analyse this primary data obtained from the interviews, MAXQDA 18.1.1 Software was used. The descriptive statistics obtained through MAXQDA 18.1.1 were evaluated in order to gain insight into LNG bunkering. The distribution of codes and parent codes were analysed. The respondents were grouped into four categories: Shippers, suppliers, technical service providers (TSP), and regulatory bodies (RB). The codes were explored based on different stakeholders' views.

4.2.2. Participant Observation

Observation is a rewarding and informative part of research. It entails systematically observing, documenting, describing, interpreting, and analyzing people's behavior (Saunders et al., 2009). Participant observation is a qualitative research approach with origins in ethnographic research that enables researchers to gain insight into the experiences of the sample population (Mack et al., 2011). Qualitative researcher either could be participant as observer or observer as participant. In this study, the researcher took part in LNG bunkering operation as 'observer as participant'. The identity and purpose are known by the participants. As the LNG bunkering modelling is part of the research, participant observation in LNG bunkering is at the centre of the research objectives and questions.

Participant observation method allows researchers to make objective notes about what they see, observation at field, have casual conversations with members of the sample community, and engage with them (Mack et al., 2011). Data obtained through participant observation provides opportunity to check participants' subjective reporting and also a useful tool to gain understanding of the physical, social, cultural, and economic contexts of the research field. The researcher develops familiarity with the research context and provides a nuanced understanding of the phenomenon which comes through certain personal experience. There is no substitute for witnessing in phenomena of human interaction, that is the case in the study, interaction with crew, superintendent, supplier, port, LNG fuelled vessel and trucks that carry the LNG.

Participant observation also enables to unlock important factors which are unknown to the researcher at the beginning of the study (Mack *et al.*, 2011).

There are also various disadvantages of the participant observation method. It could be very time-consuming depending on the research field and may not be practical. The second disadvantage could be the difficulty to document the data, instead the researcher relies on memory, the notes and the records (Saunders *et al.*, 2009). Therefore, the researcher should write down and expand the observations as soon as possible. As the observation is inherently subjective, participant observation method may risk the reliability of the study due to the observer bias. The researcher should be aware of this threat and seek to control it. Therefore, in order to ensure reliability, researcher asked himself questions such as: what other interpretations could be made, was it performed under ‘normal’ working conditions? As the video or photograph is not allowed onboard, the researcher took handwritten notes for spontaneous interview during LNG bunkering operation at Port of Rotterdam. Field notes were documented and transferred into computer right after the observation on field.

4.2.3. Multiple Regression

Regression provides important tools to understand the relation between the variables. In other words, it aims to measure the effect of an explanatory variable or variables on dependent variable (Koop, 2006). In order to investigate Turkey’s bunkering sales and its relationship with global economic variables and Çanakkale/İstanbul Strait passage statistics, regression technique was employed. As the regression analysis explains the relation of dependent and independent variables, statistical interpretation helps us to understand Turkey’s bunkering dynamics. Therefore, in this research, linear-squares regression technique was used. Linear regression models always offer an approximation of the true relation. The truth might be dependent on other variables or factors (Koop, 2006). This omitting data and linear relation of two variables can be expressed mathematically as follows:

$$Y_t = \alpha + \beta_1 X_1 + e$$

Y is referred to the dependant variable, X the explanatory variable; α and β coefficients and e is indicator of error. The intercept of regression model is defined as α , while β is defined as slop. Therefore, β is quite important that determines X-Y relation for simple regression. However, in multiple regression β coefficient is slightly different. In this case β_1 is the marginal effect of X_1 on Y while all other variables are constant. This relation is called as *ceteris paribus* (Koop, 2006). Moreover, multiple regression is formulated with same process with same additional variables indicated below:

$$Y_t = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k + e$$

Multiple regression is an important tool for time series analysis. However, from statistical perspective some points need to be clarified for the appropriate use of technique and comprehensive interpretation.

4.2.3.1. Unit Root Test

There are two problems in time series data: 1- one set of the time series data can influence other series with time lag, 2-spurious regression can rise when variables are non-stationary (Koop, 2006). Therefore, none of the variables can be non-stationary for regression modelling. Non-stationary time series are defined as time series data which contain a unit root or a stochastic trend. They are also called *difference stationary*, as their difference series will be stationary. If variables in regression have unit roots, all of the regression might be wrong, this is called spurious regression problem (Koop, 2006). Therefore, before running any regression model, unit root test must be carried out for variables in order to see if they are stationary or not.

The KPSS(Kwiatkowski–Phillips–Schmidt–Shin) test provides statistical interpretation in order to see if time series are *stationary* around a *mean* or is non-stationary due to unit root. In stationary time series, *mean* and *variance* variables are constant over the time.

KPSS test is available in EViews10 software and it determines whether the time series data has unit root or not. It is based on ordinary least square regression

(OLS). The KPSS test splits the time series into three parts as deterministic, random walk and a stationary error (Kwiatkowski *et al.*, 1992). In the KPSS test null hypothesis is stationary. If the LM statistics is smaller than Asymptotic values at 1%,5% and 10%, null hypothesis is accepted, in other words data is stationary. Table 36 shows EViews output for the KPSS test. The unit root test hypotheses are:

H_0 : KPSS test statistic < critical values at (1%,5%,10%) $\Rightarrow$ series stationary

H_1 : KPSS test statistic > critical values at (1%,5%,10%) $\Rightarrow$ reject null

Table 36: KPSS Test Outcome Sample

		LM-Stat
Kwiatkowski-Phillips-Schmidt-Shin test statistic		0.156335
Asymptotic critical values	1% level	0.739000
	5% level	0.463000
	10% level	0.347000

Source: Author

4.2.3.2. Multicollinearity

Multicollinearity is a statistical problem that arises from the strict correlation of different explanatory variables. If the variables are correlated significantly, the regression model is not able to tell which variable(s) is/are influencing the dependent variable. Therefore, the variables must be checked before using them for regression model. For this purpose, all variables in the regression model such as bunker sales, world seaborne trade time series data are checked for potential multicollinearity. If the multicollinearity exists, one of the variables can be dropped from the regression model. Variance Inflation Factors (VIF) is a method to measure the level of collinearity between the variables in the equation. It's basically calculation of dividing the variance of a coefficient estimate by the variance of that coefficient had other variables not been included in the equation (EViews8, 2013b). EViews provide tool to measure VIFs of variables.

4.2.3.3. Histogram and Normality Test

Regression, correlation, t tests, and analysis of variance statistical applications are based on the assumptions that the data follows a normal distribution. Therefore, normal distribution of the data should be assured in order to reach a reliable conclusion (Ghasemi and Zahediasl, 2012). Jarque-Bera test is a method to see whether the series is normally distributed. Basically, the difference of the skewness and kurtosis of the series with those from the normal distribution is measured by the test. The null hypothesis of normal distribution is rejected under the 5% (EViews8, 2013a).

4.2.3.4. Serial Correlation LM Test

In time series researches, when the errors related with a conferred time period hold over into future, serial correlation occurs. Serial correlation does not affect consistency of OLS estimator, but it affects their efficiency (Schechtman, 1990). Therefore, regression models need to be checked for serial correlation. Breusch-Godfrey LM test is the $\text{Obs} \times R^2$ statistic. Breusch-Godfrey LM statistic is calculated as the number of observations, times the (uncentered) R^2 from the test regression. Prob Chi-Square(2) value below 5% rejects the null hypothesis and indicates that there is a serial correlation (EViews8, 2013b).

4.2.3.5. Heteroskedasticity

Utilising particular types of cross-sectional data, observation based on average data and random coefficients could lead to heteroskedasticity and non-normal residuals (Kalirajan, 1989). Breusch-Pagan-Godfrey (BPG) test allows to test heteroskedasticity in the residuals of equation. $\text{Obs} \times R^2$ (where R^2 is from the auxiliary regression) is used. Prob-Chi-square(3) below 5% indicates heteroskedasticity (EViews8, 2013b).

4.2.4. ARIMA Forecasting

ARIMA (Auto regressive integrated moving average) models are incorporation of three tools for modelling the serial correlation in the disturbance. First tool is AR (autoregressive) term. The AR model is used not only with first-order but also high-order. Lagged values of the residual in forecasting equations are corresponded to different AR terms. An AR model has form of AR (p):

$$u_t = \rho_1 u_{t-1} + \rho_2 u_{t-2} + \cdots + \rho_p u_{t-p} + \epsilon_t$$

The second term is integration. Different integration orders are related to differencing the series being forecast. For example, first-order component means that the forecasting model is designed for the first difference of the original series.

The third tool is the moving average (MA) term. To strengthen the current forecast, the MA model utilises lagged values of the forecast error. The first order MA term uses the most recent forecast error, while the second order MA term uses the forecast error from the two most recent periods. A MA model has form of MA(q):

$$u_t = \epsilon_t + \theta_1 \epsilon_{t-1} + \theta_2 \epsilon_{t-2} + \cdots + \theta_q \epsilon_{t-q}$$

Box-Jenkins 1976 model combines three tools described above to complete forecasting model. The initial step to form an ARIMA model is to see autocorrelation properties in correlogram. It's called identification, the correlation nature of current values of residuals and their past values gives support for selecting ARIMA model. The next step is to decide which kind of ARIMA model to be used. If the autocorrelation function is decreasing at geometric rate, then first-order autoregressive model is appropriate (EViews8, 2013b). Differencing the series removes unit root and stationary series are obtained. ARMA terms are to be used as part of the equation. For example, fourth order autoregressive and second-order moving average error process will be expressed as AR(1), AR(2), AR(3), AR(4), MA(1) AND MA(2). EViews Automatic ARIMA forecasting tools takes first difference of the series if necessary and advises ARMA models and picks up the best option as lowest Akaike info criterion

(AIC). Akaike information measures are based on the estimated log-likelihood of the model, the number of parameters in the model and the number of observations. Verifying the number of ARMA terms depends on identifying a maximum number of AR or MA coefficients, then estimating every model fit for those maxima and information criteria. When each model is estimated, criterion can be computed and the lowest value is chosen (Arima, 2020). Forecasting tool has been used based on regression findings of Turkey's bunker sales and its relationship with global economic variables and strait passage statistics.

4.2.5. Optimization and Modelling

Optimization is an important instrument to analyse physical systems and provides a tool for decision science. The first step of the optimisation is to identify some *objectives*, which is a quantitative measure of the system (Nocedal and Wright, 2006). Potential energy, time, profit or any other quantity that can be defined by a single number could be an objective. This objective is subject to *variables* that constitute characteristics of the system. These variables are usually restricted that is *constrained* (Nocedal and Wright, 2006). On the other hand, *modelling* is defined by Nocedal and Wright (2006) as the process of identifying the objective, variables, and constraints for a given problem. The first step is to construct the appropriate model in the optimization process. Research objectives of the study aim to find optimum ship size, capacity, number of the ships to be utilized and their delivery. The construction of the model has been started with defining the objective as minimising the cost as fixed and operational variables. Daily charter rate, running cost of the ships, fuel consumptions have been taken as primary variables for model constitution.

The formulated model could be solved by an optimization algorithm usually with computer assistance. There are numerous optimization algorithms that can be used to solve particular problems. It's the researcher's responsibility to find and apply the appropriate algorithm in order to reach a solution. The solution has to be evaluated after applying an optimization algorithm to the model by so called *optimality conditions*. Optimality conditions provide information on how to improve the model in case the solution is not satisfactory. The *sensitivity analysis* is a tool to determine

how robust the proposed solutions are to changes (Dantzig and Thapa, 1997). The current solution can be improved or corrected by changes in model and data. In order to solve the model, LINGO 15.0.63 has been used. LINGO provides comprehensive tools to solve linear, non-linear, quadratic, quadratically constrained, second order cone, semi-definite, stochastic and integer optimization problems. It's widely used in optimization modelling problems in academic and industrial fields (LINGO, 2020).

4.2.5.1. Linear Programming

The problems of planning crop rotation, of military activities and the routing of ships between ports to organize the transfer of commodities were critical considerations during World War II. Industrial production, resource allocation as well as the management of finance all required coordination. Timing and quantity of actions is the aim of developing a system in order to achieve the goal at best possible way (Dantzig and Thapa, 1997). Dantzig and Thapa (1997:xxi) argues that *"The computational task is then to devise for these systems an algorithm for choosing the best schedule of actions from among the possible alternatives"*. Industrial, financial, and military systems can be modelled or approximated by mathematical systems which utilize linear inequalities and equations. This approach led the development of linear programming field by Dantzig's 1947 study. Although there were some studies in linear programming before 1947, none of them were aimed at optimization or a defined objective function (Dantzig and Thapa, 1997). The first applications of linear programming were seen in the petroleum industry to organize oil extraction, refining, blending and distribution systems. Dantzig, (1963) uses the term 'model building' to express the process of gathering symbols representing objects in order to form a structure, the so called the model, which matches the 'system' in the real world.

Nowadays linear programming is a valuable tool in many fields such as economics, management and engineering (Hu and Kahng, 2016). In real world applications, it's used to maximize the profits, minimize the costs and maximize the speed problems. In linear programming, the maximizing or minimizing function is subject to constraints in that field. For example, in maximizing the profit, constraints are market size or limited resources. In minimizing the cost of production, a constraint

could be certain standards that need to be satisfied. Linear programming is formulated by some assumptions (Sariaslan et al., 2017). Linear programming assumes that objective function and constraints are linear equations - linearity. The objective of the linear programming is to provide optimal allocation of the limited resources. Therefore, all resources must be limited and their limits have to be known - boundedness. Decision variables can take continuous values, meaning that variables can be fractional numbers – divisibility (Sariaslan et al., 2017). If the divisibility is not requested, or variables are required to take integer values, integer programming must be employed. Moreover, the assumptions of a linear model may not be realistic, but may provide the first approximation to understand a real world problem (Hu and Kahng, 2016). Since Dantzig, linear programming has significant implication in supply chain management. LNG supply chain, modelling, optimization and maritime transportation problems have been solved by linear programming (Hoff *et al.*, 2010; Awudu and Zhang, 2013; Msakni and Haouari, 2018).

4.2.5.2. The Linear Programming Problem

There are three basic elements in linear programming: objective function, decision variables and constraints (Vanderbei, 2008). The objective in a linear programming is to minimize or maximize some linear functions. It is formulated by decision variables in a linear form and could be a cost, profit or capacity. For instance,

$$z = C_1X_1 + C_2X_2 + \dots + C_nX_n \quad (4.1)$$

Objective function can be generalized as below:

$$Z = \sum_{j=1}^n C_j X_j \quad (j = 1, 2, \dots, n) \quad (4.2)$$

Objective function in linear programming has two constraints: resource constraints and a non-negativity constraint. Resource constraints could be as much as number of the resources to be limited and can be shown as below:

$$a_{11}X_1 + a_{12}X_2 + \dots + a_{1n}X_n \leq b_1 \quad (4.3)$$

In general constraints can be defined as below,

Variables in linear programming problems are required to not to take a negative value; as a ship, truck or bus cannot be represented as, $x=-10$, ship=-10, in this problem variables (X_j) can not take negative value. Therefore, it has to be added as a constraint.

$$X_j \geq 0$$

Linear program can be represented for maximization as follows;

$$\sum_{j=1}^n a_{ij} X_j \leq b_i \quad (i = 1, 2, \dots, m)$$

$$X_j \geq 0 \quad (j = 1, 2, \dots, n)$$

Minimization is defined as,

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$$\sum_{j=1}^n a_{ij} X_j \geq b_i \quad (i = 1, 2, \dots, m)$$

$$X_j \geq 0 \quad (j = 1, 2, \dots, n)$$

4.2.5.3. Mixed Integer Linear Programming (MILP)

Real-world problems could be designed as linear programs except the ones that include integer variables. There are many problems that should be modelled as integer programming such as scheduling problems, the travelling salesman problem, fixed costs, non-linear objective function or branch-and bound (Vanderbei, 2008). Linear programming allows non-integer values of the solution. In other words, variables can be divided until the smallest unit. However, in real-life scenarios that would not be possible. In this case, it's required to use integer programming rather than linear programming (Sariaslan et al., 2017).

Integer programming consists of some variables needing to be an integer. There are three types of integer programming: Firstly, all variables are an integer; secondly, some of the variables are integers; thirdly, 0-1 or binary integer programming requires all variables to either take 1 or 0 value (Sariaslan et al., 2017). These variables are used to describe some relationships that linear programming cannot handle. Mixed integer programming is able to overcome many limitations of linear programming (Shapiro, 2001; Topaloglu & Ozkarahan, 2011). Binary variables are able to use in supply chain models that capture operational, tactical, strategic problems. They are able to be used to model routing decisions along with scheduling of machines or vehicles. For tactical problems; fixed costs, economies of scale, logical, policy restrictions are modelled. Strategic decisions such as timing, sizing or location of investment decision are modelled by binary variables (Shapiro, 2001).

Supply chain analysis is provided with a rigorous approach by the mixed integer programming model. Important decision options, constraints, and objectives of the supply chain problem are accurately captured by the models, eventually providing a good optimal solution for the problem (Shapiro, 2001). Inevitably, mixed integer linear programming (MILP) has been employed by one of the primary methods in

order to solve supply chain optimisation problems (Jokinen et al., 2015; Bittante et al., 2017; Ye, Liang and Zhu, 2017; Mikolajková et al., 2018b; Gao and You, 2019; Zarei and Amin-Naseri, 2019; Sangaiah et al., 2020). The branch-and-bound method is used for optimising mixed integer programming as a sequence of linear programming approximations.

4.2.5.4. Branch and Bound

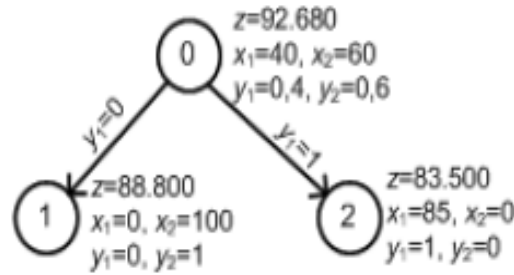
Branch and bound is a widely used solution method that can be applied not only to integer programming problems but also to non-integer types of problems (Türkay, 2006). The branch and bound principle is to partition a total set of solutions into smaller sub sets of solutions, then these smaller sub set solutions are evaluated until the best solution is found (He, Daumé and Eisner, 2014). Understanding the logic underlying the branch-and-bound model is important for the supply chain decision maker, otherwise, it may lead to more computational effort without unbalanced importance and a more complex supply chain problem (He, Daumé and Eisner, 2014).

Branch-and-bound algorithm is based on the relationship of integer variables which are allowed to take any value - called approximation. At the end of each solution, one bound is obtained for the best solution. Variables are evaluated after each solution and new nodes are created. The process is ended once:

- The variables that need to take an integer value in fully relaxed or partly relaxed problem, take integer variable for objective function,
- Objective function in one node is worse than another objective function value,
- Solution in one node does not comply with some of the constraints

According to the above rules, a branch-and-bound tree is generated and once all branches are ended, the best optimum solution is obtained (Türkay, 2006).

Figure 61: Mixed Integer Linear Programming, Branch-and-Bound Tree



Source: (Türkay, 2006)

Figure 61 shows an example of the branch-and-bound method. ‘0’ node is upper bound for objective function. It is seen that integer variables take 0.4 and 0.6 for y_1, y_2 respectively. Two new nodes are generated as taking y_1 as integer 0 and 1 values. In new nodes, all variables are integer, node 1 is taken as the best the result.

MILP is widely used in supply chain optimization. It provides a solution for strategic, tactical and operational level supply chain problems. As the objectives of the study includes sizing, timing, quantity, capacity problems in the supply chain, the MILP method has been employed in order to find optimum solutions for a small-scale LNG supply chain for bunkering purpose in Turkey.

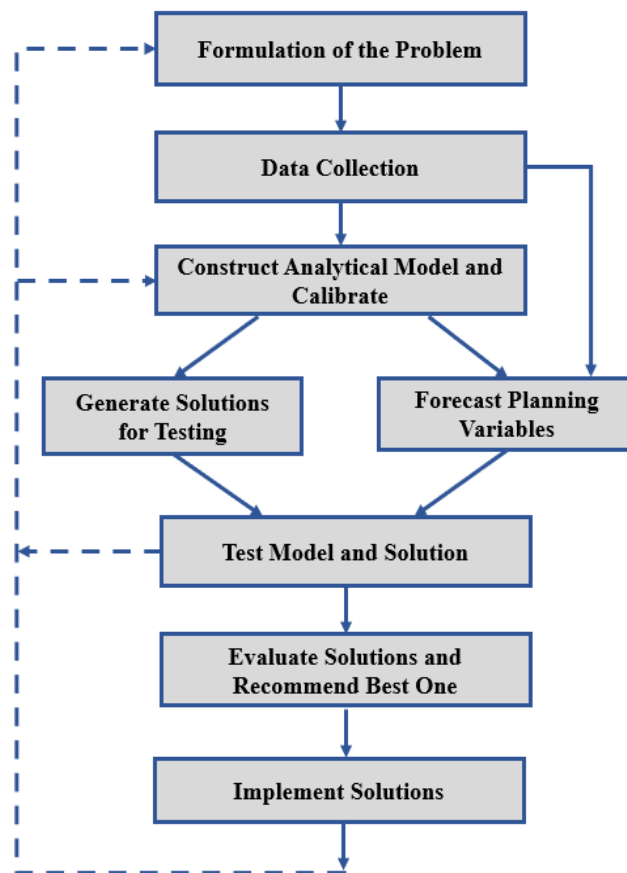
4.2.5.5. Transportation Problem

The transportation problem is one of the special application of the linear programming. Main purpose is to minimize the cost of shipping goods from one location to another (Reeb and Leavengood, 2002). Solving transportation problems only by planning is not possible (Ortuzar and Willumsen, 2011). The plans must be utilized within a decision process adapted to the chosen decision-making style. The classical transportation problem decision making process is summarised in Figure 62 with 8 steps.

The first step is to formulate a problem. Formulation of the problem requires reference to objectives, standards and constraints. Development of the analytical model is provided by data collection. Data collection is interconnected with model

development. Constructing an analytical model requires identifying, estimating or calibrating its parameters and confirming its function with data not used during calibration. Generating results for testing involves optimisation techniques such as supply and cost minimisation procedures. Forecasting the future value of the variables, which are inputs for the model, is necessary. It requires quantified descriptions or scenarios for the future of the area of the interest. The model must be tested under different scenarios in order to see whether it's reasonable and to simulate different solutions and estimate their performance for the indicators in the range. Next step is evaluation of the solutions. That includes economical, operational and financial assessment of the outcome. It is expected to provide a recommendation of a plan, strategy and policy. The last step is implementation of the solution, which is required to search for another problem and construct a new model (Ortuzar and Willumsen, 2011).

Figure 62: A Framework for Rationale Decision Making with Models



Source: Ortuzar & Willumsen (2011)

The transportation problem has been considered by the researchers since the World War II. Although the first study was conducted by Kantorovich, the first transportation problem was formulated in a model by Hitchcock in 1941. The model was improved by Koopmans but it was defined as a linear programming problem by Dantzig, for the first time (Sariaslan et al., 2017). It was used to control military deployment or relocation in Europe and Asia. The transportation problem is one of the applications of linear programming. In a base model of a transportation problem: The supply at supply centre is S_i . The demand for the good is in n different centres represented as $j = 1, \dots, n$. Demand at j th centre is D_j . The objective is to carry the good from supply centres to demand centres at minimum costs. The cost of shipping from supply centre i to demand centre j is $c_{i,j}$ and the cost is linear. It means that if $x_{i,j}$ units are shipped from supply centre i to demand centre j , total cost would be $c_{i,j} x_{i,j}$. It will be defined as:

$$\min \sum_{i=1}^m \sum_{j=1}^n c_{i,j} x_{i,j}$$

There are numerous studies that utilize transportation problem modelling in order to obtain minimum shipping costs (Jokinen, Pettersson and Saxén, 2015; Oglend, Kleppe and Osmundsen, 2016; Ye, Liang and Zhu, 2017; Zhang *et al.*, 2019). Fuel cost or shipping cost from i to j is the main expenditure on the ship operators budget (Stopford, 2013). The study also aims to find optimum alternative for LNG bunker vessel according to minimum cost scenario that fuel cost has significant effect. Different scenarios need to be employed in order to draw a framework, see the limits and obtain evaluation process while utilising linear programming. The scenarios planning at different demand levels provide insight for LNG bunkering in Turkey.

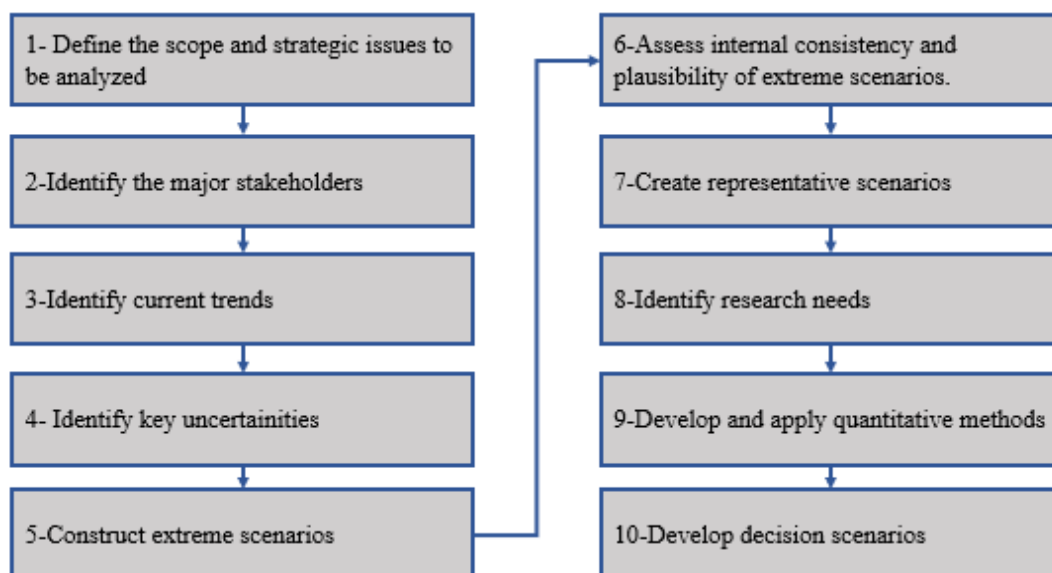
4.2.6. Scenario Planning

Scenario planning is a process in order to organize, enhance, and provide a projection for the organization for their strategic planning. The quality of the strategic planning is correlated with the quality of the scenario planning. It provides a discipline which practitioners can adapt to different needs (Shapiro, 2001). Shapiro (2001)

defines scenario as focused descriptions of profoundly different futures given in consistent descriptions. It provides the learning and exploring of interrelationships among strategic and key uncertainties. Ortuzar and Willumsen (2011) argue that developing scenarios and describing relevant characters of transport system is necessary. Once the base scenario is prepared, realistic scenarios and plans should run the same sequence of the model in order to simulate their performance. Then comparisons of the scenarios are made between costs and benefits (Ortuzar and Willumsen, 2011)

The scenarios in the study are constructed based on Schoemaker's ten-step scenario methodology that is used in supply chain design (Schoemaker, 1993; Shapiro, 2001). Schoemaker's approach argues that the multiple scenario method thus differs from traditional planning and risk analysis on a psychological basis. Moreover, critical differences exist in problem specifying, organizational implementation and the psychological premise. Schoemaker (1993) points that out the value of scenario planning seems to pivot on examining merging factors rather than single contingencies. The steps of the scenario in Schoemaker's scenario development methodology are summarised in Figure 63.

Figure 63: Ten-step Scenario Methodology



Source: Schoemaker (1993)

Details of scenario planning is explained as follow:

- The scenario development time frame for the strategic analysis was firstly defined. Due to available historical data of bunker deliveries in Turkey, it was limited to 2025. General characteristics of LNG was defined and LNG bunkering market was highlighted. Turkey's Mediterranean, Aegean and Marmara Sea Coasts were determined as delivery locations based on Turkey's trade volume, bunker delivery volume as well as Canakkale and Istanbul Strait traffic data.
- Major stakeholders of the LNG were identified as: Suppliers, shippers, ports, technical service providers and regulatory bodies.
- At the third step, interviews were conducted with experts in order to analyse current trends in LNG bunkering.
- Fourthly, based on a literature review and expert views uncertainties, barriers were defined. Demand is the key driver of the market that supplier and receiver side place emphasis.
- At the fifth step, scenarios were developed while taking into account different supply points.
- In order to provide consistency and plausibility, historical time series data of bunker deliveries of Turkey were taken as benchmark for expert consultation.
- At the seventh step, different scenarios in range of 1%,5%,10%, 15% LNG bunkering demand were created, which realistically reflects stakeholders' behaviours and market trends.
- Research objectives that question the number of the barges and capacity to be deployed for optimum delivery network with minimum cost were highlighted.
- The MILP method was employed in order to solve this problem along with regression analysis and forecasting methods.
- For the last step, based on the results, expert views are collected and literature decision scenarios were developed.

4.2.7. Semi-Structured Interviews with Experts in Turkey

The third stage of the study aims to fulfil seventh research objective which requires to make recommendations for Turkey's small-scale LNG, LNG bunkering supply chain development. Following the same research methodology as did in first stage of the study, semi-structured interviews were planned.

In line with the first stage of the study, the population covers shipowners, suppliers, regulatory body and technical service providers. The purposive sampling strategy was used in order to maximise the variations on the phenomenon. Interviews were conducted with six shipowners, five suppliers, four regulatory body and four technical service provider representatives. Number of the interviews were not determined before, rather, size of the samples was restricted in line with theoretical saturation, in other words, till data collection generates no insight.

Due to Covid 19 restrictions, all interviews were conducted through online meetings, phone conversations remotely. Since they are not obligated to host the interviewer or meet them at a certain time, managers feel less dedicated when conducting remote interviews. Remote interviewing, however, does not always favour the researcher for these reasons. Face-to-face interviews provide instant contextualization, depth, and nonverbal communication that mediated interviews lack (Easterby-Smith et al., 2015). However, internet-based or telephone conversation could be particularly useful in real-time and process-based research.

Themes of the questions were determined in parallel to stage 1 semi-structured interviews as safety, technical, operational, regulatory framework and commercial components. In addition to this template, findings of the mathematical model under three scenarios were asked to experts. Interviews were conducted between 16th November 2020 and 5th December 2021.

Rigor of the study is established through (Wallendorf & Belk (1989) protocol (Sağlam, 2019). In order to establish credibility, before each interview, the aim/scope of the research and the background of the interviewer were explained. Brief summary was made after each interview in order to confirm that the understanding of the interviewee is correct. Purpose sampling method was used to achieve transferability which is achieved through variation of participants in terms of title and segments.

Dependability is ensured through not restricting sample size and data collection process was completed once theoretical saturation was assured. In order to achieve confirmability; the responses of different participants were not shared with any other, and the findings were interpreted through quotes. Integrity of the research was assured though compliance with ethical principles. Names and company details were kept confidential.

Shipowners' representatives run bulk carriers, tankers and container vessels. One of the tanker owners has already LNG fuelled vessels on their order list. The technical service providers include shipbuilding industry, shipyard, ship design and leading LNG technology provider in the world. The shipyard representative has already built LNG fuelled vessels and other alternative fuelled vessels on their shipyard. The design/consultancy firm representative has delivered numerous projects fuelled with LNG. The suppliers in the list include port/terminal representatives and bunker suppliers. Regulatory body participants are policy makers and classification society representative. Table 37 summarises the details of the semi-structured interview participants.

Table 37: List of Interviewees with Experts in Turkey

Code	Title	Function	Type
R201	Director	TSP	M.Phone
R202	Business Development M.	TSP	Online
R203	Planning Manager	Shipowner	E-mail
R204	Country Manager	TSP	Online
R205	Country Manager	Regulatory Body	Online
R206	General Manager	Supplier	E-mail
R207	Energy Manager	Shipowner	M.Phone
R208	General Manager	Shipowner	Online
R209	Senior Technical Officer	Regulatory Body	E-mail
R210	Ass. Sec. Gen.	TSP	Online
R211	General Manager	Supplier	Online
R212	GM	Shipowner	E-mail
R213	Investment Manager	Supplier	E-mail
R214	Director	Supplier	Online
R215	General Manager	Regulatory Body	E-mail
R216	Energy Specialist	Regulatory Body	Online
R217	General Manager	Supplier	Online
R218	Operation Manager	Shipowner	E-mail
R219	Operaiton Manager	Shipowner	E-mail

Source: Author

4.3. RESEARCH QUALITY, VALIDITY AND RELIABILITY

Reliability and validity are two important concerns for the quality of the research (Saunders, Lewis and Thornhill Adrian, 2019). Saunders et al. (2019) argue that *reliability* refers to replication and consistency, on the other hand, *validity* refers to appropriateness of the measures used, accuracy of the results and generalisability of the findings. Yin (2003) proposes general four tests to be implied to case study strategy: *construct validity*, *internal validity*, *external validity*, and *reliability*. As Turkey LNG bunkering development is taken as single-embedded case study, the research's validity and reliability has been constructed in this framework.

Using different data collection sources is the main strength of the case study (Yin, 2003). Multiple methods, or triangulation, are reflection of an attempt to provide an in-depth understanding of phenomenon (Denzin, 2012). Establishing chain of evidence and multiple source of evidence provides *construct validity* (Yin, 2003). Turkey LNG bunkering case has been investigated through qualitative and quantitative data sources. Triangulation strategy allows to establish a chain of evidence as regression analysis provides data base for forecasting, forecasting ensures to determine demands for potential bunker sales. Mathematical modelling uses these data to reach research objectives while the results are evaluated along with semi-structured interviews. Link between methods and application of different data collection methods ensure construct validity of the research.

Internal validity is defined as '*the validity of inferences about whether the relationship between two variables is casual*' (Shadish et al., 2002:508). Yin (2003) argues that internal validity is a concern for explanatory case studies. Determining the relation between two events, however, failing to reveal third factor causes threat to internal validity of the study. The second concern for the internal validity of the case study is making inferences (Yin, 2003). Teddlie & Tashakkori, (2009) point out that inference quality is proposed as mixed-method term which incorporates the quantitative terms *statistical conclusion validity* and qualitative terms *trustworthiness* and *credibility* (Teddlie and Tashakkori, 2009). Although study is in exploratory and descriptive nature, utilized methods involve explanatory structure in the case study. Yin (2003) argues that there are several ways to assure internal reliability such as

explanation-building, pattern-matching, rival explanation or logic model. The logic model is an analytical technique which follows sequential stages and repeats over cause-effect pattern (Yin, 2003). The study assures internal validity with this perspective as regression analysis, forecasting and mathematical modelling have been designed in sequential way to produce a certain outcome. Exploring Turkey's bunkering dynamics provides benchmark for forecasting future trends. Future bunkering market offers another benchmark for mathematical model that is designed over potential demand.

Scholz and Tietje (2002:336) defines external validity *'as it refers to the generality of a finding, such as an effect of a cause-impact relationship, and to what degree this finding or effect can be generalized to other measurements, variables, population, settings, situations, cases, and so on'*. Easterby-Smith et al. (2015) emphasise that research conducted in large organisation may not apply to smaller one or research conducted for one nation may not be applicable to other nations. *External validity* problem is a major barrier for case study researches that it offers poor ground for generalisation (Yin, 2003). However, Yin (2003) argues that case studies rely on analytical generalisation which can be obtained through a theory. The problem lies in the notion of generalizing to other case studies. It could be achieved by the researcher through trying to generalize the findings to "theory", similar to the way a scientist generalizes from experimental results to theory (Yin, 2003).

Cresswell (2009:233) defines research *reliability* as it *'refers to whether scores to items on an instrument are internally consistent (i.e., Are the item responses consistent across constructs?), stable over time (test-retest correlations), and whether there was consistency in test administration and scoring'*. Saunders et al (2009) defines reliability as replication and consistency that is provided by repeating the same research design and obtaining the same findings. Reliability in research aims to minimize the errors and biases in a study (Yin, 2003). Scholz and Tietje (2002) argue that despite the formative approach, case analyses are not objective as they are constraint by study team's case understanding, competency with the methods, proficiency, motivation and intention. However, it is argued that as reliability is based on application and uniform measurement rules; applying clear operational definitions procedures provides consistent and stable results (Abowitz and Toole, 2010). Yin

(2003) advocates the same argument by making many steps of the research as operational as possible to allow conducting the same research by repeating the same procedures in a case study. Therefore, in order to assure reliability, each step of the study has been explained in detail, strongly documented and allowed external examiner to follow the research.

Quality of the research is assured by validity and reliability (Saunders, Lewis and Thornhill Adrian, 2019). Mixed methods and triangulation strategy have important factor on quality of the research (Jick, 1979; Baxter and Jack, 1990; Cresswell, 2009). Baxter and Jack (1990) argue that triangulation of data sources would support the principle in case study research that is allowed to explore phenomenon from different perspectives. Comparison and collection of the data increase data quality as well as provides confirmation of findings (Baxter and Jack, 1990). Jick (1979) points out that triangulation provides more complete and holistic approach, and support quality of the research as multiple measures uncover some findings that would not be explored under single method. Multiple methods of data collection and analysis reinforces reliability and internal validity (Cresswell, 2009). Small-scale LNG supply chain and LNG bunkering research has been conducted with mixed-methods and triangulation strategy. Defining each step and operationalisation throughout the research, reporting in detail provides a clear accurate picture of the methods in the study. Apart from overall quality discussion of the research, each methods' reliability and validity discussed separately.

CHAPTER V

FINDINGS AND ANALYSIS

5.1. FINDINGS OF THE SEMI-STRUCTURED INTERVIEWS

Following literature review, in the first stage of the study, semi-structured interviews were analysed. Face-to-face interviews, online interview, notes taken during the interviews were transcribed. To analyse this primary data obtained from the interviews, MAXQDA 18.1.1 Software was used. The descriptive statistics obtained through MAXQDA 18.1.1 were evaluated in order to gain insight into LNG bunkering. The distribution of codes and parent codes were analysed. The respondents were grouped into four categories: Shippers, suppliers, technical service providers (TSP), and regulatory bodies (RB). The codes were explored based on different stakeholders' views.

Table 38: Distribution of Codes Based on Frequency

Code	Frequency	Documents
Location/Operation Region	5.79	19
Commercial Factors\Demand	4.52	12
Commercial Factors\LNG Bunkering price	4.34	15
Commercial Factors\LNG Price	3.98	13
Infrastructure	3.80	14
Safety	3.80	13
Commercial Factors\Oil Prices	3.62	12
Collaboration	3.62	10
Commercial Factors \Market	3.44	12
Safety\Crew Training	3.44	11

During the first round of coding, the transcripts were read through and coded with the open-coded approach with no limitations or segmentations. In the second round, transcripts were coded based on the interpretation of the raw data. In the third round, higher-level codes and lower-level codes were defined. After the third round, the codes were refined, and the most highlighted codes were determined. The location/operational region was determined as the highest frequency in data - emphasised in nineteen documents. The top ten frequent codes were listed in Table 38.

Demand, LNG bunkering price, LNG price were found as the other significant factors. Infrastructure was discussed in 14 different interviews and followed by oil prices, market conditions, and crew training factors.

In the second stage, the codes were customized, and the categories were created. Parent codes and sub-codes were shaped in hierarchical order. In the third stage, twelve main themes were generated. Commercial factors represent the most emphasized factors that have 34% frequency and mentioned in all documents. Other theme frequencies are between 1.65 and 9.9%. Safety consideration took the second place, with 9.9% narrowly in front of the environmental considerations (8.55%). The related codes were gathered under the regulatory framework, technical factors, and infrastructure. Themes were created as Location/Operation Region, Operational factors, Collaboration, Fleet Type, and Supply Chain. Some factors, which are considered important but not frequently mentioned in data sets, were grouped under ‘Others’ category. These include transparency, work management, strategy, public opinion, etc. Parent code distribution is summarized in Table 39.

Table 39: Distribution of Parent Codes Based on Frequency

Main Code	Coded segments	Coded segments as %	Documents
Commercial Factors	228	34.18	20
Safety	66	9.90	16
Sustainability/Environmental	57	8.55	15
Regulatory Framework	51	7.65	16
Technical Factors	49	7.35	11
Infrastructure	40	6.00	14
Location/Operation Region	37	5.55	19
Collaboration	37	5.55	10
Fleet type	34	5.10	10
Operational Factors	34	5.10	14
Supply Chain	23	3.45	7
Others	11	1.65	5

As the study aims to explore different stakeholders’ insight into LNG bunkering, the respondents were grouped as Suppliers, Shipowners, Technical Service Providers/Consultants, and Regulatory bodies -Classification Society, Flag, Port respondents. There were 6 suppliers, 5 shipowners, 5 TSPs, and 4 RBs. Commercial factors are the main challenges for all stakeholders. While commercial factors are

narrowly leading factors for TSPs (22%), it represents the far biggest challenge for the shipowner perspective (44%). Infrastructure issues were indicated as the second most significant challenge for the ship owners. On the other hand, the regulatory body perspective considers safety issues as the second important challenge (20.3%). Suppliers frequently mentioned cooperation issues in second place after commercial factors. Technical service providers' perspective is broader than other groups that frequencies are more equally distributed among themes, and not surprisingly, technical factors took second place after commercial factors. The distribution of parent codes based on the stakeholder group is listed in Table 40.

Table 40: Distribution of Parent Codes Based on Stakeholders

Main Codes	Supplier	Shipowner	TSP	RB	Total
Commercial Factors	37.8%	44.7%	22.8%	33.3%	34.0%
Safety	7.8%	5.8%	5.1%	20.3%	9.4%
Sustainability/Environmental	6.7%	10.7%	8.9%	6.5%	8.0%
Regulatory Framework	7.3%	1.9%	8.9%	12.2%	7.8%
Technical Factors	5.2%	1.0%	20.3%	2.4%	8.0%
Infrastructure	2.1%	14.6%	3.8%	4.9%	5.4%
Location/Operation Region	6.2%	8.7%	3.8%	4.9%	5.7%
Collaboration	10.4%	1.0%	7.6%	1.6%	6.1%
Fleet type	3.6%	1.0%	6.3%	6.5%	4.5%
Operational Factors	2.6%	8.7%	8.9%	4.1%	5.7%
Supply Chain	7.8%	1.22%	1.9%	2.4%	3.6%
Others	2.6%	1.9%	1.9%	0.8%	1.9%
Total	6(30.0%)	5(25.0%)	5(25.0%)	4(20.0%)	20(100.0%)

At the fourth stage, theoretical links between categories were investigated in order to analyse, underpin the themes, and explain the relations between them. The data were refined through asking questions, the findings were compared, analysed, integrated, and the results were presented in a realistic scheme in order to address the research questions and objectives.

5.2. LNG BUNKERING OPERATION AT PORT OF ROTTERDAM

Observation as a method of collecting data provides different perspectives and enrich the research. As there are limited places around the world performing LNG bunkering, the researcher took initiative to witness LNG bunkering operation in

Rotterdam. For this purpose, firstly, researcher contacted with shipowner Wessels Reederi GmbH&Co KG in order to visit M/V Wess Amelie during Rotterdam call. After following the procedures, it was allowed to be on board by permission of shipowner Wessels Reeder, bunker supplier Titan LNG, charterer Unifeeder and Port of Rotterdam on 5th of February 2019.

5.2.1. Wessels Reederi GmbH & Co. KG

The company whose background goes dates back to over 100 years ago, was first established to operate river ferries in NW Germany, and expanded its business over the years. They collaborated with shipyards enlarged their fleets and brought new perspectives to European shipping. Today they have 29 vessels at seven different classes, 22 mini bulkers dwt capacity between 3500t to 4500t, 4 container vessels at 13000dwt, and three 3500dwt multi- purpose vessels.

The company is a part of the KG funds, is run by Gerd Wessels, a Naval Architect. The company actively supports sustainable innovations in shipping and takes part in SkySail kite propulsion technologies, and wind-assisted ship propulsion systems. Mr Wessels is the Chairman of the Environmental Committee of the DNV-GL and also visiting lecturer in University of Strathclyde on green shipping (Wessels, 2019b).

5.2.2. M/V Wess Amelie

M/V Wess Amelie is a container vessel, retrofitted for LNG propulsion. It has 1036-TEU capacity and its main specifications are indicated in Table 41.

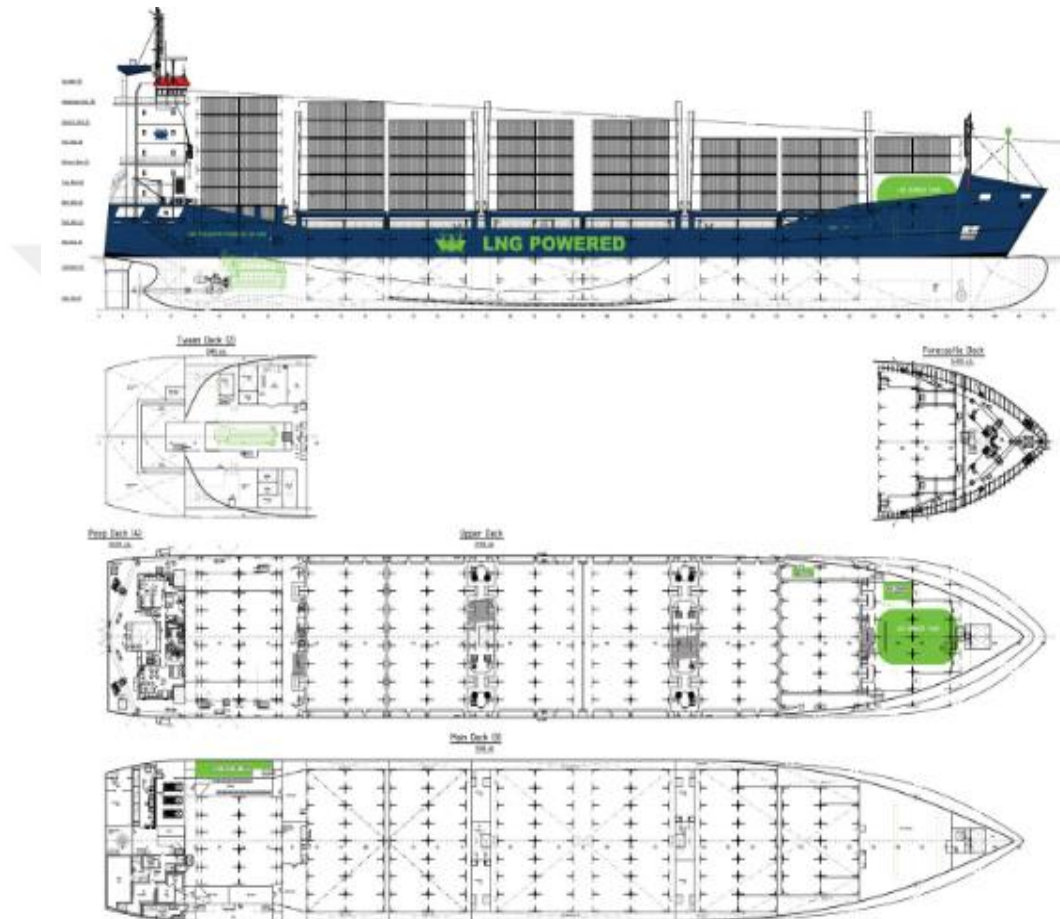
Table 41: M/V Wess Amelie

DWT	13200mt
GT/NT	10585 / 4598 mt
LOA	151.2m
Beam	23.4m

Source: (Wessels, 2019a)

The vessel was built in 2011 but retrofitted as LNG fuelled in 2017. State funding, agreement with MAN and a long-term charter agreement with Unifeeder are the main contributors to converting the vessel to LNG propulsion. Figure 64 shows general arrangement plan of M/V Wess Amelie.

Figure 64: M/V Wess Amelie



Source: (Wessels, 2019a)

5.2.3. Titan LNG

Titan LNG is an LNG supplier in Amsterdam-Rotterdam-Antwerp area. They provide full solution services for the shipowners and operators who need LNG bunker. They carry out truck-to-ship bunker supply. However recently, they launched bunkering pontoon which serve as a stationary delivery location to inland water barges and small seagoing vessels (TitanLNG, 2019).

5.2.4. Port of Rotterdam

LNG bunkering in Europe first took place in Rotterdam in 2011 for inland shipping. In accordance with port's sustainability targets, Port of Rotterdam support LNG bunker developments. Gate terminal is located in port of Rotterdam and truck to ship and ship to ship LNG bunkering can be performed within the port limits. The port also implies discount for LNG-fuelled vessels and green awarded vessels incorporated with sustainability targets. The port also develops regulatory framework for the ports and support simultaneous bunkering operations (PoR, 2019).

5.2.5. Truck-to-Ship Bunkering Operation at Port of Rotterdam

M/V Wes Amelie was moored at RST terminal and the researcher joined to vessel around 2pm on 5th of February. Cargo operation was still in progress and a meeting carried out with master and chief engineer and technical superintendent. Their operational experiences, difficulties and compared with conventional fuels were discussed. The researcher was also requested to switch off mobile phone on deck -not only because of danger of LNG but also confidentiality of tank design and LNG line up arrangement of the vessel.

After completing the cargo operation, the vessel shifted to waiting berth in order to supply LNG. During shifting, the researcher stayed in engine room to observe how to prepare dual fuel engine, shifting from MGO to LNG, engine response times, tank pressure change and other parameters. Before the bunkering operation, at 1850lt, safety meeting was carried out in the officer messroom. Titan LNG commercial director, Titan LNG finance director, Technical Superintendent of the vessel as company representative, the master, the chief officer, the chief engineer and the agent representative participated the meeting. The meeting went through truck-to-ship LNG bunkering safety check list as recommended by IAPH (International Association of Ports and Harbours). VHF working channel, emergency shut down signal were determined. Both the ship and the truck have ESD (emergency shut down device) system and response times fixed as 5sec/12sec respectively. Quantity to be transferred was agreed as 150mt whilst delivery temperature was -156degC. Shipline LNG tank

temperature was -134degC and pressure was 4.3bar. Filling limit was set as 85% and tank available capacity was 153ton. Portable manifold arrangement was connected to the vessel by hose. The system allows two trucks to discharge LNG simultaneously. Bunkering started at slow rate as max manifold pressure was 4bar and it was allowed to increase pressure up to 6.5bar. Before commencing operation, water curtain was activated, responsible person was warned, PPEs were checked, radio connection was confirmed as loud and clear between deck-engine and shore.

The operation was completed at 3A.M. on 6th of February, after the last truck discharged its cargo. The quantity received is declared as total number of trucks and their capacity. It was also compared with the ship figure.

5.2.6. Observations Before, During and After Truck to Ship LNG Bunkering Operation

The operation was conducted at the highest safety awareness. The crew members have had LNG bunkering training from Classification society as IMO Model Course has not been validated yet in February 2019. The crew members were fully donned with personal protective equipment such as face shield, gloves, helmet and safety shoes. In order to comply with crew member's company experience matrix and familiarisation with operation, the same crew were appointed to same vessel regularly so as to increase safety of the operation. The operation started at very slow rate. Temperature difference between truck and ship was another difficulty for the operation and it slowed down the transfer. The pressure of the receiving tank was monitored by the chief engineer carefully against any immediate increase. Clear radio access between engine control room and manifold area was established and checked regularly. Vapour return line was not connected to manifold. Fire precautions and water curtain was activated before the operation. Loading rate is not only restricted by trucks pumps but also temperature of the receiving tank. Port of Rotterdam has just confirmed simultaneous operation within port limits; however it had not come into force yet during operation. Therefore, the operation needed to be performed at idle berth after the cargo operation. It has been told that port authority representatives usually take part at safety meeting process before operation. Apart from operational

and technical issues, the researcher has been informed that Unifeeder as time charterer of the vessel has long term contract with Titan LNG for bunkering supply.

5.3. TURKEY'S BUNKERING DYNAMICS

Turkish straits connect Black Sea and Marmara Sea ports to Mediterranean so as to control significant maritime traffic. Turkey is listed in top 20 of world largest economy by GDP and by port call (UNCTAD, 2019). Turkey's bunkering dynamics will be investigated and analysed through statistical data obtained from Ministry of Transport and Infrastructure, EMRA (Energy Market Regulatory Authority) and UNCTAD online sources. The details of the data are given in section 5.3.2.1.

EMRA regulates electricity, natural gas, oil and liquefied petroleum gas markets in Turkey; facilitates operating, distribution, transportation and licensing activities and controls the pricing in the market. EMRA has autonomy administratively and financially with public entity. The Authority is related with Ministry of Energy and Natural Sources (MENR). EMRA publishes monthly and annual reports regarding electricity, petroleum, natural gas and LPG market in Turkey (EMRA, 2019b)

Turkey's marine traffic activity and bunker sales database have been investigated in order to understand Turkey's bunkering dynamics.

5.3.1. Bunkering Activities in Turkey

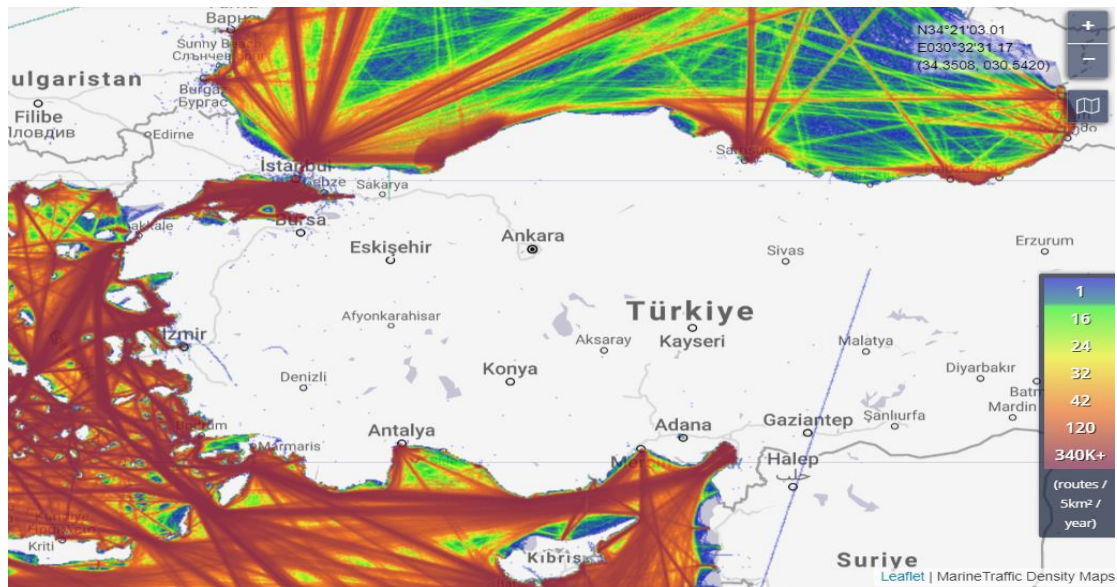
Ship supplies are critical for any shipping activity. Provision crew change, spare parts and consumable deliveries have tremendous importance to operate a vessel effectively. Bunkering could be vital among all these supplies as vessel cannot proceed from A to B or cannot perform cargo operation without fuel on board or without *convenient* fuel onboard. Ship supply hubs are strategically located on the busy maritime transportation routes. Straits, narrow seaways, busy ports create demand for any type of supply, repair, service as well as bunker (Lam et al., 2011).

Turkey is one of the top 20 economies in the world, taking advantage of being surrounded by the sea and controlling important shipping route from Black Sea to

Mediterranean. However, this geographical advantage is not reflected at same level in ship supply business as well as in bunkering (Eraydın, 2015).

Turkey has significant international and domestic shipping activities. Figure 65 illustrates marine traffic density map of all types of vessels covering 2016 and 2017. Istanbul and Canakkale Straits are the densest nodes as connecting Black Sea ports to international shipping activities. Samsun, Zonguldak and Trabzon ports are the busiest Turkish ports at Black Sea Coast. It's also observed that there is not only cabotage traffic but also international traffic connecting Russian and Ukrainian ports to Turkey. Marmara Sea has substantial marine traffic which includes not only transit traffic from Black Sea to Mediterranean but also port calls such as Izmit, Gemlik and Tekirdağ. Nemrut, Aliğa and Izmir Ports show high traffic density. Cabotage traffic around Turkey's West Coast is also significant along with connection with islands although it represents seasonality. Mediterranean ports such as Antalya and Mersin have dense marine traffic activity. However, Iskenderun Gulf is observed as the busiest region as it has substantial port activities for dry bulk, containers, oil and gas cargoes. As these ports usually handle large vessels, high traffic density not only explains not only number of the vessels, but also substantial demand potential as larger vessels lift much more bunker quantity per operation.

Figure 65: Marine Traffic Density Map of Turkey



Source:(MarineTraffic, 2020)

Port traffic in Turkey is summarised in Table 42 based on Ministry of Transport and Infrastructure database 2019. Kocaeli handles the largest proportion as total GT and by number of the vessels calling. Other Marmara Sea ports such as Ambarlı, Gemlik, Tekirdağ, Tuzla are on top ten as the total GT of the vessels calling these ports. On the other hand, two smaller ports as Çeşme and Bodrum have significant touristic traffic between the Greek Islands and Turkey. Çeşme also has regular Ro-Ro traffic which connects Çeşme to Italy and France. Iskenderun and BOTAŞ are under different port authorities in Iskenderun Gulf. Their total share takes second largest part as GT (15.3%) after Kocaeli. Top ten Port Authority region represents 86% of total port activities as GT of the vessels and can be interpreted as hubs and gateways for shipping activities in Turkey.

Table 42: Port Traffic in Turkey as GT and Number of the Vessels by 2019

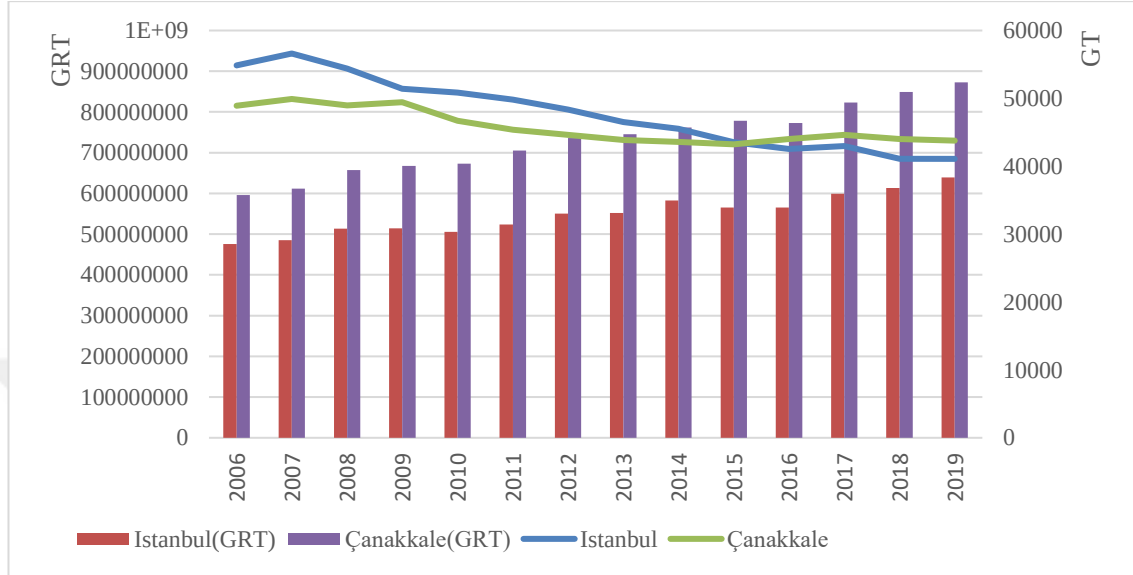
	Port Authority	Gross Ton	Share as %	Port Authority	Number of Vessels	Share as %
1	KOCAELİ	142553602	17.9	KOCAELİ	8714	15.76
2	AMBARLI	96853881	12.2	ALİAĞA	5135	9.29
3	ALİAĞA	94156168	11.8	İSKENDERUN	4259	7.70
4	MERSİN	81345719	10.2	MERSİN	3874	7.01
5	İSKENDERUN	76837289	9.6	AMBARLI	3815	6.90
6	GEMLİK	61173351	7.7	GEMLİK	3490	6.31
7	TEKİRDAĞ	49645202	6.2	TEKİRDAĞ	2555	4.62
8	BOTAŞ	45480079	5.7	BODRUM	2021	3.65
9	İZMİR	23089612	2.9	ÇEŞME	1946	3.52
10	TUZLA	15477393	1.9	İZMİR	1551	2.80
	Total top 10	686612296	86.2	Total Top 10	37360	67.56
	Total	796266565	100%	Total	55302	100%

Source: Author, compiled from (MOTI, 2020b)

In order to understand the shipping activities in Turkey, Canakkale and Istanbul Strait passages traffic provide important indicator. Figure 66 summarises the number of the vessels passing through Istanbul Strait and Canakkale Strait as number and GT by data obtained from Ministry of Transport and Infrastructure database covering 2006 to 2019. The number of the vessels passing through Canakkale and Istanbul Straits is decreasing gradually both in Canakkale and Istanbul Straits. However, total GT of the vessels are increasing in these straits -from 595,826,240GT to 872,314,222GT for

Canakkale and 475,796,880GT to 638,892,062GT for Istanbul. There are more than 40000 passages for each strait since 2006 as they are declining over the years.

Figure 66: Istanbul and Canakkale Straits' Traffic Data as Number and GT



Source: Author, compiled from (MOTI, 2020a)

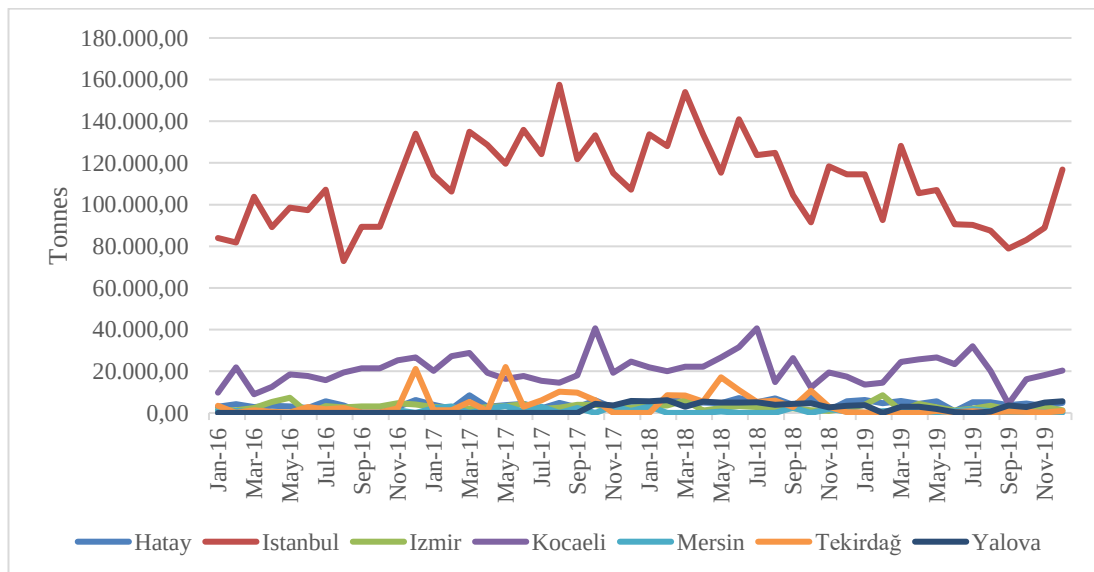
Table 43 summarises Turkey's total bunker deliveries with special consumption tax, without special consumption tax and delivery under transit regime. The table excludes 'export' figures as it does not distinguish 'cargo' and 'bunker' exports. Another reason is explanation remark of EMRA report states that "Deliveries based on Cities\ Turkey have been included in transit regimes and export". However, once we calculate the data, it is observed that deliveries to city table exclude exports and only taking into account figures in Table 45. Deliveries to cities take crucial part in the research. In order to clarify data, it was consulted to EMRA specialist. It was recommended to stick to one table for consecutive years. Therefore, for the consistency of the research, below table was used as it provides solid data over the years, although real bunker deliveries of Turkey are higher than these figures.

Table 43: Total Bunker Deliveries of Turkey

Year	Delivery with SCT	Delivery without SCT	Delivery under Transit Regime	Other	Total(ton)
2018	9548	34258	1999129	0	2036934
2017	5501	35720	1891362	0	1932583
2016	5629	38610	1434790	0	1479029
2015	234	0	324633	0	507332
2014	8687	36139	1279474	0	1324300
2013	4625	356008	688555	0	1049188
2012	25452	479368	1325632	0	1830452
2011	6879	278021	1331803	0	1616703
2010	11693	232343	1105909	0	1349945
2009	14343	266638	942064	0	1223045
2008	15049	266089	1109477	0	1390615
2007	11401	243541	1085211	0	1340153

Source: Author, Compiled from EMRA Annul Reports covering 2007 to 2018

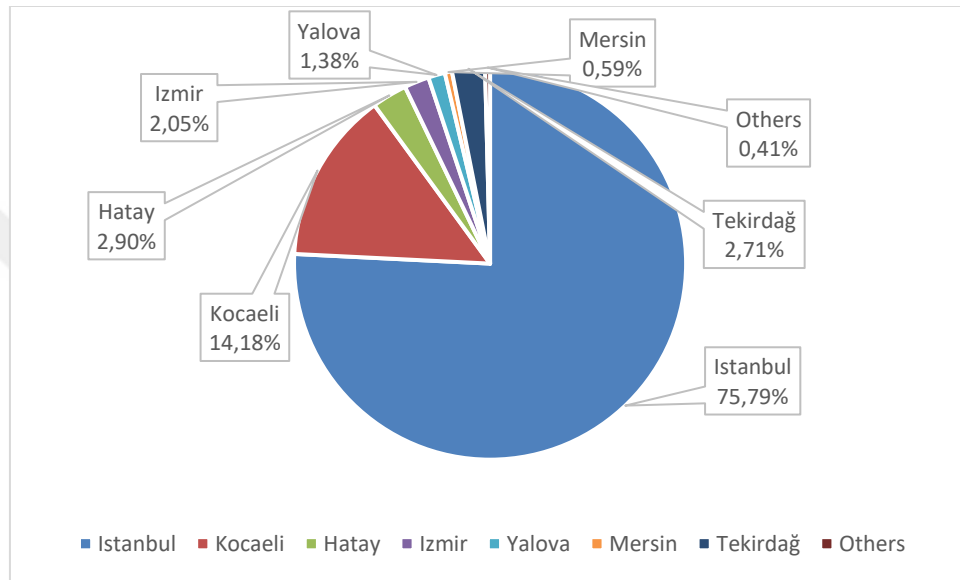
Figure 67 shows delivery quantity according to cities between January 2016 and December 2019 with monthly intervals. Although Istanbul stands alone in deliveries, other cities represent important ports which significant shipping activities take place such as Iskenderun Gulf (Hatay), Izmit Gulf (Kocaeli), Aliaga, Izmir, Nemrut, Marmara Ereğlisi.

Figure 67: Distribution of Bunker Deliveries by City from January 2016 to December 2019

Source: Author, Compiled from EMRA Monthly Reports (Jan 2016- Dec 2019)

Cumulative deliveries covering the years from 2016 till 2020 is illustrated in Figure 68. Istanbul is the major location for marine fuel deliveries as it takes 76% of total and it is followed by Kocaeli as 14%. Other locations out of these six locations take less than 0.5% over the years.

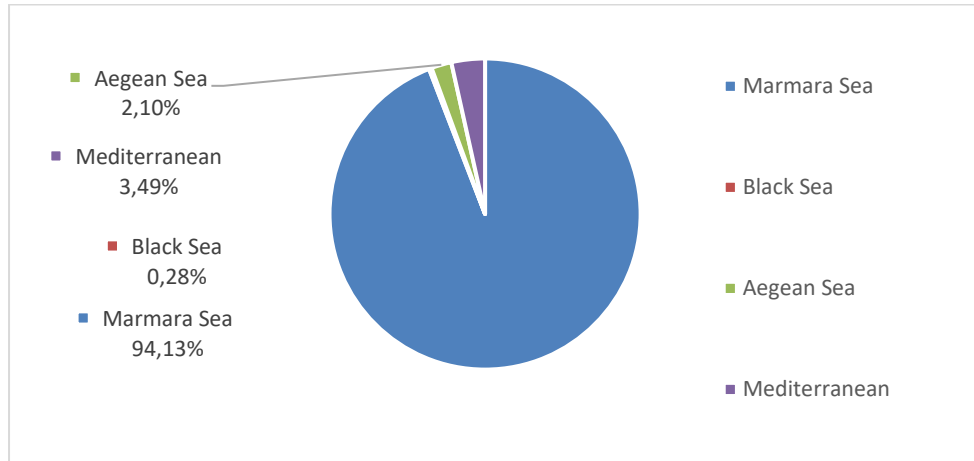
Figure 68: Total Bunker Deliveries Shared by the Cities



Source: Author, compiled from (EMRA, 2020c)

Based on cumulative data between January 2016 and December 2019, distribution of deliveries by sea region is shown in Figure 69. Marmara Sea takes the largest part in bunker deliveries as 94% of total deliveries in Turkey. The region has advantage of having large ports, shipyards, repair facilities, technical service connections, easy provision supply and crew change service. Tupras Izmit Oil Refinery, oil storage facilities are also in Marmara Sea and provides logistics advantages. Being on transition route from Black Sea to Mediterranean brings absolute comparative advantage against other regions.

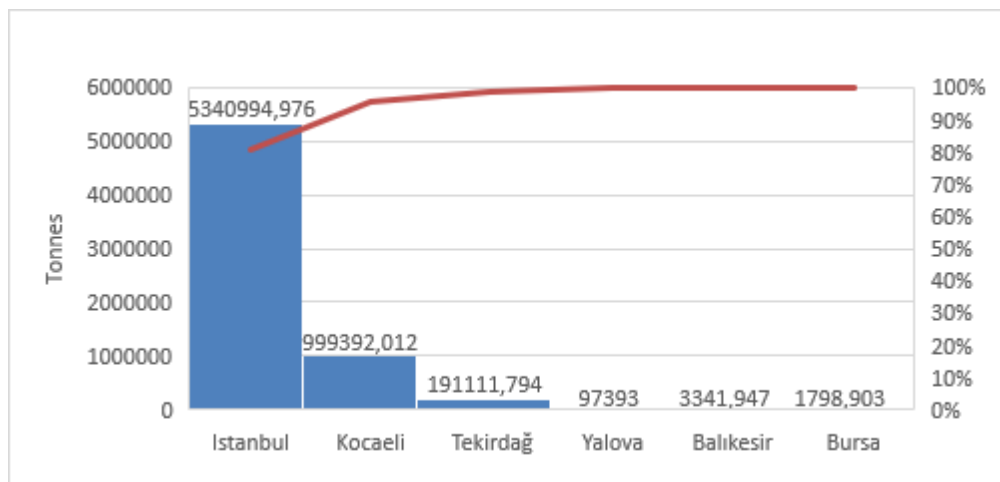
Figure 69: Distribution of Deliveries by Sea Region



Source: Author, compiled from (EMRA, 2020c)

Figure 70 shows distribution of deliveries within Marmara Sea covering January 2016 to December 2019. Istanbul takes the leading position, Kocaeli has significant delivery volume and is followed by Tekirdag. Yalova's cumulative volume reached almost 10 thousand tons, although there is not any delivery recorded before mid-2017. Canakkale is excluded from the list as most of the deliveries are made in Aegean Sea, south of Bozcada.

Figure 70: Distribution of Deliveries in Marmara Sea



Source: Author, compiled from (EMRA, 2020c)

5.3.2. Relation of Turkey's Bunker Deliveries with Economic Variables

Globalisation of trade is an important driver for the world's bunker demand. World seaborne trade and maritime traffic are the consequence of global trade. Information of world GDP provides an indicator for global trade growth and oil prices are substantial drivers of bunker prices(UNCTAD, 2020b). As the vast majority of the bunker deliveries of Turkey are performed in Istanbul, vessels traffic by number and tonnage are evaluated along with other criteria in order to see bunker deliveries' relation with indicators that provide model to forecast future trend. EViews 10 software has been used for statistical data analysis.

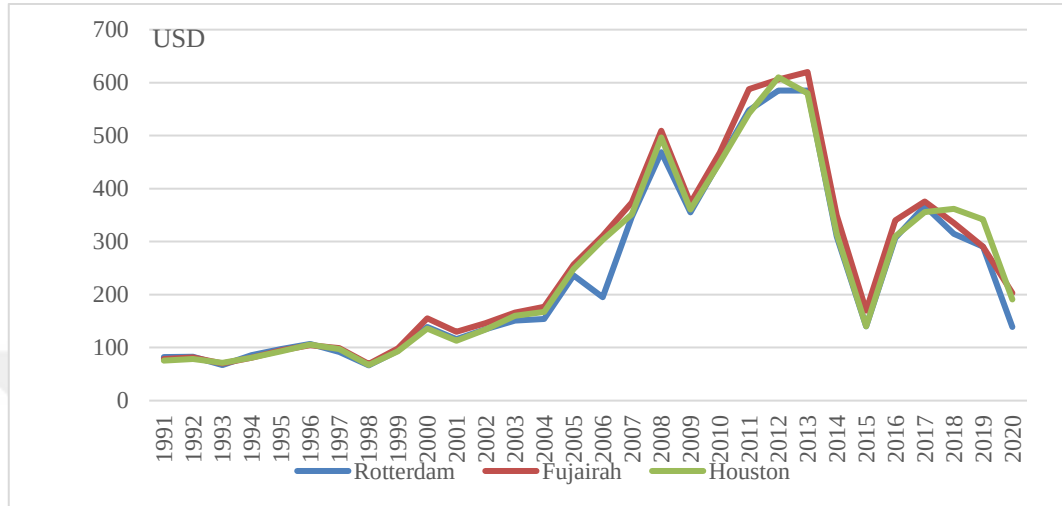
EViews is a software which offers data analysis, regression and forecasting tools on windows-based computers. EViews is substantially being used in scientific data analysis, macroeconomic forecasting, financial analysis, cost analysis and simulation. It provides smooth data entry and analysing tools along with visual features (EViews, 2019) .

5.3.2.1. Data sets

Total bunker deliveries of Turkey data were obtained from EMRA's annual reports. Data provide annual deliveries between 2007-2018 including transit deliveries, with and without special consumption taxes but exclude marine fuel sells as cargo. EMRA data do not distinguish marine fuel export sells as 'cargo' or 'bunker'. Therefore, exports listed on the report were not taken into consideration in this calculation -although it represents significant quantity. The world GDP, Brent oil price, world seaborne trade, world fleet by number and total tonnage data were taken from UNCTAD statistics. World GDP covers annual data between 1980-2019. World seaborne trade as metric tons in millions time series data covers the years 1980-2018. World fleet by number and total tonnage data is between 1980-2019. Brent oil price data covers annual information from 1995 to 2018. Istanbul Strait and Canakkale Straits statistics were taken from Ministry of Transport and Infrastructure database that covers annual 2006-2019 data. As Istanbul historical bunker price is not available as time series data, Athenian shipbrokers report that covers Rotterdam, Fujairah and

Houston bunker prices from 1991 to March 2020 was checked. It was observed in Figure 69 that three different ports at different continents follow the same pattern.

Figure 71: Bunker Prices in Fujairah, Houston and Rotterdam IFO 380cst



Source: Author, Compiled from (Athennianshipbrokers, 1990-2020)

Historical data was evaluated in EViews as well. Table 44 indicates that there is a very strong positive correlation between ports (0.994467, 990979, 0.988892) and It's statistically significant (0.0). These ports are located at different continents and have different market structures. Despite the fact that, prices are not identical, there is significant correlation between bunker supply locations. Therefore, Rotterdam bunker price was added to regression analysis as independent variable instead of Istanbul bunker price time series data which is not available as long historical data.

Table 44: Bunker Price relation of Fujairah, Houston and Rotterdam

		Fujairah	Houston	Rotterdam
Fujairah	Correlation	1.000000		
	t-Statistic	-----		
	Probability	-----		
Houston	Correlation	0.994467	1.000000	
	t-Statistic	50.09232	-----	
	Probability	0.0000	-----	
Rotterdam	Correlation	0.990979	0.988892	1.000000
	t-Statistic	39.12674	35.20523	-----
	Probability	0.0000	0.0000	-----

Source: Author

Data to be used in the research is illustrated in Table 45. Time series data, units of series, covering years and the source of the data are summarised.

Table 45: Time Series Data Summary

Data	Years	Source
Annual Bunker Deliveries as metric tonnes	2007-2018	(EMRA, 2019a)
World GDP	1980-2019	(UNCTAD, 2020d)
Brent Oil price as USD	1995-2018	(UNCTAD, 2020d)
World Seaborne Trade as metric tonnes	1980-2018	(UNCTAD, 2020d)
World Fleet by Number	1980-2019	(UNCTAD, 2020d)
World Fleet by DWT Tonnage	1980-2019	(UNCTAD, 2020d)
Bunker Price HSFO 380cst as USD	1991-2020	(Athennianshipbrokers, 2020)
Istanbul Strait Passages by Number	2006-2019	(MOTI, 2020c)
Istanbul Strait Passages by GT	2006-2019	(MOTI, 2020c)
Canakkale Strait Passages by Number	2006-2019	(MOTI, 2020c)
Çanakkale Strait Passages by GT	2006-2019	(MOTI, 2020c)

Source: Author

5.3.2.2. Statistical Interpretation

In order to see Turkey's marine fuel sells relation with some economic indicators; correlation, ARIMA forecasting and multiple regression methods were used. Dependent variable is defined as total bunker deliveries of Turkey.

5.3.2.2.1. Multiple Regression

Multiple regression models were employed in order to see the relation of the variables and how these variables influence bunkering demand in Turkey. The dependent variable as total bunker deliveries in Turkey was evaluated with independent variables as Brent oil price, bunker price, GDP per capita, world seaborne trade as miles per ton, number of passages from Istanbul and Canakkale Straits, total GT of passages from Istanbul and Canakkale Straits, world fleet as deadweight tonnage. EViews10 data analysis software was used.

Different combination of regression models which include data in Table 47 were tried in order to determine the convenient model that jointly influences bunker demand in Turkey. The models compared with their R^2 adjusted R^2 , F statistic and Prob(f-statistics) values firstly. However, only one model's outcome was found

statistically meaningful. It was concluded that the bunker deliveries in Turkey are jointly influenced by world seaborne trade and bunker price. The regression process is explained as below.

The data set of year between 2007-2018 were used. Before running the model, time series variables were checked in order to see whether variables are stationary or not. The KPSS unit root tests were performed for each variable which is available under EViews10. The test results confirm that three time series data are stationary according to KPSS criteria. Test results are summarised in Table 46.

Table 46: KPSS Test Results

Time Series	KPSS test	1% Critical Value	Result
Bunker Deliveries	0,156335	0.739000	Stationary
Bunker Price	0.214874	0.739000	Stationary
World Seaborne Trade	0.496457	0.739000	Stationary

The relation of variables are formulated in regression model. Dependent variable is defined as the total bunker deliveries of Turkey and independent variables defined as world seaborne trade and bunker price. EViews ‘equation estimation’ function was used with Least Squares method and regression equation was written as follow:

$$total\ bunker = c(1) + c(2)*wst + c(3)*bpr$$

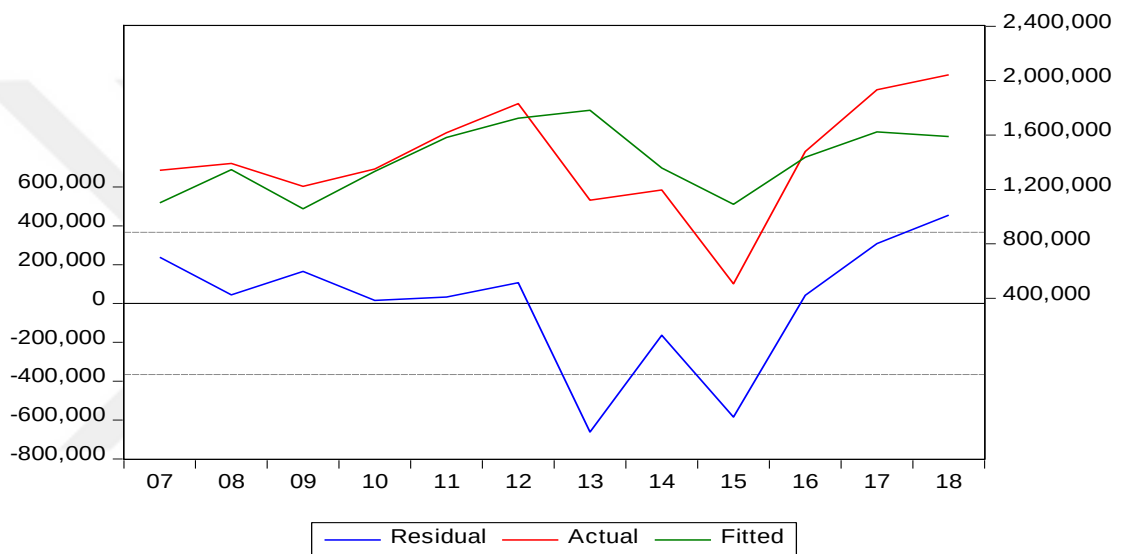
Table 47: Multiple Regression Model-1 Outcome

R-squared	0.359425	F-statistic	2.524935
Adjusted R-squared	0.217075	Prob(F-statistic)	0.134762

Table 47 summarises outcome of the model. The multiple regression output indicates that Prob(F-statistics) is bigger than 0.1 (0.134762). World seaborne trade and constant’s p values are bigger than 0.1 (0.1248 and 0.4102). Therefore, variables do not jointly influence total bunker deliveries in Turkey and regression model does not provide a ground for forecasting.

In this case residual graph of regression model, which is obtained through Eviews, was investigated in order to see how the residual graph is changing compared to fitted and actual line. Figure 70 indicates that the difference between actual line and fitted line gives two dip points in 2013 and 2015. Parallel to this observation, it was pointed out in 2015 EMRA report that calculation method of deliveries was changed in 2015. Another big residual is observed in 2013 compared to the rest of the historical trend.

Figure 72: Residual Graph of Regression Model



Regression with dummy variables are quite useful in time series application, they are used to isolate certain periods that are systematically different from other periods in data set (Wooldridge, 2015). Dummy variables could be dependant variable or on of the independent variables. They can take either '1' or 0' and could be used with qualitative data (Koop, 2006). Therefore dummy variables were added to regression model for the years 2013 and 2015(Wooldridge, 2015). New regression model was written as below:

$$total\ bunker = c(1) + c(2)*d1 + c(3)*bpr + c(4)*wst$$

New model with the same variables along with dummy variable were run in Eviews10 and the model summary was represented in Table 48. Coefficient gives relation of the variables, it was seen that explanatory variables, bunker price and world

seaborne trade, positively affect total bunker deliveries. In other words, coefficient values measure influence of the independent variable on total bunker delivery, while all other explanatory variables are equal. Prob(F-statistic) statistics provides smallest evidence whether we should reject null hypothesis or not. As the sample size is too small, statistically significance limit was taken as 10% that covers constant's prob. value (0.0529), while bunker price and world seaborne trade is already below 5%. R squared (R^2) measures the success of the regression model in predicting the values of dependent variable. It scales from 0 to 1 and $R^2=1$ means that the regression fit the data properly. R^2 was found as 0.87 and it proves that the model is successful. F-statistics and Prob(F-statistics) are used to test the hypothesis that none of the explanatory variables explain. In other words, it measures whether variables influence dependent variable jointly. Prob(F-statistics), p value, if it is less than 0.05, it means that explanatory variables can jointly influence dependent variable. As Prob(F-statistics) was found 0.000592, null hypothesis is rejected and model has predictive value.

Table 48: Multiple Regression Model-2 Outcome

Dependent Variable: Bunker Deliveries				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-1313848.	578803.6	-2.269938	0.0529
Dummy1	-778326.5	136318.4	-5.709620	0.0004
Bunker Price	1625.855	419.8365	3.872592	0.0047
World Seaborne Trade	237.4126	53.46386	4.440618	0.0022
R-squared	0.873778	F-statistic		18.46005
Adjusted R-squared	0.826444	Prob(F-statistic)		0.000592

The regression model was evaluated from statistical point of view. Explanatory variables are significant, R^2 is close to 1 and good to predict dependent variable, adjusted R^2 also proves the goodness of fit statistics. F-statistics is 18.46 which explains overall significance of independent variables. In the model all variables significantly affect dependent variable. Prob(F-statistics) is also below 5%. It means that jointly all variables in the model significantly affect the dependent variable. Moreover, residual diagnostic checks were carried out in order to see samples are normally distributed, if there is serial correlation or not and finally checked for

heteroskedasticity. Therefore, we can conclude that regression model provides good ground for estimation.

Before using regression model in forecasting some tests should be carried out such as Multicollinearity, Normality, Serial correlation and Heteroskedasticity. Test results are summarised in Table 49.

Table 49: Summary of the Tests for Regression Model

Test	Seri	Value	Criteria	Result
VIF Multicollinearity	Dummy 1	1.041340	<10	No multicollinearity
VIF Multicollinearity	Bunker Price	1.157334	<10	No multicollinearity
VIF Multicollinearity	W. Seaborne	1.181630	<10	No multicollinearity
Jarque-Bera test	Regression	0.653251	>0.5	Normally distributed
Breusch-Godfrey	Regression	0.8735	>0.05	No serial correlation
Breusch-Pagan-Godfrey	Regression	0.2591	>0.05	No Heteroskedasticity

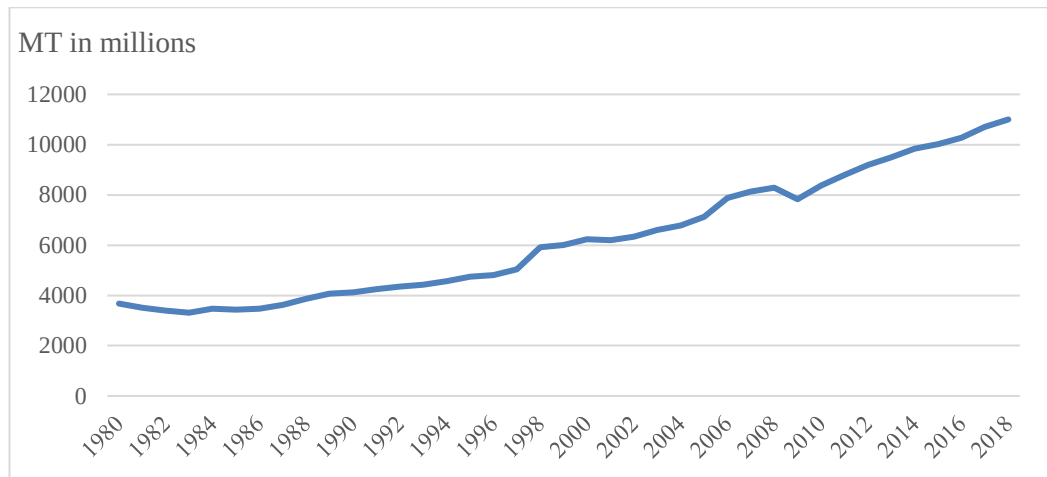
The meaning of the tests is that jointly all variables in the model significantly affect the dependent variable. Moreover, residual diagnostic checks were carried out in order to see that the samples are normally distributed, if there is serial correlation or not and finally checked for heteroskedasticity. Therefore, we can conclude that regression model provides good ground for estimation.

5.3.2.2.2. ARIMA Forecasting

Two time series data, -world seaborne trade and bunker price, jointly influence bunker deliveries in Turkey by multiple regression modelling. This relation of dependent variable and explanatory variables could be used to forecast the future of bunker delivery quantities. In other words, estimated equation could be used for forecasting future bunker deliveries, if future data of these explanatory variables are available. In order to determine future data of the series Automatic ARIMA (Auto-Regressive Integrated Moving Average) Forecasting tool of EViews10 was used.

Firstly, world seaborne trade variable was evaluated. ARIMA forecasting tool of EViews was run in order to see the advised estimation model for the data set from UNCTAD report covering 1980 to 2018. Historical trend of world seaborne trade total goods loaded as metric tons in millions is illustrated in Figure 73.

Figure 73: World Seaborne Trade Total Goods Loaded



Source: UNCTAD, 2020

Automatic ARIMA model set was at 4 AR and 4 MA specification. Forecast length determined as 7 in order to see till 2025 value. ARMA model selection applied at 5% KPSS significance. Automatic ARIMA forecasting outcome was summarised in Table 50.

Table 50: Summary of ARIMA Model for World Seaborne Trade

Selected dependent variable	DLOG(ST)
Selected ARMA model	(0,0)(0,0)
AIC value	-3.64989223537

The results indicate that selected dependent variable is differenced logarithmic of time series data (dlog). Figure 74 illustrates the lowest AIC value as -3,64 and corresponding ARMA model is (0,0). It means that World Seaborne Trade time series data contains neither autoregressive nor moving average terms, so as the mean equation is a constant. Based on this criteria, world seaborne trade forecasting value was calculated till 2025 and found as 13462 million ton.

Figure 74: Akaike Information Criteria (ACI) Top 20 Models

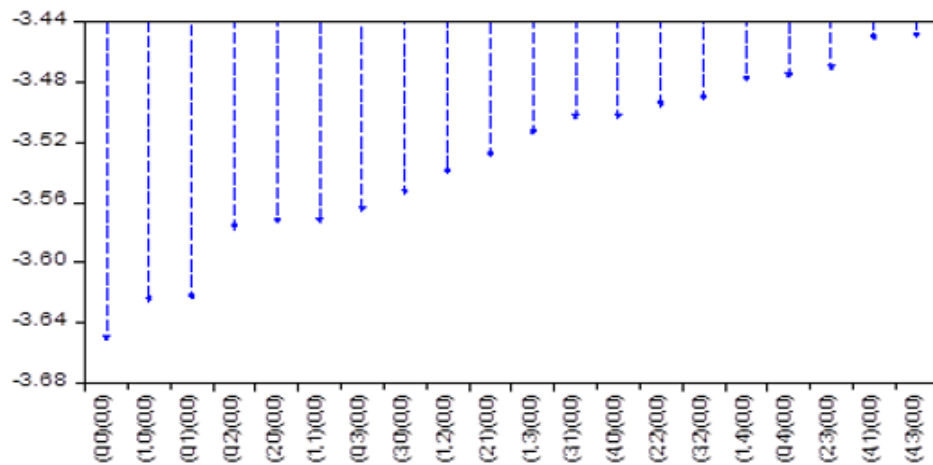
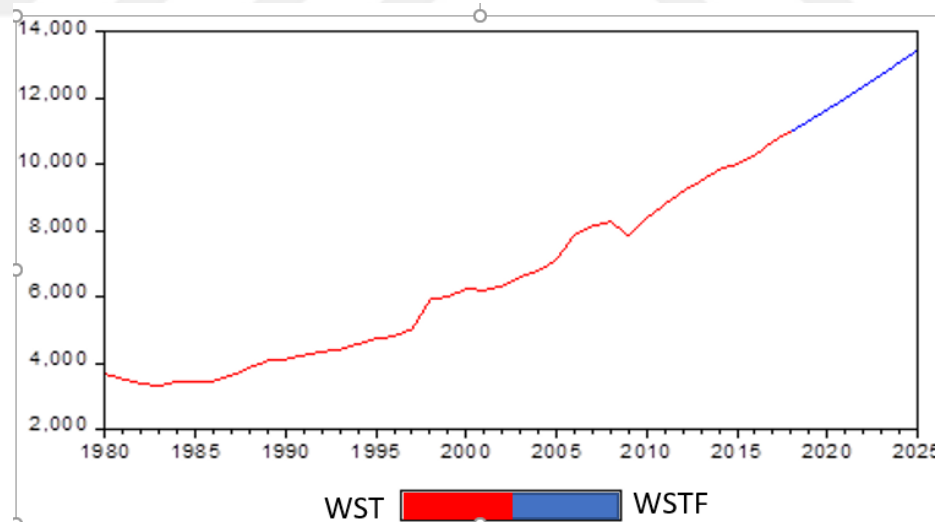


Figure 73 illustrates actual and forecast values of seaborne trade till 2025. Forecast value of 2025 is 13462 million ton based on historical trend and ARMA Model.

Figure 75: World Seaborne Trade Forecast till 2025 as million tons



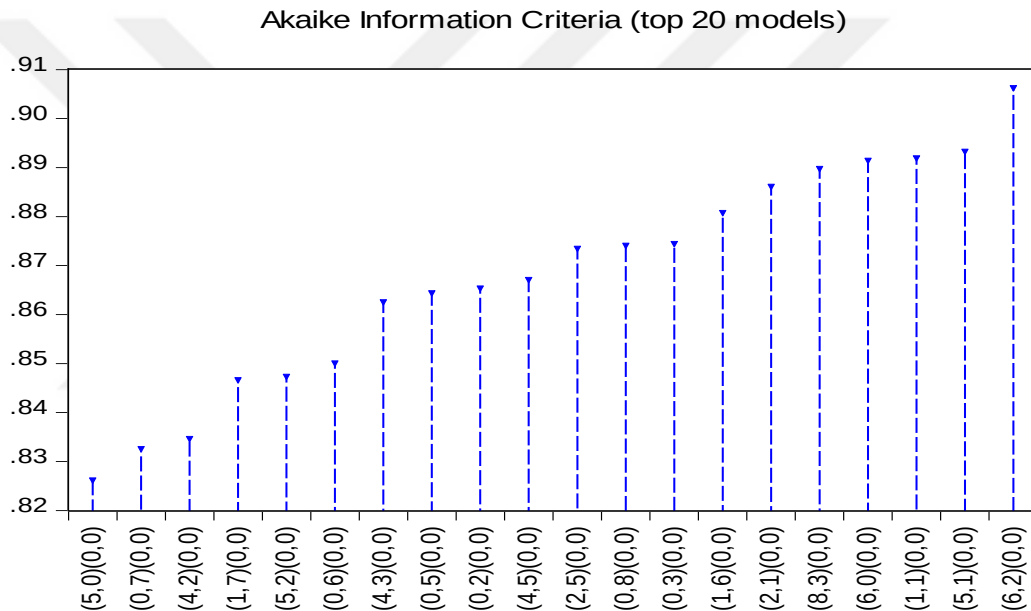
Secondly, bunker price data set was prepared covering from 1991 to 2020. Automatic ARIMA Forecasting tool was employed in order to see the best model. ARIMA tool was set at 8AR and 8MA specification with 5% KPSS significance. Automatic ARIMA forecasting outcome is summarised in Table 51.

Table 51: Summary of ARIMA model for Bunker Price Time Series Data

Selected dependent variable	DLOG
Selected ARMA model	(5,0)(0,0)
AIC value	0.826190053566

The results indicate that selected dependent variable is differenced logarithmic of time series data. Figure 74 illustrates lowest AIC value as 0.82 and corresponding ARMA model is (5,0). It means that the selected model contains autoregressive terms 1 to 5.

Figure 76: Akaike Information Criteria (ACI)



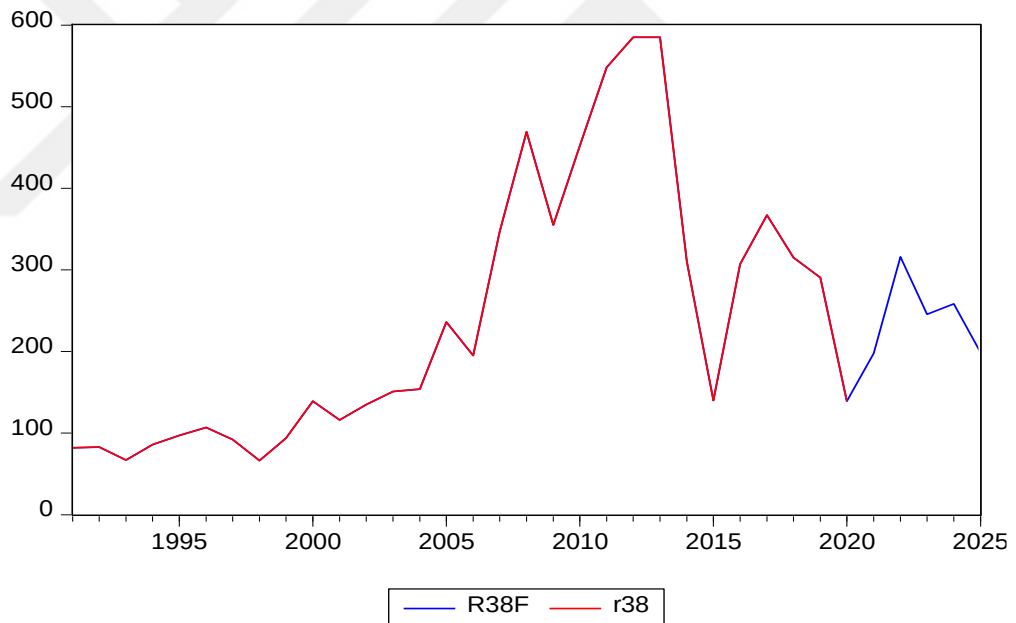
Based on the selected ARMA model, equation model was formulated including 1 to 5 Autoregressive contents. Summary of the model indicates in Table 52 that based on Prob(F-statistics) value model is significant at 10% as it is 0.061964.

Table 52: ARMA Model for Bunker Price

Dependent Variable: DLOG				
Method: ARMA Maximum Likelihood (OPG - BHHH)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.034471	0.082907	0.415778	0.6816
AR(1)	0.056150	0.208544	0.269249	0.7902
AR(2)	-0.400929	0.182262	-2.199744	0.0386
AR(3)	0.157575	0.431591	0.365102	0.7185
AR(4)	-0.280266	0.337231	-0.831081	0.4149
AR(5)	0.510528	0.353253	1.445219	0.1625
SIGMASQ	0.076440	0.016229	4.710127	0.0001
Prob(F-statistic)	0.061964			

Same model was used for forecasting the years from 2020 to 2025. Figure 77 illustrates historical data and forecast for Bunker Price.

Figure 77: Bunker Price Forecast for IFO 380 cst, as USD



At the third step, statistical data obtained through ARMA forecasting were used in order to forecast future bunker deliveries of Turkey till 2025. Based on the confirmed regression model which provides significant relation between dependent variables and independent variable was employed.

$$Y_t = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3$$

$$Y_{2019} = -1313848 + 1625.855X_1 + 237.412X_2$$

Table 53: Bunker Deliveries Forecast of Turkey

Year	Forecast (mt)
2019	1846748.704
2020	1737293.311
2021	1942875.528
2022	2214080.312
2023	2178689.802
2024	2279848.592
2025	2291728.402

Forecast results are indicated in Table 53. In 2025 Turkey's bunker supply has been forecasted as 2291728,402mt.

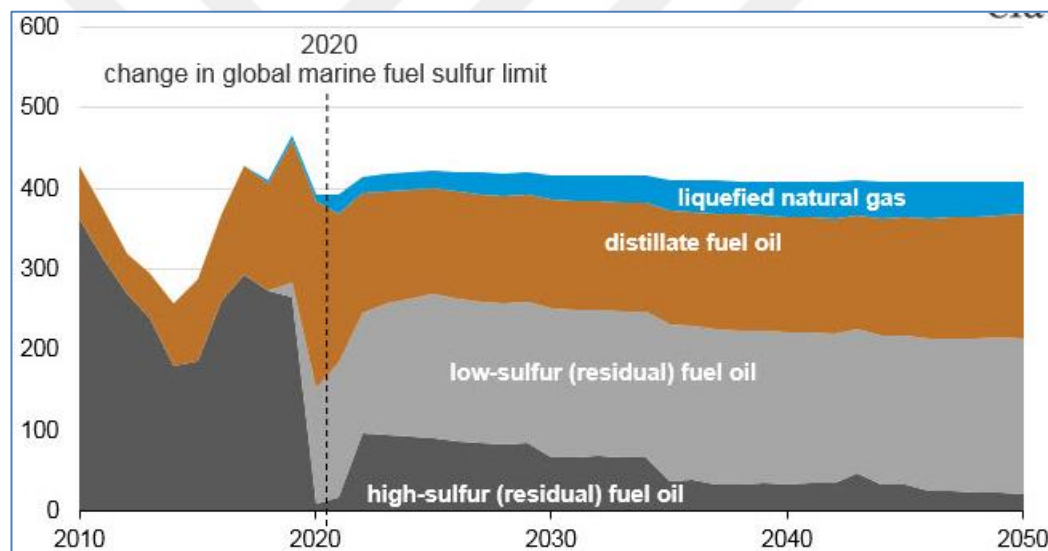
5.4. GLOBAL MARINE FUEL MARKET

Marine fuels are available in different grades according to their specifications. IMO 2020 regulations let industry to introduce new fuel oil grades and definitions. Fuel oil with a maximum sulphur content of 0.1 percent is known as ULSFO; fuel oil with a sulphur content of less than 0.5 percent is known as VLSFO; fuel oil with a sulphur content of less than one percent is known as LSFO; and fuel oil with a sulphur content of less than 3.5 percent is known as HSFO. LSFO is made by hydrotreating or hydro-processing residual fuel oil, and VLSFO is made by mixing ULSFO with LSFO or MGO with LSFO (DTTL, 2019). The largest component of bunker fuel is residual oil which is the remaining hydrocarbon after separating lighter hydrocarbons in refinery process. While distillate fuels have alternative use out of marine use, 80% of the residual fuel is for marine bunkering in USA. Therefore, IMO 2020 regulations are expected to change patterns in marine fuel market in term of demand, refinery productions and pricing. Asia is the biggest market for residual fuels, takes 22% of global fuel oil production and also largest importer of fuel oil (CERI, 2018). European Union and non- EU Europe are important fuel oil producers and account 15% and 19% of the total global oil respectively. The EU is also the second largest user of fuel oil

for international bunkering. The Middle East is accounting 18% of production but consumes about 16% of the global fuel oil used in international bunkers(CERI, 2018).General fuel oil consumption is highest in Asia and followed by Middle East, Europe and South America. According to UN statistics Bunkering takes 40% share, Combustion 24% and Transformation 36%. Fuel oil is important source of energy for industrial heat, or electricity generation in Asia, Middle East or in Europe(CERI, 2018)

Energy Information Administration (EIA) projection in Figure 78 indicates that scrubber installed vessels will be limited. Share of low-sulphur residual fuel oil consumed in US by the vessels in international trade will increase from 38% in 2020 to 43% in 2025 (EIA, 2019).

Figure 78: Bunkering at US Ports Projections



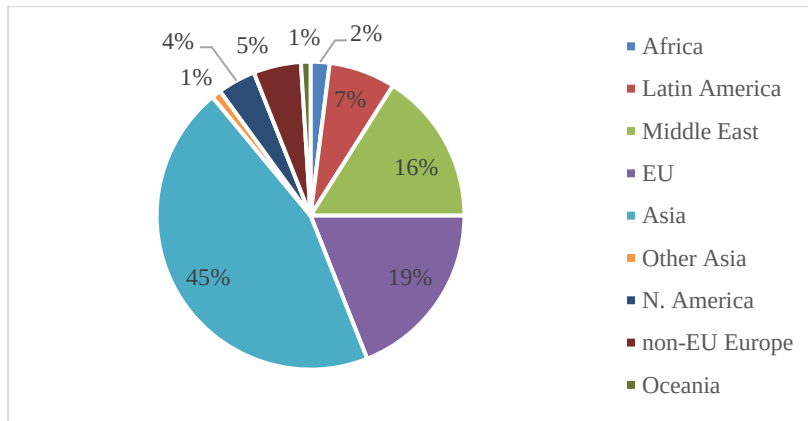
Source: (EIA, 2019)

According to EIA forecasts, a shift in demand in the global bunker fuel market from high/low sulphur fuel oil to low sulphured distillate fuel and low-sulphur fuel oil will affect price relation of those fuels. Increase on low-distillates price and decrease on high sulphur fuel oil price is expected (EIA, 2019).

Figure 79 illustrates the distribution of bunker consumption by region. Asia consumes largest amount of fuel oil for bunkering, it accounts up to 45% of the global fuel oil for international shipping in 2015. As it covers almost half of the global

demand, regulations change has significant effect in the region in terms of price fluctuations (CERI, 2018).

Figure 79: Bunker Consumption by Region



Source: (CERI, 2018)

Current world fleet appearance is listed in Table 54. UNCTAD (2020) report classifies oil/chemical tankers and gas carriers under other types of ships section. According to UNCTAD (2020) data bulk carriers take 42.6% of all tonnage supply and followed by oil tankers (28.7%) and container vessels 13.4%. On the other hand, number of the ships statistics represent different picture, while general cargoes taking the biggest percentage (19%), deadweight wise they only represent 3.7% of total supply. Oil tankers, bulk carriers and container vessels' average size are larger than others and they are the main driver of marine fuel market as they create significant demand.

Table 54: Global Shipping Fleet and Tonnage

Category	Dwt in thousands	Number of Ships	% of Total DWT	% of Number of Ships
Oil tankers	567532.627	10766	28.7	11.2
Bulk carriers	842437.549	11373	42.6	11.8
General cargo	73999.646	18993	3.7	19.7
Container ships	265667.517	5269	13.4	5.5
Other types of ships	226853.719	49894	11.5	51.8
Total fleet	1976491.058	96295	100	100

Source: Author, compiled from (UNCTAD, 2020d)

Fevre (2018) provides insight for fuel consumption by ship type based on LNG equivalent. Table 55 shows that container vessels take 52.5 mton LNG_{eq}. and average consumption of one container vessel is 10491 tonnes of LNG_{eq} per annum. Bulk carriers are second largest fuel consumer and followed by oil tankers. On the other hand cruise vessels are far the biggest consumer of fuel per ship as it reach to 20170 tonnes LNG equivalent (Fevre, 2018).

Table 55: Global Fuel Consumption by Ship Type in 2015

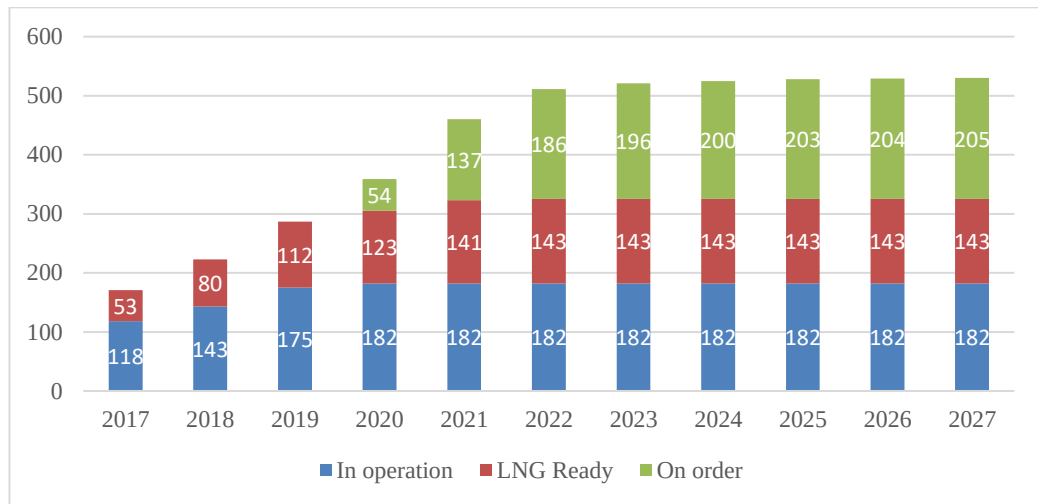
Category	Fuel consumed (million tonnes LNG _{eq})	Number of Vessels	Average consumption (tonnes LNG _{eq})
Container	52.5	5009	10491
Bulk carrier	43.6	10650	4097
Oil tanker	31.6	6395	4938
Chemical tanker	14.2	4720	2999
General cargo	13.2	10973	1202
LPG/LNG tankers	12.7	1687	7509
Cruise	9.6	477	20170
Ferry(ro-ro and pax)	10.2	5288	1933
Vehicle/ro-ro	11.4	2236	5658
Service	8.8	25317	397
Refrigerated	3.8	4876	779
Offshore	3.5	785	4477
Other +Unclassified	23	21021	1094
Total	238.1	99434	2393

Source: (Fevre, 2018)

5.5. LNG FUELLED SHIPS OVERVIEW

DNVGL's current data indicate that there are 182 LNG fuelled vessels around the world in operation and 55 vessels on order for 2020. Moreover 123 vessels are classified as 'LNG Ready' statues, it means that their design is ready for retrofitting to LNG fuelled operation (DNV GL, 2020c). Based on confirmed orders, 389 LNG fuelled vessels will be in operation and 143 vessels will be LNG ready by 2025. LNG fuelled fleet is shown in Figure 80. IEA Energy Outlook 2019 report point out that LNG fuelled vessels represents around 4% of the total order book for new vessels (IEA, 2019b).

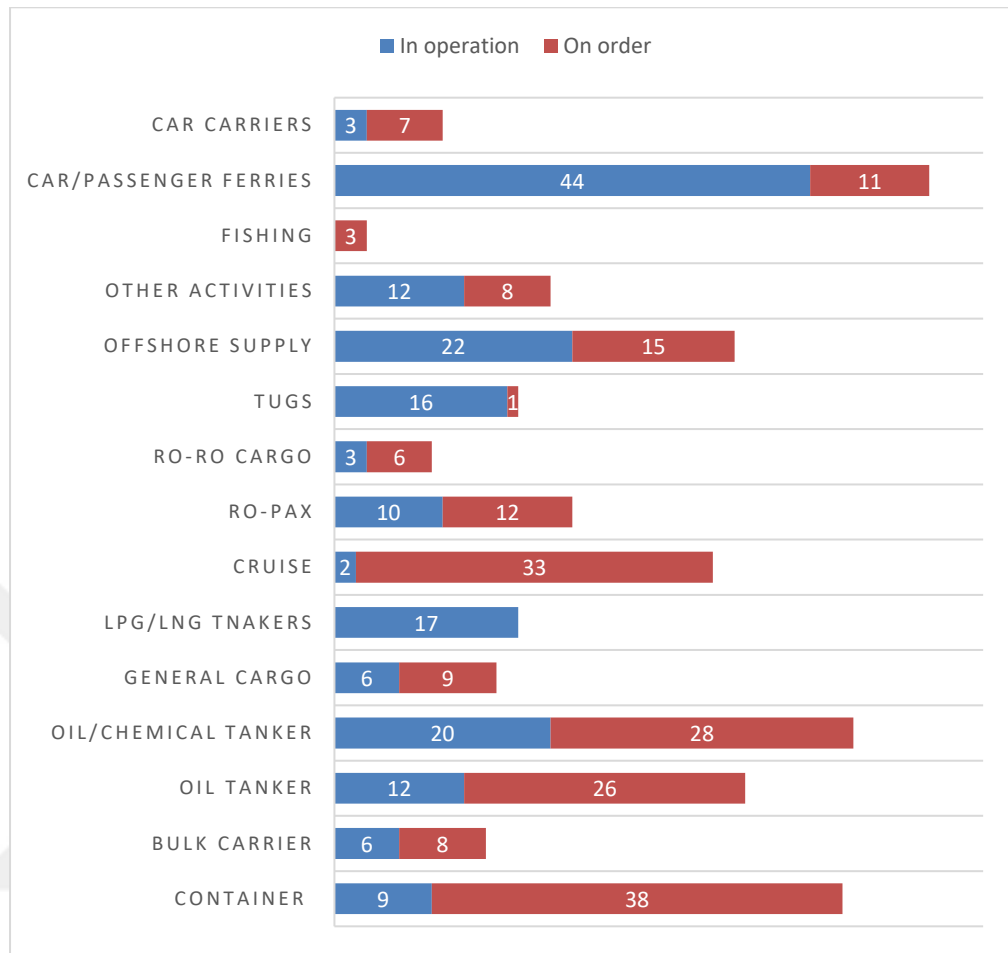
Figure 80: Number of LNG Fuelled Vessels



Source: (DNV GL, 2020c)

The breakdown of the number of the ships is shown in Figure 81. Car/Passenger carriers are the leading segment in shipping with number of LNG fuelled vessels. Currently there are only 9 container vessels in operation, however, there are 38 new container vessel orders which are the highest number among all ship segments. It's followed by cruise vessels (33). The third highest number of the order are shared by oil tankers and oil/chemical tankers (28). As it is discussed above, tonnage and size of the vessels provide more meaningful ground than number of the ships. Cruise vessels are far the biggest fuel consumer per ship and followed by container vessels and oil tankers. Creating demand in bigger volume is vital for global supply chain development.

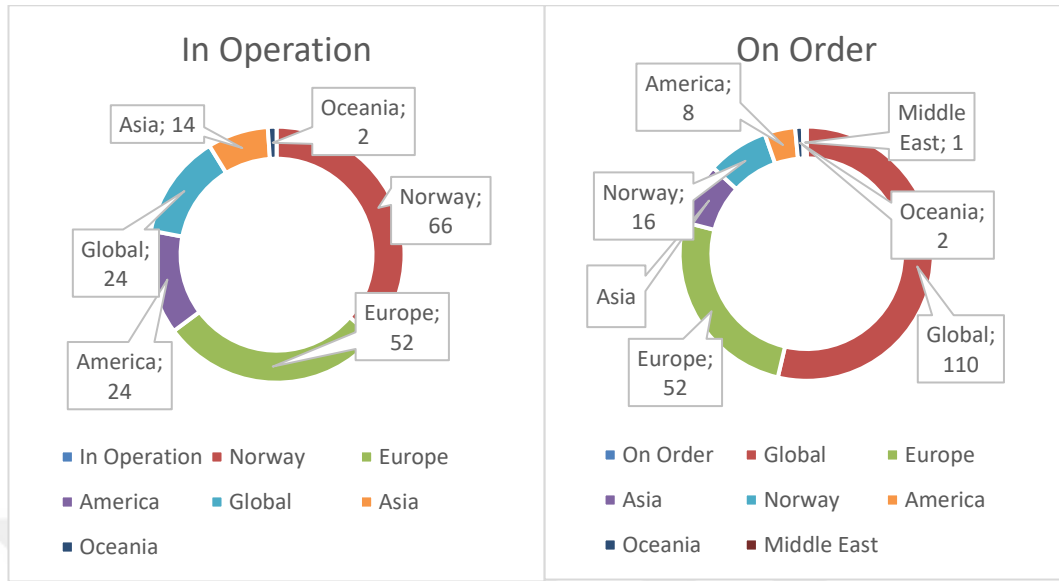
Figure 81: LNG Fuelled Fleet by Vessel Type



Source: Author, compiled data from (DNV GL, 2020c)

Figure 82 illustrates distribution of LNG fuelled fleet by region as in operation and on order. According to DNVGL data 66 of the LNG fuelled vessels are operating in Norway and 52 of the vessels are in Europe. The vessels in global trade and America are 24 for each. However, if we look at new order book data, the vessels expected to operate globally take the biggest part (110). This may be indicator of globally LNG demand, rather than the local one which is observed so far as in Baltic Sea. Europe takes the second place by 52 new orders. Asian market and Norway have 16 new order. The Middle East is slow-paced that there is only one new order.

Figure 82: Distribution of the LNG fuelled vessels by Region



Source: DNVGL,2020

5.6. WORLD LNG BUNKERING DEMAND FORECAST

As marine fuel pricing is strictly correlated with Brent Oil price, lower oil prices along with a slower than expected infrastructure development have negative effect on LNG as marine fuel use (Fevre, 2018). Forecasting LNG bunkering demand under several uncertainties is difficult. Uncertainty in global shipping markets, and world economic variables are a question mark. In parallel to technological improvement, energy efficiency measures, operational factors, vessel utilisation and speed optimisation are other dynamics that need to be taken into account for forecasting. Moreover, environmental regulations and increasing number of viable alternative fuel options make the future more complicated. Therefore, existing number of the vessels and confirmed new orders provide more reliable forecasting framework.

There are several studies regarding marine fuel demand as well as LNG marine fuel use. Lloyd Register provides comprehensive forecast report based on fuel price, technology development, ship type, environmental regulations in three different scenarios while taking into account alternative fuels (LR, 2014). According to Status que scenario LNG will take 11% of the global marine fuel demand by 2030. Forecast for the 2025 is between 6%-9% of global market.

DNVGL Maritime Forecast (2019) has three different pathway for world fuel: 1- Based on design requirements, 2-Based on operational requirements, 3-Based on current policies (DNV GL, 2019). The models consider baseline fleet, seaborne trade, technology costs and effects, fuel prices and regulations. In all three cases dominated fuel is liquified methane but from different energy sources -fossil, biomass, and other renewables.

IHS tanker market outlook (2019) stresses that IMO 2020 is only the starting point of radical change in marine fuels. The study predicts strong initial demand on gasoil and slow pace in LNG bunkering. However, after 2030 expecting increase on LNG demand based on IMO long-term CO₂ reduction targets and efficiency improvements as other fossil fuel demand decrease (IHS, 2020)

Boston Consulting Group's study argues that high cost of engine and infrastructure, storage onboard barriers will not be allowed to increase demand in LNG in the near term, however, over the long term, if pressure on emission control increases, LNG could become popular option for shipowners. Their humble prediction for LNG by the 2030 is approximately 4.4% of overall energy demand of global marine fuel market (Webster et al., 2019)

EIA (2019) report indicates that use of LNG as marine fuel will be limited in next five years up to 2025 due to high initial infrastructure cost and the limited available infrastructure nowadays. In the middle and long term, as infrastructure barriers decrease, LNG share of US bunkering grows to 7% in 2030 and 10% by 2050 (EIA, 2019).

IEA World Energy Outlook report indicates that according to Stated Policies Scenario, in international shipping, the use of LNG reaches to 50bcm by 2040 and it accounts 13% of shipping fuel mix as it takes less than 1bcm today(IEA, 2019b).

TOTAL's global marine fuel calculation argues that LNG demand in 2025 will be approximately 10 Mtpa, meaning that LNG will be accounted for 4.1% of global bunker demand (Pfeuty, 2019).

The summary of the forecasts are listed in Table 56. LNG and HSFO or MGO have different energy contents. Comparing the volumes misleads the understanding of the tables (Aronietis et al., 2016). Therefore, energy content of the marine fuel are used in the table in order to standardize the data. The forecasts of the LNG marine fuel

demand for 2025 are varying between 3.6% and 10%; however, for the year 2030, there is a big difference between forecasts up to 17%.

Table 56: Global LNG fuel Demand Forecast as Energy Share

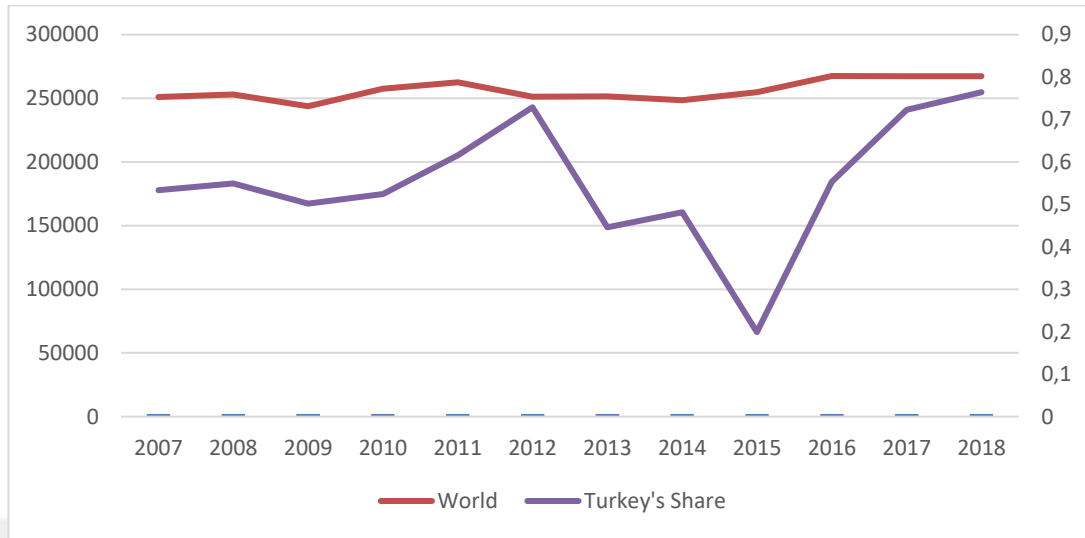
Organization	2025	2030	2040	2050
Lloyd Register (2014)	6%-9%	10%-11%	N/A	N/A
DNVGL(2019)	10%	21%	41%	44.4%
IHS (2019)	4%	4%	13%	29%
BCG(2019)	3.6%	4.4%	N/A	N/A
IEA (2019)	N/A	N/A	13%	N/A
TOTAL (2019)	4.1%	N/A	N/A	N/A

Source: Author, based on data, Lloyd Register (2014) DNVGL (2019),IHS(2019), BCG (2019), IEA (2019), TOTAL (2019)

5.7. TURKEY'S LNG BUNKERING DEMAND ASSUMPTION

Global LNG bunkering demand scenarios have different aspects; resulted from different calculation methods or different weight of indices. Forecasting the share of Turkey from global LNG bunkering demand is a difficult task to achieve as there are uncertainties. Global LNG bunker scenarios do not assure that Turkey's LNG bunker demand will be in the same percentage. The study aims to calculate LNG bunkering utilisation for Turkey. Therefore, firstly Turkey's present bunkering dynamics are evaluated by bunker volume, locations, Istanbul and Canakkale Strait passages and regional shares. Secondly, global LNG bunkering demand is evaluated and forecasts from leading research groups are aggregated. In order to make realistic assumptions, Turkey's bunkering volume is compared with global bunkering volume in historical trend as benchmarking. Figure 81 summarises historical trend of global marine fuel sells including HFO and MGO in total and Turkey's share in global market.

Figure 83: World Bunker Sales and Turkey's Share



Source: Author, compiled from (Mackenzi, 2019) and (EMRA, 2019a)

It is seen that Turkey's volume is between 1% and 0.5% of global market, excluding the year of 2015 which is explained in section 5.3.1. It's assumed that Turkey's LNG bunker sales volume will be 1% of total bunker sales in Turkey by 2025. The second demand case assumed that LNG marine fuel demand will be parallel to global demand. The forecasts for global LNG bunker demand by 2025 changing between 3.6% and 10%, average was taken as 5%. Therefore, in the second case, bunker demand assumed that it will be 5% of total LNG bunker demand of Turkey. For the third scenario, it was taken as optimistic scenario, Turkey' LNG bunker deliveries volume will be 10% of total bunker deliveries in Turkey. As Turkey real bunker deliveries are more than summarised EMRA data in section 5.3.1, fourth demand case was added to cover this deficit. As the fourth case, it was assumed that LNG fuel sales volume will cover 15% of the total bunker sales in Turkey. Distribution of the demand has been performed according to Figure 66 which reflects current distribution of bunker deliveries in Turkey by city.

5.8. MATHEMATICAL MODELLING

In this section firstly problem was described, and mathematical model was formulated. Objective function and the constraints were explained. The section concluded with computational results.

5.8.1. Problem Description

Based on the research questions which aim to determine the optimum numbers of the barges and their capacity, mathematical model was formulated. The model was developed based on Turkey's current bunkering dynamics, demand points and predicted demand by the year 2025. The model involves strategic decision representing multiple-period maritime mixed fleet size problem. It determines number of the barges and sizes of the small-scale LNG bunker carriers from a discrete set of five bunker barges model. Although the problem involves strategic decisions, the study also takes into consideration tactical and operational level decision components. The focus point of the study is ship-to-ship maritime bunker supply. Ship-to-ship bunker deliveries are conventional bunker supply options and practices in shipping. The vast majority of the bunker deliveries globally and in Turkey are performed by ship-to-ship option. Truck loading is an option for smaller vessels and larger amount of demand is met by ship-to-ship operations as their supply capacity is much higher and efficient than truck loadings. Therefore, in this study, the focus point has been taken as potential ship-to-ship LNG deliveries in Turkey.

LNG bunker supply was planned from import terminals to potential demand points which were decided according to present bunker sales at subject locations. Two LNG import terminals of Turkey: Marmara Ereğlisi BOTAS LNG Terminal and EgeGaz Aliğa LNG Terminals were determined as bunker barges' loading ports. EMRA data provides the delivery points as city not as port; Istanbul, Tekirdag, Kocaeli, Izmir, Mersin and Hatay. In order to make the delivery locations more specific, the biggest port at that region was taken and distance table was calculated as pilot-to-pilot. Distance from pilot points to berth was ignored for two reasons; firstly,

specific berth is not clear and secondly, pilot-to-berth distances are negligible compared to the overall distance. As the routes are not predefined, the model is formulated as arc-flow. The barges travel from port i to port j , while keep track of both travel time and load on the barges (Christiansen et al., 2007).

LNG bunker barge designs are relatively new concepts as conventional LNG carriers are working in long hauls and large sizes. Wartsila is one of the leading technology-based company in maritime field and providing significant numbers of all dual-fuel engines in the world. Therefore, in order to provide consistency of the bunker barges, Wartsila's LNG bunker barge design concepts were taken at five different sizes as 10000 cbm and below capacity. It provides discrete variables as heterogenous fleet option to find optimum barge numbers and capacities. Wartsila's technical data include consumption figures which allow to calculate fuel cost per mile for each barge (Wartsila, 2020). Fixed costs -running cost and daily charter rate figures were obtained from a consultant in LNG industry, who also took part in interview process. The figures also were cross checked with an expert from shipbuilding industry.

The study's focus point is at strategic and tactical level, therefore some operational obstacles which are not necessary at this stage of the study were ignored in order to achieve reasonable computation time, simplify the problem and fulfil the objectives of the study. The neglected constraints include boil-off, weather condition, current, speed reduction before arrival or time spend to increase full design speed, speed differences at laden voyage and ballast condition, light dues, port call expenses etc were ignored. The deliveries are planned for the ship-to-ship operations, therefore there is no storage at destination ports.

The barges are banned to travel until minimum demand requirement for the ship-to-ship delivery is satisfied, therefore model was designed in multiple time periods. As the bunker demand involves uncertainties for ship-to-ship delivery schedule, the time horizon was taken as one week with rolling horizon up to one month. By this way, satisfying all demand was prevented at last days of the month and provide equally distribution as long as demand is satisfactory.

5.8.2. Mathematical Formulation

The model was formulated in order to solve aforementioned problem addressed in research objectives: optimum number and size of the barges to be utilized, and distribution channel.

The mathematical model indicates all nodes as set of I and consider supply port as S , and discharge locations as set of customers C . Demand is satisfied by different types of ship $k \in K$, within set of time periods $r, t \in T$. Decision involving ship type is formulated with integer variables $z_{k,t}$ for time period t . Travels between loading port and delivery points are defined with $y_{i,j,k,t}$ as integer variables. Quantity of LNG transferred between ports with ship type k in time period of t was indicated as $x_{i,j,k,t}$ continues variables. Quantity of LNG delivered to customers is specified as decision variable $Del_{i,t}$ in period t . Discharging time required by corresponding shipment of customer i with ship type k in period t represented as $ut_{i,k,t}$ decision variables. Minimum ship delivery is determined with integer variables $w_{j,t}$. Parameters of LNG demand for customer j is defined as D_j . Minimum amount of LNG that can be shipped to a customer defined as Mn . Ship related parameters are indicated as r_k running cost, c_k fuel cost, c_k^c charter cost, Q_k capacity of ship type k . Distance between node i and j is defined as $d_{i,j}$. Available sailing time in period t which is 168h in this case, indicated as l_t . Big M is also used as large parameter. The model is based on linear equations and constraints which involves integer variables and defined as mixed integer linear programming (MILP). The set and indices, objective function and constraints have been explained as below.

Indices and Sets

- i, j, m : indices for nodes that represent the ports and bunkering locations (customers)
- k : index for ship type
- r, t : indices for time period
- I : Set of all nodes, $i \in I$
- S : Set of suppliers, $i \in S$
- C : Set of customers, $i, j, c \in C$
- T : Set of time periods in weeks, $r, t \in T$

- K : Set of different type of barges, $k \in K$
- A : Set of i and j pairs such that shipments from the customers to the port ($\forall i \in I, i > 1, j = 1$, and from the port and customers to customers ($\forall i, j \in I, i < j$) in the given order.

Parameters

- D_j : LNG demand of customer j
- $d_{i,j}$: Distance between nodes i and j
- c_k : Propulsion cost per nm for ship type k
- r_k : Running cost of ship type k
- Q_k : Capacity of ship type k
- u_k : Discharging rate of ship type k
- v_k : Speed of ship type k
- c_k^c : Charter cost per ship type k
- t_i : Berthing time at node i
- l_t : Available time for sailing in period t in hours -168h in our case
- M : Big number
- Mn : Minimum amount of LNG that must be shipped to a customer
- Mt : Minimum time required for service at each customer port (taken as 1,5 hours in our case)

Decision Variables

- $y_{i,j,k,t}$: 1 if ship type k travels between nodes i and j and, 0 otherwise in period t
- $x_{i,j,k,t}$: Quantity of LNG in terms of percentage of capacity of ship type k that is transferred from i to j in period t
- $z_{k,t}$: 1, if ship type k is used in period t and, 0 otherwise
- $Del_{j,t}$: Quantity of LNG (cbm) delivered to customer j in period t
- $w_{j,t}$: 0-1 decision variable to guarantee the minimum ship delivery to customer j in period t
- $ut_{j,k,t}$: Unloading time required for the corresponding shipment of customer j ship type k in period t
- $mut_{i,k,t}$: Maximum of durations Mt hours and $ut_{j,k,t}$

Objective Function

Objective function was determined according to minimum cost strategy. Traditionally operating costs of shipping are classified under two major expenditure: voyage costs and fixed costs (Mokia and Dinwoodie, 2002). Voyage costs are associated with related voyage and could be different according to travelling distance, port expenses, light dues, or canal passage if they are involved (Polo, 2012). On a voyage charter party agreement, voyage cost is usually paid by shipowner. Under time charter or bareboat charter agreement, voyage cost is usually paid by charterer (Stopford, 2013). On the other hand, fixed costs are free from voyage and ship owner need to deal with these expenditures regardless of vessel's position at sea, at port or at anchor. These are called 'running cost' and it depends on vessels type, size and specifications. Another item for fixed cost could be charter cost that charterer need to pay with fixed intervals to ship owner (Stopford, 2013). In other words, fixed cost is distinguished as the capital cost (CAPEX) which is derived from property of the ship – depreciation, interests of financing credits and running cost or fixed operation cost (OPEX) which are necessary to keep the vessel ready for the operation (Polo, 2012).

The objective function was formulated with minimum cost strategy that consists of two sides of the shipping cost -voyage cost and fixed costs. Fuel cost as the major expenditure of the shipping cost is added to the objective function. Other typical voyage costs such as light dues, anchor dues, port costs were ignored as these costs are negligible compared to fuel costs. The objective function was formulized with a shipowner perspective that provides overall picture of running LNG bunker barge associated with voyage and fixed costs. It aims to find optimum number of the barges, size and travelling pattern at different demand scenarios. Finally, the objective function has been formulated as follows:

$$\begin{aligned} \min \text{cost } Z &= \text{voyage cost} + \text{fixed costs} \\ \min \text{cost } Z &= \text{fuel cost} + (\text{OPEX} + \text{CAPEX}) \end{aligned}$$

$$\text{Minimize } \sum_{i \in I} \sum_{j \in I} \sum_{k \in K} \sum_{t \in T} c_k d_{i,j} y_{i,j,k,t} + \sum_{k \in K} \sum_{t \in T} r_k z_{k,t} + \sum_{k \in K} \sum_{t \in T} c_k^c z_k \quad (5.1)$$

Constraints

$$Del_{j,t} = \sum_{i \in I} \sum_{k \in K} Q_k X_{i,j,k,t} - \sum_{m \in C} \sum_{k \in K} Q_k X_{j,m,k,t}$$

$$\forall j \in C, t \in T, j \neq m, j \neq i \quad (5.2)$$

Constraint (5.2) computes the quantity of LNG delivered to customer j in period t .

$$\sum_{r \leq t} Del_{j,r} \leq \sum_{r \leq t} D_{j,r} \quad \forall j \in C, t \in T, t \neq 4 \quad (5.3)$$

Constraint (5.3) ensures that the amount of total LNG delivered to customer j for the first t weeks should be less than or equal to the total demand of customer j for those weeks. This constraint provides delivering no more than the demanded LNG by customer j up to period t and prevents piling up at bunkering locations.

$$\sum_{t \in T} Del_{j,t} = \sum_{t \in T} D_{j,t} \quad \forall j \in C \quad (5.4)$$

Constraint (5.4) guarantees that total amount of LNG delivered to customer j by the end of the planning horizon -in this case 4 weeks, should be equal to the total demand of customer j during this planning period.

$$Del_{j,t} \leq Mw_{j,t} \quad \forall j \in C, t \in T \quad (5.5)$$

$$Mn - Del_{j,t} \leq M(1 - w_{j,t}) \quad \forall j \in C, t \in T \quad (5.6)$$

Constraints (5.5) and (5.6) ensure that amount of LNG delivered to customer j in period t must be greater or equal to the minimum amount ship delivery required (Mn).

$$y_{i,j,k,t} \geq x_{i,j,k,t} \quad \forall (i,j) \in A, \forall k \in K, t \in T \quad (5.7)$$

Constraint (5.7) is required for shipments from the customers to the port ($\forall i \in I, i > 1, j = 1$), and from the port and customers to customers ($\forall i, j \in I, i < j$) in the given order. This constraint provides the relationship between the variables

$y_{i,j,k,t}$ and $x_{i,j,k,t}$. If there are no planned voyages between nodes i and j with ship type k in period t , no LNG will be shipped.

$$\sum_{i|(i,j) \in A} y_{i,j,k,t} = \sum_{i|(i,j) \in A} y_{j,i,k,t} \quad k \in K, t \in T \quad (5.8)$$

Constraint (5.8) guarantees the route continuity.

$$ut_{i,k,t} = \sum_{i|(i,j) \in A} x_{c,i,k,t} Q_k \frac{1}{u_k} - \sum_{i \in I|(i,j) \in A} x_{i,j,k,t} Q_k \frac{1}{u_k} \\ \forall j \in C, k \in K, t \in T \quad (5.9)$$

Constraint (5.9) computes discharging time at customer i for ship type k in period t .

$$mut_{i,k,t} \geq \sum_{j|(i,j) \in A} y_{i,j,k,t} Mt \quad \forall i \in C, k \in K, t \in T \quad (5.10)$$

Constraint (5.10) provides that unloading time at customer i should be at least Mt hours for ship type k in period t , regardless of quantity of LNG to be discharged.

$$mut_{i,k,t} \geq ut_{i,k,t} \quad \forall i \in C, k \in K, t \in T \quad (5.11)$$

Constraint (5.11) ensures that if unloading time at customer i is longer than Mt hours, in that case, actual unloading time should be taken, which is used in Constraint (5.12). Constraint (5.10) and constraint (5.11) help us to choose that maximum Mt and $ut_{i,k,t}$.

$$\sum_{(i,j) \in A} \frac{1}{v_k} d_{i,j} y_{i,j,k,t} + \sum_{j \in C} \frac{1}{u_k} Q_k x_{1,j,k,t} + \sum_{i \in C} mut_{i,k,t} \leq l_t z_{k,t} \\ \forall k \in K, t \in T \quad (5.12)$$

Constraint (5.12) ensures that total time for ship type k including loading time at the port, unloading time at the customers and sailing times between the nodes should not exceed the available time in each period t .

$$Z_{k,t} - Z_{k(t+1)} = 0 \quad t \in T, t \neq 4 \quad (5.13)$$

Constraint (5.13) ensures that if ship type k is used in the first period, it is used for the rest of the periods.

$$y_{i,j,k,t} \in \{0,1\} \quad (5.14)$$

$$Z_{k,t} \in \{0,1\} \quad (5.15)$$

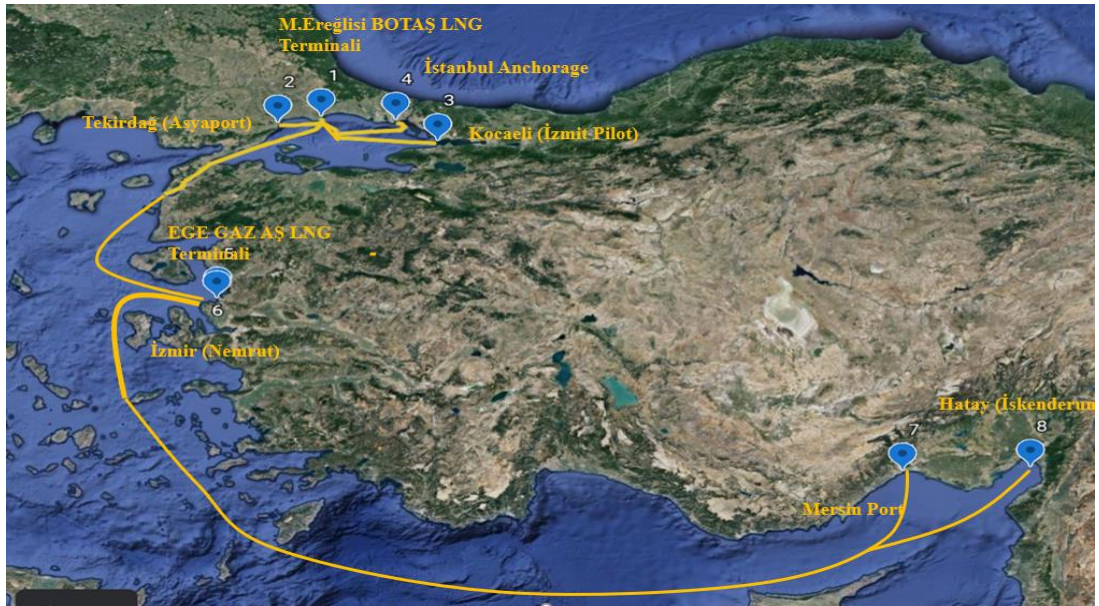
$$w_{j,t} \in \{0,1\} \quad (5.16)$$

Constraints (5.14), (5.15), (5.16) define 0-1 integer variables.

5.8.3. Turkey LNG Bunkering Case

Turkey LNG Bunkering case was evaluated under three different scenarios. Marmara Ereğlisi BOTAS LNG Terminal and Aliğa EGE GAZ AŞ are the two import terminals distribution centres for potential LNG marine fuel option. Therefore, scenarios were developed according to these two potential loading ports. Discharging points, potential STS transfer locations are determined according to present bunker deliveries of Turkey which are explained in detail in Section 5.7 Turkey's LNG bunkering demand assumption. Istanbul, Kocaeli (Izmit), Tekirdağ, Izmir, Mersin and Hatay(Iskenderun) ports were selected.

Figure 84: Bunker Delivery Points and Loading Ports



Source: (Google Earth, 2021), routes are illustrated as generic

The specific points were taken as pilot boarding positions for Mersin, Iskenderun, Asya Port (Tekirdağ) and Nemrut (Izmir) and explosive, and inflammable goods anchorage area for Istanbul. These positions were taken as reference distance table because, STS bunkering operations either can be carried at anchor or within ports. The distances between pilot boarding position to any jetty/berth in ports are negligible compared to overall distances. All open ports at seaside and no long canal or river passage are being performed. Kocaeli (Izmit Gulf) port could be exception while taking into account pilot boarding position and potential terminals. As there are a number of ports/terminals around the gulf, the distance could change from 3nm to up to 25nm. Therefore, in order to provide consistency with other ports, pilot boarding position was taken as the reference point. Istanbul anchorage area is the main bunkering hub for Turkey (EMRA 2020, Muhtaroglu 2020) and tanker anchorage area was taken as reference point as potentially LNG driven vessel could use this designated area if no other position is introduced. Table 57 shows distance between the ports.

Table 57: Distance Table

(nm)	Marmara Ereğlisi	Tekirdağ Pilot	Kocaeli (Izmit) Pilot	Istanbul Anchorage Area	Nemrut Pilot	Mersin Pilot	Iskenderun Pilot
M.Ereğlisi LNG	-	30	64	59	243	791	846
Tekirdağ P.	30	-	96	75	226	774	829
Kocaeli P.	64	96	-	37	314	862	917
Istanbul A.	50	75	57	-	272	819	874
Nemrut P.	243	226	290	272	-	637	692
Mersin P.	739	774	794	819	637	-	87
Iskenderun	846	829	863	874	692	87	-
Ege Gaz	-	220	308	266	4	639	694

Source: (SeaRoutes, 2020)

Typical LNG bunker barge specifications were taken from Wartsila website (Wartsila, 2020). The barges' capacities are in range of 3000 cbm to 10000 cbm as defined small-scale LNG carrier as listed in Table 58. As LNG loading/discharging operation practices, 6% volume of the barges was calculated and determined as constant volume remaining onboard. Based on gas consumption at design speed, consumption per mile was calculated as metric ton and eventually total fuel cost. In order to calculate cost per mile, metric ton was converted to mmBtu and cost for each

bunker barge was calculated - based on BOTAŞ's official LNG price as Turkish Lira for 2020. Turkish lira was converted to USD based on TL/USD rate as of 5th May 2020.

Table 58: Bunker Barges

Ship	Capacity LNG/MGO (cbm)	Deducted 6% (cbm)	Daily Cons. (t/day)	Speed (knot)	Rate L/D (cbm)	Consmpt. (t/nm)	Consmpt. mmBtu	Cost usd/nm (ck)
1	3000/830	2820	7.5	12	600	0.0260	1.3879	9.87
2	5000/270	4700	11.9	14	800	0.0354	1.8897	13.44
3	6500/550	6110	9.8	13	1000	0.0314	1.6761	11.92
4	7500/400	7050	8.4	13.5	1000	0.0259	1.3825	9.83
5	10000/2400	9400	12.1	14	1200	0.0360	1.9217	13.67

Source: (Wartsila, 2020)

Table 59 indicates barges' capacity as mmBtu and DWT based on Wartsila database. OPEX and CAPEX value of the barges have been obtained from a consultant in LNG industry, who took part in the interview process.

Table 59: Barges' OPEX and CAPEX

Ship	Capacity LNG/MGO (cbm)	mmBtu	DWT	OPEX usd/day	CAPEX usd/day
1	3000/830	67736,4	2000	8600	11000
2	5000/270	112894	3000	11000	14000
3	6500/550	146762,2	4200	11400	14600
4	7500/400	169341	4100	11800	15000
5	10000/2400	225788	7200	12300	15700

Source: (Wartsila, 2020 and expert view)

Demand was determined based on present bunker sales share. Yalova's share was added to Kocaeli, as some destinations of Yalova is located in Izmit Gulf and use same pilot boarding position with other destinations in Izmit Gulf. 'Other' cities' share is evenly distributed selected ports and final share of the ports were determined. LNG demand cases were organized as 1%, 5%,10%,15% of expected total bunker sales volume of Turkey. These categories also represent pessimistic, average and optimistic demand cases. Bunker figures in EMRA reports are defined in metric ton. These metric ton units were converted to energy unit as there is significant density and energy

content differences between conventional marine fuels and LNG. Table 60 shows distribution of demand figures for each destinations.

Table 60: Demand Figures for Each Bunkering Destination

Port	Share	Monthly	1%	1%	5%	10%	15%
	(%)	Demand mmBtu	mmBtu	cbm (LNG)	cbm (LNG)	cbm (LNG)	cbm (LNG)
Tekirdağ	2,7	208003	2080	87	433	866	1299
Kocaeli	15,6	1193725	11937	497	2485	4970	7455
Istanbul	76,1	5813062	58131	2420	12100	24201	36301
İzmir	2,1	156946	1569	65	327	653	980
Mersin	0,6	45143	451	19	94	188	282
İskenderun	2,9	222215	2222	93	463	925	1388
TOTAL	100,0	7639095	76391	3180	15902	31803	47705

Source: Author, 1m³ LNG=24.02 mmBtu, (IGU, 2012)

Table 61 indicates different demand figures for each destination point as mmBtu based on Turkey's 2025 bunker demand forecast. This mmBtu figures, then converted to LNG as cbm in order to find each ports demand quantity as cbm. The data used to develop the model is summarised in Table 61.

Table 61 : Summary of Reference List for the Model

Component	References	
Ship1	Wartsila/ Gas Carriers	(Wartsila3k, 2020)
Ship2	Wartsila/ Gas Carriers	(Wartsila5k, 2020)
Ship3	Wartsila/ Gas Carriers	(Wartsila6.5k, 2020)
Ship4	Wartsila/ Gas Carriers	(Wartsila7.5k, 2020)
Ship5	Wartsila/ Gas Carriers	(Wartsila10k, 2020)
OPEX	Expert Interview - R115	
CAPEX	Expert Interview- R115	
Distance table	Searoutes	(SeaRoutes, 2020)
LNG Price	Petroleum Pipeline Company (BOTAŞ) 2020 Tariff, 1.82 TRY/1Sm ³ (without tax)	(EMRA, 2020b)
USD/TL Rate	The Central Bank of the Republic of Turkey 5th May 2020, 1USD=7,055TRY	(TCMB, 2020)
Conversion factors	International Gas Union – Natural Gas Conversion Guide	(IGU, 2012)

Source: Author

Turkey case was evaluated under three cases. At the first case, Marmara Ereğlisi BOTAŞ LNG Terminal was taken as the loading port for bunker barge. The barge was distributed to LNG according to predicted demand to all designated ports -

Tekirdağ (Asyaport), Istanbul (Tanker Anchorage Area), Izmir (Nemrut), Mersin and Hatay (Iskenderun). Different demand scenarios of LNG supply 1%, 5%, 10%, 15% were evaluated. The second scenario took Aliğa Ege Gaz LNG Terminal as the loading port and distributed the LNG according to different demand cases to all designated ports. The third scenario used two ports for loading separately -Marmara Ereğlisi BOTAŞ and Aliğa Ege Gaz LNG terminals. While Marmara Ereğlisi BOTAŞ was serving at Marmara Sea region as a loading port, Aliğa Ege Gaz LNG Terminal served to the ports Izmir, Mersin and Iskenderun.

The MILP model was run with Intel®Core™i7-7500U CPU @2.70GHz-2.90GHz, 12,0GB RAM computer and LINGO/Win64 15.0.63 software was used.

5.8.4. Computational Results

Mathematical model provides insight about optimum number of bunker barges to be utilized, optimum capacity of the barges, minimum cost scenario and optimum distribution patterns based on different demand scenarios. Three scenarios were developed under four different demand cases. The results of the model are explained in following sections.

5.8.4.1. Scenario I

In the first scenario, Marmara Ereğlisi BOTAŞ LNG terminal was determined as the loading port and LNG bunker was distributed according to demand quantities of the ports. The model guaranteed weekly requested quantities within one-month period.

The MILP model includes 1529 total variables, 584 integer variables and 1313 total constraints in 4.59 elapsed runtime seconds for the 1% demand case. Optimal result for routing and quantity onboard figures are summarised in Table 62.

Table 62: Scenario I -1% demand

Route	Quantity onboard ($x_{i,j,k,t}$)
M. Ereğlisi – Tekirdağ	264
Tekirdağ – İzmir (Nemrut)	176
İzmir-Mersin	112
Mersin-İskenderun	92
İskenderun – M.Ereğlisi	0
M.Ereğlisi -Kocaeli	2916
Kocaeli-Istanbul	2420
İstanbul- M.Ereğlisi	0

The results of the model show that 5000cbm barge is the optimum one, and due to low demand, distribution is carried out only in the 4th week.

Secondly 5% demand option was run under MILP model. It includes 1649 total variables, 584 integer variables and 1313 total constraints in 11.62 elapsed runtime seconds. In parallel to the increased demand, distribution was carried out in the 2nd, 3rd and 4th week. The model results are summarised in Table 63. 5k cbm barge makes its first trip to Istanbul in the second week with full capacity. In the third week, two separate voyages were carried out in order to fulfil demands in Istanbul and Kocaeli. In the fourth week, the model suggests two separate routes for optimum distribution: the first one follows Tekirdağ-Izmir-Mersin-Iskenderun route and the second one follows Kocaeli-Istanbul route.

Table 63: Scenario I – 5% demand results

Route	Quantity onboard as cbm ($x_{i,j,k,t}$)	Week
M. Ereğlisi-Istanbul-M.Ereğlisi	4700	2
M.Ereğlisi- Kocaeli- M.Ereğlisi	1863	3
M. Ereğlisi-Istanbul-M.Ereğlisi	3321	3
M.Ereğlisi-Kocaeli	4700	4
Kocaeli-Istanbul	4079	4
Istanbul- M.Ereğlisi	0	4
M.Ereğlisi-Tekirdağ	1316	4
Tekirdağ-Izmir	884	4
Izmir-Mersin	556	4
Mersin-Iskenderun	464	4
Iskenderun-M.Ereğlisi	0	4

The third step of the second scenario investigates 10% LNG Bunker demand case. The model includes 1529 total variables, 584 integer variables and 1313 total constraints in 19.79 elapsed runtime seconds. The model defines optimum barge

capacity as one barge at 10k cbm capacity. The first delivery was carried out at second week to Istanbul and followed by two separate delivery to Kocaeli and Istanbul in third week. Relatively low demand of Tekirdağ, Izmir, Mersin and Iskenderun were fulfilled in the fourth week. Table 64 summarises 10% demand case of Scenario I.

Table 64: Scenario I – 10% demand results

Route	Quantity onboard as cbm ($x_{i,j,k,t}$)	Week
M.Ereğlisi-Istanbul-M.Ereğlisi	7778	2
M.Ereğlisi- Kocaeli- M.Ereğlisi	2590	3
M. Ereğlisi-Istanbul-M.Ereğlisi	9400	3
M.Ereğlisi-Tekirdağ	2628	4
Tekirdağ-Izmir	1764	4
Izmir-Mersin	1112	4
Mersin-Iskenderun	924	4
M.Ereğlisi-Kocaeli	9400	4
Kocaeli-Istanbul	7022	4

The model was run at 15% demand case for Scenario I. It includes 1529 total variables, 584 integer variables and 1313 total constraints in 49.16 elapsed runtime seconds. The results define optimum barge capacity as two barges at 3k and 5k cbm capacity. Table 65 summarises 15% demand case for Scenario I.

Table 65: Scenario I – 15% demand results

Route	Quantity onboard as cbm ($x_{i,j,k,t}$)	Week Number	Barge Capacity
M.Ereğlisi-Istanbul-M.Ereğlisi	2820	1	3000cbm
M.Ereğlisi-Istanbul-M.Ereğlisi	4700	1	5000cbm
M.Ereğlisi-Tekirdağ	4230	2	5000cbm
Tekirdağ-Istanbul	3600	2	5000cbm
M.Ereğlisi-Istanbul	4700	2	5000cbm
Istanbul-Izmir	490	2	5000cbm
M.Ereğlisi-Istanbul-M.Ereğlisi	2820	2	3000cbm
M.Ereğlisi-Kocaeli-M.Ereğlisi	2820	2	3000cbm
M.Ereğlisi-Istanbul-M.Ereğlisi	2820	3	3000cbm
M.Ereğlisi-Istanbul-M.Ereğlisi	4700	3	5000cbm
M.Ereğlisi-Tekirdağ	4700	4	5000cbm
Tekirdağ-Istanbul	4070	4	5000cbm
Istanbul-Izmir	490	4	5000cbm
M.Ereğlisi-Istanbul-M.Ereğlisi	2350	4	3000cbm
M.Ereğlisi-Kocaeli-M.Ereğlisi	4636	4	5000cbm
M.Ereğlisi-Mersin	1668	4	3000cbm
Mersin-Iskenderun	1388	4	3000cbm
M.Ereğlisi-Istanbul-M.Ereğlisi	4700	4	5000cbm

Supply was provided to Istanbul by two different barges for the first week. The second week 5k cbm barge fulfil the demand of Tekirdağ, Istanbul and Izmir. Istanbul and Kocaeli supplies were provided by 3k cbm barge separately. Demand of Istanbul in the third week was fulfilled by two different barges. In the fourth week, Mersin and Iskenderun demand quantities were provided by 3k cbm barge. On the other hand, 5k cbm barge was utilised for the rest of the destination points. Table 66 summarises results of the MILP model for Scenario I.

Table 66: Summary of Scenario I Results

LNG Demand	Optimum Number of Barge and Capacity	Min Cost- (OPEX+CAPEX+ Fuel Cost) usd
1%	1 / 5000 cbm	726960.6
5%	1 / 5000 cbm	731852.8
10%	1 / 10000 cbm	816397.9
15%	2 / 3000 cbm ve 5000 cbm	1296467.0

Three different demand cases were satisfied with one barge; however, 15% demand case requires two barges and optimum capacities were calculated as 3k cbm and 5k cbm. Parallel to the demand, minimum cost value was gradually increased due to the distance covered by the barges. As the 15% case requires two barges, minimum cost value dramatically increases.

5.8.4.2. Scenario II

In the second scenario Aliğa Ege Gaz LNG terminal was defined as the loading port and LNG fuel was distributed according to demand quantities of the ports. The model guaranteed weekly requested quantities within one month period.

The worst demand case (1%) MILP model includes 1529 total variables, 584 integer variables and 1313 total constraints in 5,40 elapsed runtime seconds. The model results show that 5k cbm barge is the optimum one and due to low demand, all distribution was carried out in the 4th week. Optimal result for routing is summarised in Table 67. The barge first discharges the biggest quantities in Marmara Sea following Tekirdağ, İzmit, Istanbul route then discharges the remaining figure to Mersin and Iskenderun. Izmir demand was fulfilled with separate voyage.

Table 67: Scenario II – 1% demand results

Route	Quantity onboard as cbm ($x_{i,j,k,t}$)
Aliğa – Tekirdağ	3116
Tekridağ - Kocaeli	3028
Kocaeli-Istanbul	2532
Istanbul-Mersin	112
Mersin-İskenderun	92
İskenderun-Ege Gaz	0
Aliğa-Izmir	64
Izmir-Aliğa	0

The second phase of the second scenario is based on 5% LNG bunker demand forecast. The model includes 1529 total variables, 584 integer variables and 1313 total constraints in 16.35 elapsed runtime seconds. As the demand increases 5 times according to the first case, distribution takes place in the 2nd, 3rd and 4th week. Optimal result for routing is summarised in Table 68.

Table 68: Scenario II – 5% demand results

Route	Quantity onboard as cbm($x_{i,j,k,t}$)	Week
Aliğa – Istanbul- Aliğa	4700	2
Aliğa - Istnabul- Aliğa	4375	3
Aliğa - Kocaeli- Aliğa	1863	3
Aliğa – Tekirdağ	4634	4
Tekridağ - Kocaeli	4202	4
Kocaeli-Istanbul	3851	4
Istanbul-Mersin	556	4
Mersin-İskenderun	464	4
Aliğa-Izmir-Aliğa	328	4

The barge (5k cbm) first performs Istanbul voyage in the 2nd week and it's followed by two separate voyages to Kocaeli and Istanbul in the 3rd week. 4th week loads remaining quantity except for Izmir and follow Tekirdağ, İzmit, Istanbul, Mersin, İskenderun and Ege Gaz pattern. Lastly it makes the short trip to Izmir.

The third step of the second scenario investigates 10% LNG Bunker demand forecast. The model includes 1529 total variables, 584 integer variables and 1313 total constraints in 20,45 elapsed runtime seconds. Table 69 summarises routing for the 10% demand scenario.

Table 69: Scenario II – 10% demand results

Route	Quantity onboard as cbm ($x_{i,j,k,t}$)	Week
Aliaga – Istanbul- Aliaga	9400	2
Aliaga - Istnabul- Aliaga	8750	3
Aliaga - Kocaeli- Aliaga	3726	3
Aliaga – Tekirdağ	9268	4
Tekridağ - Kocaeli	8404	4
Kocaeli-Istanbul	7162	4
Istanbul-Mersin	1112	4
Mersin-İskenderun	924	4
Aliaga-Izmir-Aliaga	652	4

The model defines optimum barge capacity as one barge at 10k cbm capacity. The first delivery was performed in the second week for the optimum voyage performance. 3rd week, same as 5% scenario, two separate voyages were conducted to Istanbul and Kocaeli. In the 4th week balanced demand of all ports fulfilled along with previously served ports as Kocaeli and Istanbul.

At the fourth stage, 15% demand case was investigated. The model includes 1529 total variables, 584 integer variables and 1313 total constraints in 61,88 elapsed runtime seconds. The model defines optimum barge capacity as two barge and 3k and 5k cbm capacity. Table 70 summarises 15% demand case of Scenario II.

Table 70: Scenario II – 15% demand results

Route	Quantity onboard as cbm($x_{i,j,k,t}$)	Week Number	Barge Capacity
Aliaga - Kocaeli- Aliaga	2820	3	3000cbm
Aliaga - Izmir	2628	4	3000cbm
Izmir-Mersin	1668	4	3000cbm
Mersin-Iskenderun	1388	4	3000cbm
Aliaga-Tekirdağ	4700	1	5000cbm
Tekirdağ-Istanbul	4385	1	5000cbm
Istanbul-Izmir	20	1	5000cbm
Aliaga-Istanbul-Aliaga	4700	1	5000cbm
Aliaga-Tekirdağ	4700	2	5000cbm
Tekirdağ-Istanbul	4385	2	5000cbm
Aliaga-Istanbul-Aliaga	4700	2	5000cbm
Aliaga-Tekirdağ	4700	3	5000cbm
Tekirdağ-Istanbul	4385	3	5000cbm
Aliaga-Istanbul-Aliaga	4680	3	5000cbm
Aliaga-Tekirdağ	4700	4	5000cbm
Tekirdağ-Istanbul	4385	4	5000cbm
Aliaga-Kocaeli-Aliaga	4635	4	5000cbm
Aliaga-Istanbul-Aliaga	4700	4	5000cbm

The 5000cbm capacity barge was utilized every week of the scenario. On the other hand, 3000cbm one was only used in the 3rd and 4th week of the scenario. It has fulfilled demand of the Kocaeli in the third week and Izmir (Nemrut), Mersin and Iskenderun in the 4th week.

Table 71: Summary of Scenario II Results

LNG Demand	Optimum Number of Barge and Capacity	Min Cost- (OPEX+CAPEX+ Fuel Cost) usd
1%	1 / 5000 cbm	726880.0
5%	1 / 5000 cbm	749875.8
10%	1 / 10000 cbm	834729.4
15%	2 / 3000 cbm ve 5000 cbm	1337784.0

Table 71 summarises overall results of Scenario II according to different LNG demand cases. Minimum cost figures gradually increased in parallel to travelled distance and 15% case showed the highest cost due to utilised two barges and demand.

5.8.4.3. Scenario III

Scenario three investigates two potential loading ports for LNG bunkering separately. At the first step, the model was run for the M.Ereğlisi BOTAS loading port. It was started with 1% LNG bunker demand case. The case results are summarised in Table 72.

Table 72: Scenario III - %1 Case of M. Ereğlisi

Route	Quantity onboard as cbm ($x_{i,j,k,t}$)	Week
M. Ereğlisi-Tekirdağ	2508	4
Tekirdağ-Istanbul	1420	4
Istanbul-M.Ereğlisi	0	4
M.Ereğlisi- Kocaeli-M.Ereğlisi	497	4

The model includes 605 total variables, 212 integer variables and 605 total constraints in 0.56 elapsed runtime seconds. All supply was provided by 3k cbm barge.

LNG demand case 5% model includes 605 total variables, 212 integer variables and 605 total constraints in 0.56 elapsed runtime seconds. All supply was carried out by 5k cbm barge. The case results are summarised in Table 73.

Table 73: Scenario III- %5 Case of M. Ereğlisi

Route	Quantity onboard as cbm ($x_{i,j,k,t}$)	Week
M. Ereğlisi-Istanbul-M.Ereğlisi	4700	2
M. Ereğlisi-Istanbul-M.Ereğlisi	4700	3
M.Ereğlisi-Tekirdağ	4700	4
Tekirdağ-Istanbul	4268	4
Istanbul-M.Ereğlisi	0	4
M.Ereğlisi- Kocaeli-M.Ereğlisi	2485	4

The third step of the second scenario investigates 10% LNG Bunker demand forecast. The model includes 605 total variables, 212 integer variables and 605 total constraints in 0.8 elapsed runtime seconds. The model defines optimum barge capacity as one barge at 6500cbm capacity. Results are summarised in Table 74.

Table 74: Scenario III- %10 Case of M. Ereğlisi

Route	Quantity onboard as cbm ($x_{i,j,k,t}$)	Week
M. Ereğlisi-Istanbul-M.Ereğlisi	5870	1
M. Ereğlisi-Istanbul-M.Ereğlisi	6110	2
M. Ereğlisi-Istanbul-M.Ereğlisi	6110	3
M.Ereğlisi-Tekirdağ-M.Ereğlisi	864	4
M.Ereğlisi- Kocaeli-M.Ereğlisi	4968	4
M. Ereğlisi-Istanbul-M.Ereğlisi	6110	4

The model was run at 15% demand case for the Scenario III M.Ereğlisi loading port option. It includes 605 total variables, 212 integer variables and 605 total constraints in 0.42 elapsed runtime seconds. The results define optimum barge capacity as 10k cbm. Table 75 summarises 15% demand case.

Table 75: Scenario III- 15% Case of M. Ereğlisi

Route	Quantity onboard as cbm ($x_{i,j,k,t}$)	Week
M. Ereğlisi-Istanbul-M.Ereğlisi	8425	1
M. Ereğlisi-Istanbul-M.Ereğlisi	9400	2
M. Ereğlisi-Istanbul-M.Ereğlisi	9400	3
M.Ereğlisi-Tekirdağ-M.Ereğlisi	1299	4
M.Ereğlisi- Kocaeli-M.Ereğlisi	7455	4
M. Ereğlisi-Istanbul-M.Ereğlisi	9075	4

The demand of Istanbul was fulfilled at all weeks, remaining ports' demand were provided in the last week at Scenario III-15% case of Marmara Ereğlisi.

The second part of the Scenario III distributes LNG bunker from EgeGaz to Nemrut (Izmir), Mersin and Iskenderun. Aliğa-centred distribution option of Scenario III is summarised in Table 76.

Table 76: Scenario III- Case of Aliğa

Route	Quantity onboard as cbm ($x_{i,j,k,t}$)				Week
	1%	5%	10%	15%	
Aliğa-Izmir	176	884	1765	2648	4
Izmir-Mersin	112	557	1112	1668	4
Mersin-Iskenderun	92	463	925	1388	4
Iskenderun-Aliğa	0	0	0	0	4

All four cases have had 605 total variables, 212 integer variables and 605 total constraints each and less than a second elapsed runtime. All cases found 3k cbm barge as the optimum barge capacity and utilised only one barge. The barge also followed the same distribution pattern for all cases and demands were satisfied in the 4th week.

Table 77 indicates the summary of the Scenario III. Marmara Ereğlisi-centred distributions' barge choice was changed in parallel to demand increase. On the other hand, optimum barge was defined as 3k cbm for all cases from Aliğa. Minimum cost values of Marmara option are higher in three cases, only exception is 1% scenario.

Table 77: Summary of Scenario III Results

LNG Demand	Optimum Number of Barge and Capacity	Min Cost- (OPEX+CAPEX+ Fuel Cost) USD	Optimum Number of Barge and Capacity	Min Cost- (OPEX+CAPEX+ Fuel Cost) USD
1%	1 / 3000 cbm	551682.0	1 / 3000 cbm	562835.1
5%	1 / 5000 cbm	707096.3	1 / 3000 cbm	562835.1
10%	1 / 6500 cbm	735867.2	1 / 3000 cbm	562835.1
15%	1 / 10000 cbm	793022.2	1 / 3000 cbm	562835.1

Minimum cost for the Aliğa centred case is fixed. This is resulted from low demand as only one barge was utilised, all shipment was made at 4th week, and discharging times were under minimum time window. Therefore, total cost was remained below Marmara Ereğlisi centred cases.

5.9. FINDINGS OF THE SEMI-STRUCTURED INTERVIEWS IN TURKEY

At the third stage of this research, semi-structured interviews were conducted with experts from Turkey. This stage aims to explore the views of the experts in Turkey related to or potentially relating to LNG bunkering. Another reason for the semi-structured interviews in Turkey was to evaluate the mathematical model findings with these experts. In order to provide consistency to the research, the interviewees were classified according to their fields of expertise as was also implemented in the semi-structured interviews in the first stage: namely, Shipowners, Suppliers, Regulatory Body (RB) members and Technical Service Providers (TSP). The questions, in parallel with literature findings, were organized according to environmental, safety, technical, commercial and regulatory frameworks from a Turkish perspective. The Turkey LNG bunkering case was investigated along with the mathematical model findings. As Covid-19 restrictions were in place, the interviews were conducted through online applications, mobile phone networks or e-mail. 5 shipowners, 6 suppliers, 4 TSPs and 4 RBs representatives participated in the interviews. Interviews were transcribed and analysed thoroughly. Content was categorised in four dimensions as supplier, shipowner, TSP and RB. Frequently the highlighted facts of each group were determined, critical key words even if it's not frequently emphasised were revealed.

The use of LNG as ship fuel is seen as a positive development because it is a cleaner energy source and is economical compared to other fuels. LNG not only complies with today's emission limits, but also offers various advantages over other alternatives in terms of available infrastructure and capacity.

- For this reason, LNG bunkering was considered as a promising alternative marine fuel for the future by 14 participants out of 19. Two shipowners and 1 technical service provider participant do not see any future in LNG marine fuel.

Turkey's LNG bunkering potential was evaluated in terms of transit via the Turkish Straits, large ports, the domestic fleet, the proximity to some main maritime trade routes, the existing LNG terminals and the LNG market.

- Suppliers and Technical service providers point out that Turkey has significant potential for LNG bunkering based on the aforementioned

criteria thus highlighting Turkey's advantage. On the other hand, 2 shipowners and 1 supplier underlined that Turkey is not in an advantageous condition due to market structure and geographical location.

The challenges for LNG bunkering in Turkey were defined in parallel to global challenges. Its environmental advantage compared to other fossil fuels is important but it is not sufficient to meet global targets.

- Commercial factors, LNG demand, LNG price and the LNG market were some of the key words underlined by 19 participants.
- High capital expenditure is not affordable for shipowners is another finding that is highlighted by 19 participants.
- Infrastructure is developing rapidly but global coverage has not yet been established.
- Crew competency along with safety considerations are other key subjects that were highlighted by 6 shipowner participants. 2 of the TSP also underlined the same issue.
- Fleet type, such as container vessels in liner services, RoRo fleet, and large carriers (either tankers or container vessels) were emphasised by shipowners highlighting some potential LNG fuelled vessel applications in different segments.

Turkey's LNG bunkering legislation and regulatory framework are important items which were emphasised by the supplier and regulatory body participants.

- To date, there is no legislation in place for LNG bunkering. This is another factor that is slowing down the LNG bunkering infrastructure development process from the supplier side as they seek references and standards to comply with local regulations.

Technical service providers are the most optimistic stakeholders regarding LNG bunkering development. Well-known problems of LNG bunkering such as BOG and methane slip can be minimised with technological improvements. The IGF standard for BOG treatment in bunker barges has been set at 15 days and the industry is able to comply with these restrictions. The Turkish shipbuilding industry is already producing LNG fuelled vessels as well as other alternatively fuelled vessels.

Commercial factors were again highlighted by the technical service providers, specifically that individual investment by a shipowner is unlikely due to the high capital expenditure costs.

Suppliers in Turkey are closely monitoring developments in alternative fuels in shipping. There are tangible investments in LNG bunkering facilities which were mentioned during the interviews.

- Collaboration was one of the key words to advance LNG bunkering developments in Turkey. It was emphasised by 4 suppliers.
- With regards to collaboration, 5 suppliers also highlighted government subsidies in order to encourage investment in infrastructure and develop the markets.
- Oil price, LNG price market structure and demand are the other key words which were emphasised frequently by shipowners and suppliers. High capital expenditure and the pay-back time of the investment were defined as barriers to enter the market.

The mathematical model findings were summarised to the participants as the optimum number of barges, their capacity and distribution channels. 3,000cbm and 5,000cbm barge sizes were found to be realistic for the expected LNG bunker potential market. The 10,000cbm barge result in the 10% demand case was criticised by some participants as they do not see demand for LNG at that level in 2025.

The study collected data through literature review, semi-structured interviews and participant observation at the first stage. The second stage consist of multiple regression and forecasting in order to investigate Turkey's bunkering dynamics and prediction for Turkey's bunkering volume in 2025. Mathematical model uses these data in order to find the optimum number of the barges and their capacity. The third stage involves semi-structured interviews in Turkey in light of research objectives. Findings of the study are analysed thoroughly in the following sections.

5.10. ANALYSES

At the first stage of the study small-scale LNG supply chain and LNG bunkering development were explored through different stakeholders' perspectives:

suppliers, shipowners, technology developers, and regulatory bodies. As the main difficulties are represented as lack of infrastructure and prices, there are other factors affecting directly or indirectly; so the overall supply chain development is interlinked. Main themes -environmental, safety, operational, technical, regulatory framework, and commercial challenges were critically discussed in order to bring a holistic approach to overall supply chain design.

5.10.1. Environmental Considerations

LNG has a positive impact on air quality as sulphur content and PM are almost zero. Short sea shipping and cabotage shipping require more attention as local communities are directly affected. However, one respondent argues that environmental considerations are still neglected as in business context, only economic factors are being discussed without taking into account where we live and how the next generation is to be affected by present air quality. IMO 2020 regulations could be a positive contributor to LNG bunkering development. Stricter regulations have a positive impact on LNG bunkering, however; if major oil/gas companies are not involved in LNG fuel, it will not be the future fuel of shipping. Methane slip is still a drawback for LNG as it has thirty times more impact on global warming compared to CO₂. However, technology improvement is promising (R104). Low distillates and scrubbers are other viable options for shipowners for strict regulations compliance. Shipowners could decide to do nothing and follow low distillates option. In this case, the availability and price of the low distillates could be a question mark as refineries could have difficulties to satisfy the increase in demand. Another option is to install scrubber and take advantage of cheaper HSFO. The scrubber option has two alternatives as closed-loop and open-loop. Closed-loop scrubber installed ships need to deliver their waste to shore periodically. Waste reception facilities, their availability, price of handling, and reluctant port authorities could be an obstacle for ships. On the other hand, open-loop scrubbers drain the washing waters into the sea -rather than air. Some ports across the world already have banned open-loop scrubbers within their port limit. RB (R119) participant also emphasises that:

... "you have chemical waste that you need to deal with it and ports don't seem particularly eager to do that. So although those two options investment wise obviously are much less, it seems that longer term that it is going to be hard to sustain that solutions... "

Alternative fuels are still infant compared to LNG either due to global availability, technological competency, or regulatory standards. All parties agree that LNG is a viable option for the environmental sustainability of shipping. While shipowners' calculation is based on economic variables, technology providers emphasized technological improvement in the methane slip issue, being a transition fuel for future carbon-neutral fuels. Life cycle assessment of LNG as fuel, taking into account the entire supply chain, is arguable as different approaches bring different results.

5.10.2. Safety Considerations

All stakeholders are concerned about conducting LNG bunkering operations safely. Crew training is the most important part strongly emphasized by different respondents. Safety concerns usually come up with a regulatory framework and safety standards are stressed by regulatory bodies. Shipowners focus more on the availability of the qualified crew and higher industrial standards' economic impact on LNG marine fuel (R115). LNG is not a new issue for shipping as already being transported by ships for years. It's pointed out by supplier participant (R112) that:

"LNG Industry has one of the most successful safety record because of the robust and well maintained regulatory frameworks, all oil/gas majors and industry groups want to keep it the same way which is positive,"

The industry has safety standards to handle it as cargo. Special precautions need to be taken to handle it out of LNG carriers. Crew training is a very crucial step to handle LNG as a marine fuel (R101,102,117,120). Crew dealing with bunkering should be qualified with a fundamental understanding of the product (R117). Safety awareness of the crew is highly related to the type of the vessel they work on. Therefore, training of the crew is a primary concern, especially other than the tanker segment. The training process could need a long time as there are not many places where you can get LNG bunkering training. The key risk is a gas release that could

lead to ignition or asphyxiation. The liquid release is also important, which causes fractures on steel. Exposure of cryogenic liquid is going to be resulting in life threatening skin burns. Water curtain, personal protective equipment are basic precautions against any liquid release (R120). The location where LNG bunker operation is to be conducted must be safe and to be avoided from nautical risk areas. Approach area, fendering, mooring, and passing vessels through channels are the factors affecting the safety of the operations. Restricted zones should be set for safety reasons. Flow rate and pressure are the two key indicators to determine the safety zone (R103). Quantitative and qualitative risk assessments should be carried out to see if the risk is acceptable. Location choice is critical in reducing the risks to a reasonable limit. Providing simulator training and hands-on training are critical for crew improvement.

5.10.3. Operational Considerations

LNG bunkering operation has difficulties. Different respondents argue that these are mostly related to lack of experience and globally standardized process, which will be sorted over time. The compatibility of the vessel could be fixed as industrial practices for different sizes of the flanges, and the distance between manifolds can be overcome with flexible hoses. Both facilities exchange information and come up with an appropriate transfer system. However, one respondent argues that the size of the bunker barge could cause some compatibility concerns at loading terminals, as small barge will not fit LNG receiving terminals and some modifications are required (R111). LNG bunker barges are typically designed as Type C tanks, which have no issues with sloshing, and it provides flexibility to load slack cargo according to the client's request. On the other hand, it has been pointed out by shipowner respondent for operational efficiency as follows:

"Subject to the size and capacity of the receiving vessel, location (port or offshore) – initial operations typically take longer due to many pre-checks and evaluations. To reduce unit cost you want to fully load ship/barge (as port cost are fixed) and then distribute as much as possible before returning for new loading."(R116)

Delivered LNG bunker calculation is being made by mass flow meters in Ship-to-Ship transfers. Truck to Ship transfers could be calculated based on the number of

trucks. Characteristics of the LNG is different based on the sources. Therefore, BDN (Bunker Delivery Note) should include the quantity transferred as volume, mass, and energy. Which figure will be taken into account is subject to a contract between the receiver and the supplier. Simultaneous operation is another critical stage for LNG bunkering as it allows us to perform cargo or passenger operation at the same time. Larger vessels require a longer time for bunkering, and simultaneous operation resolves time concerns over LNG bunkering (R117). One of the serious obstacles in front of the shipowners could be sorted.

5.10.4. Technical Considerations

The shipping industry has had experience over LNG handling on a bigger scale for years; however, small or mid-scale handling is relatively new, and some technical problems still exist, or standardized solutions have not been provided yet.

Methane slip at the engine is still one of the biggest drawbacks of the LNG as a marine fuel. Technology providers are very ambitious to minimize it (R104). In addition to the engine, it was highlighted that long hose connections without proper insulation cause leakage and evaporation, which eventually leads to global warming that the industry ignores. The vessels working in long haul need sufficient bunker tank capacity to complete the round trip. The bigger fuel tank means relatively less cargo space. The boil-off gas (BOG) problem was pointed out by several respondents (R103, R104, R115, R119). Reliquefaction plant or sub-cooling systems are the solutions to the industry so far. Burning of the BOG in auxiliary engines is another alternative to handle the issue. BOG management is the responsibility of each individual vessel, and it has been incorporated into the design of the LNG fuel system onboard the vessel, and the LNG cargo system onboard the LNG bunkering vessel. Quality and methane number of LNG affects the performance of the engine (R105). As LNG is provided from different sources with different quality, it's a question mark for the vessels which need to supply bunker across the world. So standardization in methane number is required for the performance of the vessels' engine. Standardization is achieved in a temperature of the LNG as -158°C in industry. Temperature difference of the LNG also slows down bunkering operation that leads in time concern (R104). Technical

obstacles affect the shipowner's investment decision, as it leads to high capital expenditure. Technology providers are optimistic about developments and technical standards. However, the industry still needs to be standardized, and some technical factors are to make LNG marine fuel a more acceptable option globally.

5.10.5. Regulatory Framework

Handling LNG is already well set by the highest industry standards and regulations. An extended part of the handling LNG involves the bunkering purpose, which is covered by some guidance and best practices prepared by SGMF, EMSA, IMO, SIGTTO, or OCIMF. However, it was observed during the interviews that different stakeholders have different views in terms of implementation, coverage, or practices of the regulatory framework.

Supplier respondents were satisfied with the regulatory coverage of LNG bunkering. However, the other groups were critical in the overall implementation. IGF Code has been developed based on safe handling, environmental considerations in mind; however, it is argued that IMO does not take into account standardization. One RB participant argues as follow:

"...it is about regulation,....a lot of respect to develop, a common regulatory framework, but, obviously not only ports, every country has different regulations. Even in Europe you couldn't see consistency in between the ports about regulations, all need to comply with the EU rules but still there are different applications...."(R105)

The process is implemented in various ways, and it makes the process complicated for the ships. Local regulations are different, and they require a different process even within NW Europe. It was highlighted by a respondent that standards have been transferred from conventional LNG handling to LNG bunkering, and it might be too high and difficult to implement at a small scale(R105). However, small revisions and updates on IGF could be sufficient to cover the industrial needs(R119). The technical service provider argues that even if the regulatory framework is in place, there are different opinions between classification societies, and it's hard to keep balance in case of working with different societies of classification. Their experiences in LNG bunkering are at different levels, and it is reflected on site. Standards are made

by experts, not by regulatory bodies. Therefore, IACS should propose canons to facilitate similar implementations in the industry (R103). Shipowners have a more optimistic view that as operations are conducted, the industry will set its own standards on the way (R115, R101).

5.10.6. Commercial Considerations

Inevitably commercial factors are far important criteria for all stakeholders. Energy demand, pricing, contracts, supply and demand along with market structure and available funds were discussed through different perspectives.

Commercial viability of LNG fuelled ship investment is critical for ship owners. They have to calculate financial sources, private equity, indirect finance via shipyards or green funds (R110). European Commission or governments subsidize significant amount of the project, 'green' funds are available for investments, however, it requires some work to introduce it to 'shipping' and how to match with 'green'(R112). LNG bunkering investment decision is not an easy process as it comes up with sum of uncertainties. Supplier side points out that there are not so many vessels available in order to serve at regularly basis LNG to customers so they can organize logistics in advance (R107). Shipowner side argues that the main challenge is supply as they cannot reach out LNG fuel as they want (R101, R106). However, regulatory body and technical service providers see the challenge mostly: lack of demand as supply chain for LNG is already available in many places (R104, R105, R117, R120). However, the market does not really exist yet, in progress, bunkering facilities are still on developing stage. Shipowner representative argues as follow:

"... It is going slower than what people are expecting.....It is not like something you take off the shell and go with it. It is a big decision, it is very costly. It requires bit a how you are going to operate where are going to operate, then fuel is a big question mark."(R101)

Normally, volume of the market is the key point to decide, however, it was overridden by big oil majors' decision -irrespective volume of the market and they invested in bunker barge (R103). As LNG bunkering market has not been matured yet, the market development depends on where your client is, and you must see potential demand in order not to pursue your client when supply chain is oversized for a single

client. Economies of scale is critical at this stage that suppliers will concentrate bunkering stations at these locations (R117). However, small scale LNG logistics could be very expensive compared to conventional LNG logistics as it requires high CAPEX with unsatisfied demand (R109).

Scalability is important to initiate LNG bunkering supply, relative less investment can afford small amount of LNG by trucks until the market gets matured (R102). The first need is to see the market, and then market will set supplying limits to set the price (R106). One important factor for market development is price. Shipowner side argues that there are very few LNG suppliers in the market without competition, which leads to high LNG fuel prices. It's also pointed out as follows:

"With very few LNG suppliers in the market, which resulted in LNG being priced prohibitively high, the business case for LNG made no sense outside Norway."

(R115)

Availability and the cost related logistics chain is an obstacle (R111). Apart from logistics added cost of LNG, competition with oil price is critical as well. The gap between MGO and LNG will affect shipowners' decisions. Price is also criticised as follow:

"Until 2014 most of the LNG suppliers liked to index their LNG prices to MDO, which created little incentive for commercial ship owners to convert to LNG, if there were no overriding environmental reasons or generous subsidies."(R119)

Moreover, LNG has different prices in different regions. Pricing in Europe is relatively stable and fluctuating less than that in Far Eastern market where gas price absolutely linked in the contract to the oil prices or where gas price oppositely is linked to the oil price in the USA. Conventional fuels have standard products and limited specifications, then it's easy to price this product. However, in LNG, reference quality does not exist, therefore pricing LNG based on specification is not easy (R105).

Another difficulty is there is not much transparency in the industry, and stakeholders do not have knowledge of LNG bunker prices (R117). It's something that needs to be negotiated by shipowners which is still another challenge for LNG contracts (R103). Supplier side seeks long term contracts to set infrastructure according to demand. On the other hand, shipowners want to see spot market and don't want to commit to long term contracts as they need flexibility and may change their trade patterns (R101). Therefore, contracts should be short -spot deal agreements.

Longer term contracts may provide more price security for both LNG suppliers and the LNG consumers, but take away the opportunity for ship owners / charterers to profit from a drop in LNG prices (R116). As global market is changing, with an impact on price, contracts and LNG bunkering pricing, IMO 2020 regulations and new LNG bunkering infrastructures are expected to have positive impact. However, uncertainties are inevitable in a relatively new business case, and sharing the risk is a critical stage to start up new concept.

5.10.7. Infrastructure, Operational Region and Fleet Type

Lack of infrastructure is an outstanding challenge in front of LNG fuel. Availability and affordability are not established in the industry where owners/operators can be relieved (R115). For the shipowner, the challenges are securing a reliable source of LNG in all ports that the vessel will call (R119). Traditional bunkering hubs where main shipping trade pass through are the key locations for LNG fuel development as large vessels lift substantial amount of bunker and generate demand. Specific vessel types and trade could be important factors (R106, R120). Container vessels, car carriers or cruise vessels need very large volume of fuel, and usually their port of call list is prepared in advance and they are represented as good customers. The vessels which are on tramp trade still need to see more supply security. Baltic Sea and NW Europe already have infrastructure, busy shipping routes, environmental pressure and subsidies from EU to comply with the emission mitigation targets. If there is a cluster of several LNG users or potential users with sufficient LNG demand in around specific location, the investment in an LNG bunker barge will be viable as we have seen in Baltic region or NW Europe (R116). LNG bunkering barge means large volume of supply along with less bunkering time.

5.10.8. Small-scale LNG Supply Chain and LNG Bunkering Development

Challenges in LNG bunkering development were discussed and analysed through different perspectives. Outstanding concerns were defined, and how they are interlinked was highlighted. As the research objective questioned how to develop the

LNG bunkering supply chain, challenges that stakeholders faced were identified, and the key factors were proposed to link different parties and bring solutions to these observations.

Collaboration is the core element for LNG marine fuel development. It is a relatively new business case that different stakeholders need to work together. Traditional LNG suppliers are not bunker suppliers. The same implies to another side of the chicken-egg paradox; traditional shipowners are not LNG marine fuel customers. As it is still observed in the industry today the link between suppliers and shipowners is missing. Both sides are not willing to take the risk for this high CAPEX investment. A strategic approach in terms of creating clusters in certain regions could link all stakeholders and facility infrastructure development, secure a certain level of demand and competitive prices. Public interest and opinion bring green fund initiatives as well as government subsidies. A network between stakeholders should be set to create a business case and feasibility for new investments. Agreement between parties, a joint venture for bunker barge, or partnership for technology development is necessary.

Transparency is required to cope with uncertainties in pricing. One of the biggest commercial challenges for LNG marine fuel development is 'price'. The price gap between MDO and LNG is an important criterion for investment decisions. However, despite the relatively stable LNG prices, shipowners are still hesitant to take firm decisions, as the LNG bunker price is still speculative and expensive on a small scale. LNG price is listed in TTF, Henry Hub, JKM, or NBP. These are references to LNG marine fuel. However, logistics cost has not been set, and the profit margin of the supplier is not clear. It's interlinked between suppliers and shipowners. It needs to be negotiated between supplier and receiver sides, and the market needs to see more transparency. The price of LNG fuel is not clear, and it is questionable for shipowners that they need to do their calculations based on the final price of LNG fuel that needs transparency. Flexibility is required to persuade shipowners into business as they avoid long-term commitments and take the opportunity of the market during up and downs times. Another reason is flexibility in the trading area. It is the case not only for tramp shipping, but also for some container vessels that may change their lines according to

the market conditions or manage their fleet without considering bunkering infrastructure or fuel availability.

Safety culture is critical for LNG marine fuel implementations and starts with training. Training needs were emphasised by all stakeholders. One of the crucial points is qualified crew to handle LNG. Even though shipowners make decisions to shift to LNG fuel today, there are not qualified crew to handle or institution to give proper training. Not only bunkering operations, hose connections, safety precautions, but also engine staff who need to know how to operate dual-fuelled engines are necessary to be adequately trained for this purpose. Shipowners and regulatory bodies are primarily responsible for crew training. Setting safety culture with training and on-board implementations are important to keep LNG's clear safety record and to prevent any resistance that could arise from the public.

Standardisation is still a crucial issue for LNG marine fuel development in some places. There are industrial standards and guidelines in place; however, implementations are not standardized. Technical standards of classification societies are different, and still handling by expertise is on duty's decision in many places. Each port or country sets its own rules, and even within Europe, complying with these standards is not easy. Unlike conventional bunkers, LNG marine fuel itself is not standardised with specifications in terms of quality. It makes it difficult to set prices commercially and comes up with technical problems on the engine side. Therefore, technical service providers and regulatory bodies need to work together to improve standards clearly to make LNG fuel a more reliable option. Otherwise, the industry in the course of time will set its own standards in different regions, and LNG will not be a viable option for shipowners who trade worldwide at a large scale.

Figure 85: Key Approaches to Overcome The Challenges and Stakeholders' Relation

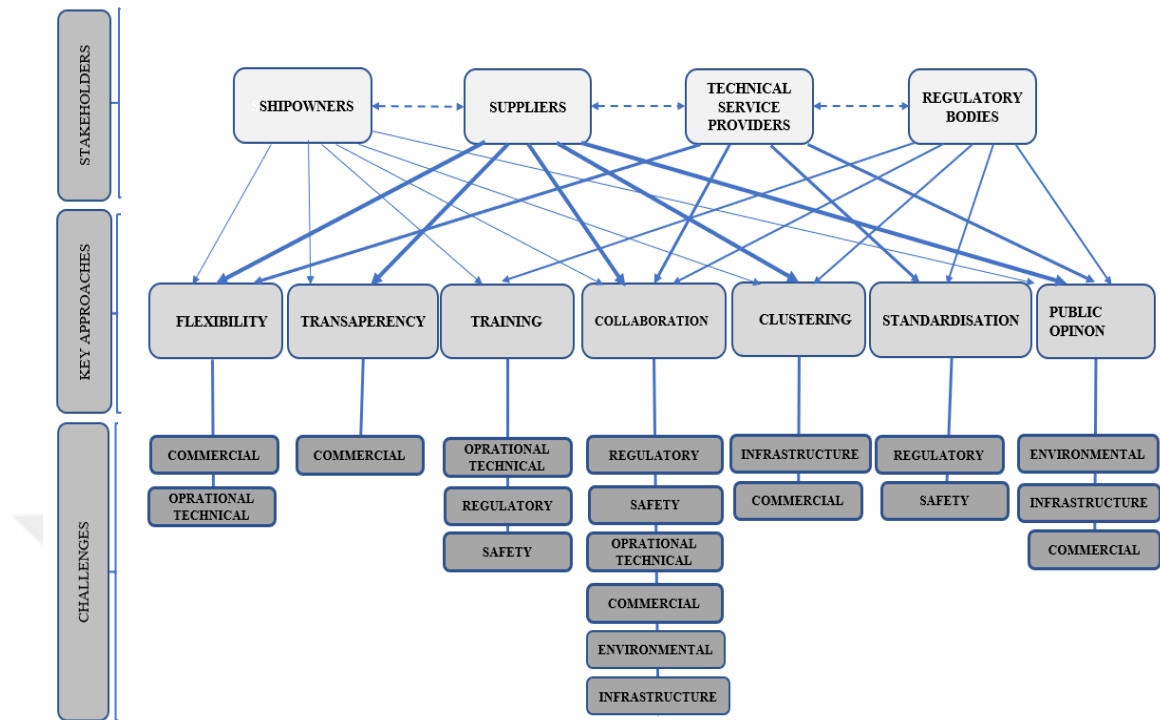


Figure 85 summarises the findings of the research. The rationale behind using LNG marine fuel concerns environmental considerations, air pollution, and global warming. IMO's new regulations are coming into force to achieve global CO₂ emission mitigation targets and to reduce air pollution that causes dramatic health problems. Therefore, while discussing alternative fuels or LNG marine fuel, 'public interest' needs to be in the centre rather than just 'economy'. Public opinion on green awareness is vital for environmental sustainability. Shipowners, suppliers, technical service providers, or regulatory bodies all have the responsibility to collaborate and achieve emission targets. Pollution causing health problems as well as public interest and public opinion should be a strong driver for this. The fundamental approaches, which are critical in overcoming subject challenges, have been interlinked to related stakeholders, and it is conceptualised as a model.

5.10.9. LNG Bunkering Case for Turkey

Turkey is an important ship-supply location in maritime traffic. The Istanbul area provides not only bunkering but also crew change, provisions, spare parts, water/oil supply and repair facilities which all contribute to Turkey's economy. Traffic density in the Istanbul and Canakkale Straits makes this place one of the busiest shipping routes and the total tonnage of vessels passing through has been increasing gradually over the years. In addition to transit passage through the straits, the growing shipping activities at ports is crucial to the measure of bunkering potential. By the end of the 2018, Turkey's total bunkering volume reached 3 million tonnes. It is provided by 55 bunker barges in service (Muhtaroğlu, 2020). However, it is argued that this is still below the potential of Turkey as only about 1,200 ships per year receive bunker in Istanbul and this is only approximately 3% of the total transit passage of the Istanbul Strait. Another crucial item is the storage facilities which are located in the Izmit Gulf and the logistics issues which affect the competitive price of bunker deliveries. In light of these bunkering facts in Turkey, the LNG bunkering case was discussed.

Bunker supply chain stakeholders in Turkey generally have a positive attitude towards utilising LNG as alternative marine fuel. One of the regulatory body participants justified using LNG as a marine fuel as follows:

"The use of LNG as an alternative ship fuel provides a 90 percent reduction in nitrogen oxide emissions as well as almost zero sulphur emissions and particular matter. A reduction in the carbon emission rate by 10 to 20 percent can be achieved with the use of fuels with low-sulphur content in accordance with the IMO decision. However, it could increase to 27 percent with the use of LNG. On the other hand, when considering the IMO goal to reduce GHG emissions from ships by 50 percent by 2050 based on 2008 levels, LNG emerges as an important alternative fuel. Considering the operational costs, LNG is advantageous as a fuel compared to low sulphur fuel in terms of lower prices and higher energy efficiency. All these points show that LNG stands out as an alternative fuel for ships compared to other options. " (R216).

The Marmara region is a highly populated area and there is significant marine traffic in the Marmara Sea. Ship-induced air pollutants such as SO_x, NO_x, and PM have significant effect on human health and ecosystems. The positive contribution of LNG to air pollution should have great importance for the city of Istanbul, which is located

around one of the busiest waterways in the world. These environmental benefits are supported by operational benefits for the supplier participants:

".. In addition, bunker LNG reduces the operational costs of ship machinery such as maintenance and attitude and creates less vibration, soot and odour in ships (especially for cruises ships), which provides important advantages"(R213).

On the other hand, one of the shipowner participants is not optimistic about LNG as a marine fuel. He argued against it as follows:

"I think it is difficult to use it as ship fuel in the short term due to current market conditions, economic crises, high costs, alternative fuels, alternative systems and challenging conditions, insufficient incentives, operational-operating costs and insufficient supply points " (R218).

These arguments are similar to other shipowners' perspective not only in Turkey but also globally.

The Turkish perspective on LNG as a marine fuel seems slightly less promising than the views held by their foreign counterparts during interviews in stage 1. Although environmental benefits are emphasised by all participants; 2 out of 4 shipowner participants did not view LNG to be important alternative fuel, taking into account high capital expenditure. This is the primary reason why shipowners are reluctant to invest in alternative fuels. Unless forced by regulation, shipowners seek less risky and less costly alternatives in their operational and tactical decision making processes.

Turkey's LNG bunkering potential was usually evaluated via its geostrategic location and existing LNG handling facilities by the participants. This potential was underlined by one of the regulatory body participants as follows:

"..as of the 2019 data, the Istanbul Strait has 41,000 ship movements. An important part of this is the transit passages accounting for around 60 percent, where it brings in maritime trade in the Black Sea and Mediterranean axis, including oil and petroleum-based cargoes. And again, in 2019, the number of ships carrying out supply in the Istanbul Strait, including bunkering, is around 8,200. In light of all these data, the Istanbul Strait stands out as an important supply hub. Considering this potential, it is important to be able to supply LNG as a bunker, which stands out as an alternative fuel in ships depending on the worldwide trend, environmental constraints and regulations, as well as the conventional bunker supply" (R215).

An existing LNG infrastructure, knowledge, and experience are the advantages for Turkey in the East Mediterranean and Black Sea region. This is pointed out by a supplier as follows:

"...Due to the existing LNG Terminals and an established / experienced market structure in the bunker fuel trade, it is possible to access bunker LNG from Turkish ports at competitive prices and under favourable conditions" (R218).

Apart from Turkey's LNG import terminals, there are other LNG activities in the region: Greece's import terminal Ravithoussa and FSRU Alexandropolis. Greece's LNG bunker barge agreement is already signed. Pireaus is an important bunkering location which competes with Istanbul. However, Turkey's LNG volume and distance to main maritime traffic route could still bring advantages.

Turkey has a very dynamic ship building industry. LNG fuelled vessels have already been built in Turkey. There are number of shipyards in Turkey which have the knowledge and capability to build vessels in Green Ship concepts which are fuelled by alternative fuels such as Cemre Shipyard, Tersan Shipyard, Sanmar Shipyard. This point was emphasised by several participants to illustrate the potential of Turkey.

The challenges for LNG bunkering development in Turkey have similar considerations as is the case in the global scale. Insufficient demand for LNG bunker is a major challenge for suppliers in taking the decision to invest in LNG. The long pay-back time prediction due to the infancy of the market was underlined by all supplier participants. On the shipowner side, parallel to global concerns, the high CAPEX requirement and lack of global coverage of infrastructure were defined as the main reasons to be reluctant to invest in LNG fuelled vessels. At the same time, shipowners will remain in favour of traditional solutions as long as the regulations allow, relying on economic facts. Another outstanding challenge highlighted by all shipowners is the lack of qualified crew. It was argued that even if they made took the decision to invest in LNG fuelled vessels, it would be difficult to find and employ qualified crew who are certified in LNG fuelled vessels. However, one technical service provider argued that:

"...Turkey has had LNG handling experience with BOTAŞ and EGEGAZ over the years, crew training could be easily arranged with these companies and a collaboration between universities and shipowners" (R204).

There are numerous training institutes in Turkey for ship crew. These institutes are providing manpower for shipowners. On the other hand, there is not any shipowner running a LNG vessel, and LNG qualified crew requirement for the Turkish shipowners. FSRU units are manned by foreign crewmembers. As it's argued by a TSP, Turkey could develop training facilities for crew members while taking into account LNG handling experience over the years in LNG import terminals.

Technical standardisation and the regulatory framework at the global scale are *almost* ready as it was argued in the first stage of this study. However, it is still attracting substantial criticism from the supplier participants in the Turkish case. One of the suppliers argued that:

"The technical standards are not yet ready. When making such a high-cost investment, it is necessary to know what the local rules, limitations and requirements are. Therefore, first of all, there should be legislation that we need to follow" (R217).

Another participant who represents a supplier also pointed out that:

"...Even though we have invested in LNG bunkering, we do not have the chance to compete with foreign countries with the current customs legislation. Profit margins are very low due to the current legislation and the operational constraints it imposes" (R206).

In addition, the RB participant points out that in terms of legislation, the Ports Regulation adopted in 2012 needs to be updated regarding LNG bunkering safety and other related issues. On the other hand, in 2019, the necessary arrangement was made in the Turkish Straits Maritime Traffic Regulation in order to regulate the passage of LNG fuelled vessels through the Turkish Straits (R215).

Legislation for LNG bunkering is not yet ready in Turkey. This has a significant effect on how stakeholders deal with uncertainties with respect to high cost investment. The legislation is crucial for defining the technical specifications and structuring limits of the investments. Moreover, as LNG transfer is not the same as conventional bunkering, current customs legislation also needs to be updated regarding operational standards and safe handling procedures for LNG.

Table 78: Comparative Table of the LNG Bunkering Challenges based on Experts in Global and Experts in Turkey

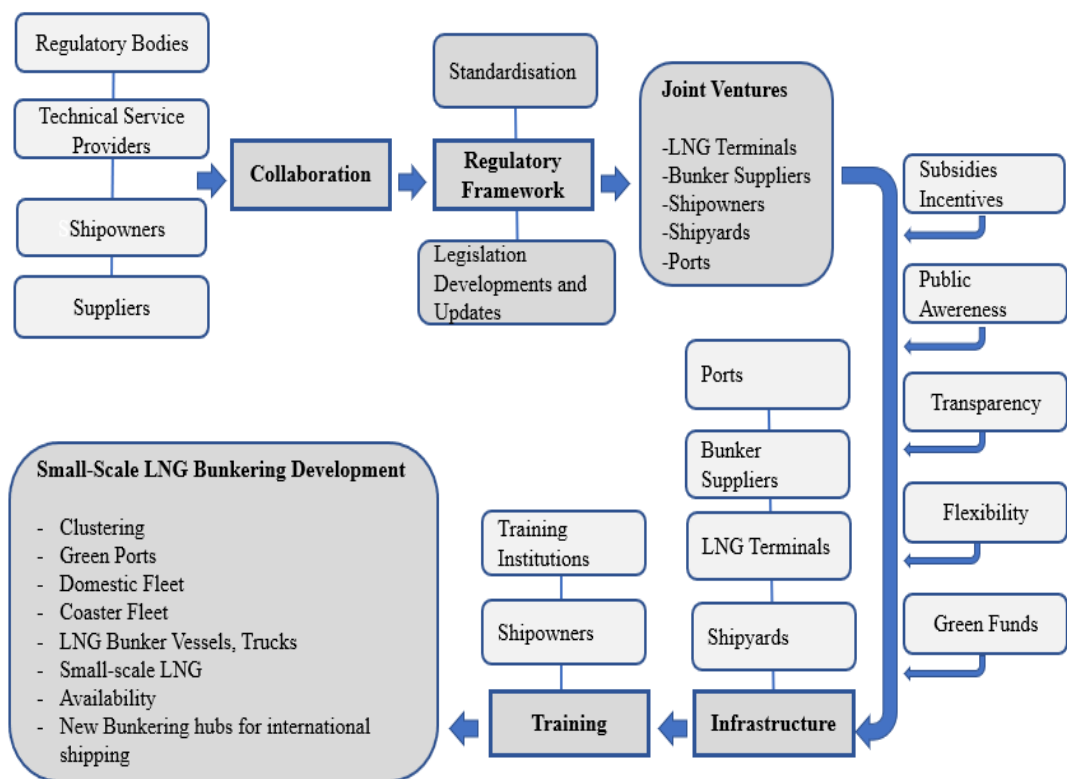
No	The first study in Amsterdam January 2019	The second study with experts in Turkey (Nov' 20- Jan'21)
1	Commercial Factors	Commercial Factors
2	Safety	Regulatory Framework
3	Sustainability/Environmental	Safety
4	Regulatory Framework	Operational Factors
5	Technical Factors	Crew Training
6	Infrastructure	Operating Region
7	Location/Operation Region	Infrastructure
8	Collaboration	Subsidies
9	Fleet type	Collaboration
10	Operational Factors	Environmental

Table 78 summarises some outstanding components of the semi-structured interviews in global context and with experts in Turkey. The table includes frequently highlighted issues by the experts. It should be emphasised that there are almost two years' time-lag between two the studies. However, challenges show similarities in many contexts. Inevitably, commercial factors take the highest concern for all the experts. LNG bunkering price, LNG contracts, uncertainty, lack of transparency are important factors along with high CAPEX requirements. Participants from Turkey pointed out regulatory concerns more than their counterparts in global. This is one of the important concerns in front of Turkey side -missing clear legislation for LNG bunkering. Safety factors, operational consideration, collaboration, infrastructure are the common elements almost equally emphasised through both studies. One important key word for Turkey side is the 'subsidies. This was also highlighted in global context but for Turkey case it was one of the top key words stressed by all the participants. Environmental concerns were underlined and acknowledged as the one of the most important drivers for LNG bunkering in global context. However, in Turkey case, it took limited attention while justifying LNG as marine fuel but was not underlined as main driver for LNG bunkering supply chain development. In parallel to this finding, public awareness was highlighted frequently as well. In Turkey case, it was only mentioned by one TSP. Public awareness or public opinion is one of the strongest developments for LNG bunkering case, when the existing small-scale LNG supply chain investigated in NW Europe and Baltic Sea. Public opinion also triggers green funds and government subsidies for high CAPEX investments. In Turkey case, public

pressure in environmental issues is not strong or just parallel to daily politics. Reaching out subsidies and incentives are not easy as in the developed countries.

Figure 86 summarises LNG bunkering development pathway in Turkey. Collaboration is a must between stakeholders. Regulatory framework needs to be updated and standards should be in place. Joint venture agreements are necessary for high CAPEX required new business. The risk of the new investment decision should be shared by the stakeholders. The organisation should be supported by subsidies and incentives. Infrastructure should be developed by joint venture participants. Crew members should be trained in cooperation with shipowners and training institutions. Small-scale LNG supply chain and LNG bunkering development should be supported by clustering approach, renewing domestic fleet, renewing coaster fleet and green port concept. Trucks could be used firstly while the market is immature and demand is low. Creating the demand at small-scale scale and availability will lead to growing demand, larger ships and new hubs as it has been seen in other locations across the world.

Figure 86: LNG Bunkering Development Pathway in Turkey



Source: Author

Evaluation of the Mathematical Model Findings

Turkey's potential LNG bunkering supply chain components such as barge size, capacity and distribution channel were developed based on current bunkering dynamics. The demand forecast of 2025 was calculated by using time series data for bunker deliveries, regression modelling and a forecasting method based on EMRA reports. The MILP method was used as a decision support method in order to answer research questions which require strategic and tactical level decision making processes for investment. This model also takes into account operational level decisions such as minimum loading quantity and minimum operation time limitations. Three locations were evaluated as potential LNG bunkering distribution points:

- 1-Marmara Ereğlisi BOTAS LNG Terminal as a loading port,
- 2- Aliğa Ege Gaz LNG Terminal as a loading port,
- 3-Marmara Ereğlisi-centred for the Marmara region and Aliğa-centred for the Mediterranean ports.

The mathematical results were also evaluated for practical implications and from a managerial point of view by the Turkish experts.

The Marmara Ereğlisi BOTAS LNG Terminal has the infrastructure required for vessels. However, back loading of LNG into smaller LNG carriers or LNG fuelled vessels is considered as a different operation and loading lines, new manifolds and mooring arrangements may be required. It is expected to provide LNG bunker supplies by the second quarter of 2021 (Shipandbunker, 2020). The Marmara Sea is surrounded by ports which serve in the fields of container, dry bulk, Ro/Ro, passenger and tanker segments. The Istanbul Strait is also a major supply point not only for bunker but also for crew change, repairs, provisions, spare parts and any other needs of vessels. According to EMRA reports, 94% of the bunker supply in Turkey between January 2016 and December 2019 was performed in the Marmara region. This busy traffic makes the Marmara Sea a potential bunkering hub. However, it was argued by some participants that traffic coordination is necessary to organize the travel of LNG carriers and LNG ship-to-ship transfer as they require additional safety standards.

The results of mathematical modelling indicate that with just one barge, demands of 1%, 5% and 10% can be met at all supply points for scenario 1. A single

5k cbm capacity barge gives optimum results for the demand cases of 1% and 5%. The first demand case (1%) distribution pattern was provided by two separate loadings. One route covers Tekirdağ-Izmir-Mersin-Iskenderun and the second route provides for the Kocaeli and Istanbul demands with a single bunker lift. The second demand case at 5% utilizes the same barge starting from the 2nd week and following the same pattern of distribution as the 1% case. The demand case of 10% indicates the optimum barge number to be one, but its size is calculated to be 10k cbm. This demand case follows the same distribution pattern as in the case of 5%. The results were evaluated to be quite reasonable by the experts. However, some participants argued that a 10k cbm barge is too big for supply and it would not be possible within the next 10 years. This point was not accepted by all participants; it was pointed out that LNG bunker demand in the world grows in parallel to the size of the vessels that shift to LNG as ship fuel. The CMA CGM new order 23,000TEU capacity container vessel has a 18,600 cbm LNG fuel tank capacity and a 10k cbm LNG bunker barge would only be able to fill this size vessel in two trips. On the other hand, the 15% demand case found the optimum results to be two barges with 3k and 5k capacity. Both barges were utilized in different patterns that cover all potential demand points as indicated in Table 67. The increase in demand makes it impossible for the required capacity to be met by single vessel. The two smaller barges give optimum results. Therefore, the optimum number of barges and their size must be evaluated not only according to demand but also potential customers, who in our case are potential LNG fuelled ships requiring LNG.

The Aliğa Ege Gaz LNG Terminal centred distribution was evaluated in the second scenario. The Aliğa Ege Gaz LNG terminal is located on the West Coast of Turkey and in the neighbourhood of an industrial area along with other busy ports, namely Nemrut and Izmir (Alsancak). Marine traffic in this port area cannot be compared to the Istanbul Strait. However, being in the vicinity of busy marine traffic between the Marmara Sea and Mediterranean brings advantages to the Ege Gaz LNG Terminal. South of Bozcada is an already important bunkering location which provides bunker for those vessels waiting for passage through the Canakkale Strait. Another advantage emphasised by the participants was the developing LNG market in the Greek Islands. LNG is already in use for power production, in addition to the marine

fuel option. This small-scale LNG network has also potential for power generation in the Greek archipelago which still runs on diesel generators and is not connected to the national electricity grid. Turkey has a strong LNG infrastructure in the region. The Etki FSRU LNG terminal is also in Aliğa and the new FSRU terminal is planned for the Saros Gulf. The existing and planned LNG infrastructure provides a competitive advantage for Turkey in the region. Another point for LNG bunkering development in Turkey which was highlighted was the safety considerations in terms of traffic congestion and the designated bunkering area in the Marmara Sea. Two shipowner participants raised the issues of the population living around the Marmara Sea, and the potential LNG traffic which may bring extra load to the already congested marine traffic. It was recommended to carry out LNG ship-to-ship transfers outside of the Marmara Sea, potentially on Aegean side of the Çanakkale Strait. Taking into account LNG infrastructure in the Aegean Sea, an Aliğa-centred supply network could take advantage of being in vicinity of the main trade route from the Black Sea to the Mediterranean and also could provide clear zones for ship-to-ship LNG bunkering operations.

The mathematical results for the second scenario are parallel to the first scenario. Demand cases for 1%, 5% and 10% were met by only one bunker barge. A single 5k bunker barge again was found to be the optimum barge capacity for the first two demand cases. A distribution route for the case of 1% follows the Aliğa-Tekirdağ-Kocaeli-Istanbul-Mersin-Iskenderun-Aliğa-Izmir pattern in the 4th week. The second demand case of 5% could carry out distribution with the same pattern at week four and also make separate voyages to Istanbul and Kocaeli in the 2nd and 3rd weeks. The third demand case (10%) was met by a 10k bunker barge as was the case in the first scenario. The most optimistic case (15%), again, found the optimum barges to be 3k and 5k. The 3k bunker barge could conduct its first delivery to Kocaeli in the 3rd and 4th week, it could meet the demand of the Izmir-Mersin-Iskenderun ports. On the other hand, the 5k vessel could be utilized from week 1 to meet the demand of the Marmara region. The distribution pattern is summarised in Table 72. The barge sizes and capacities were found to be appropriate by the experts. However, one supplier and shipowner participants had objections concerning the 10k bunker barge for the 10% demand case, it was considered to be too big for LNG bunkering. On the other hand,

another point of view argues that the Iskenderun, Mersin and Aliğa regions are regular calls for larger vessels, and it is not possible to meet the potential bunker demand for these vessels by truck.

The third scenario considers two regions separately - Marmara Ereğlisi as the loading port for the Marmara region and Aliğa as the loading port for other destinations, namely, Izmir, Mersin and Iskenderun. As the biggest demand portfolio is sourced from the Marmara region, different barges were utilized in parallel to the growing demand from 1% to 15%. These are 3k, 5k, 6.5k and 10k as demand grows. The minimal scenario (1%) utilizes the 3k barge only on the 4th week, the 5k barge was utilized starting from the 2nd week and for the 10% and 15% demand cases, the barges were employed during all weeks. The Aliğa centred distribution was carried out in the 4th week in all demand cases by a 3k barge as demand is very low compared to the Marmara region. The size and number of barges was found to be appropriate by the participants as they are in range of their consideration. The 10k bunker barge again raised objections concerning its operational limitations due to its size. However, it was argued by one supplier participant that the 10k bunker barge would provide opportunity to supply LNG bunker for larger vessels and it could help to create new markets for LNG fuel. Demand forecast was carried out based on the current bunker supply view of Turkey. Creating new markets and being the first adopter may change this bunker breakdown in favour of the larger ports of Turkey in the Mediterranean region. The Iskenderun Gulf consists of large ports dealing with dry bulk, containers, oil terminals and LNG FSRU. Lifting bunker quantity per vessel is crucial for market development and fixing the optimum size of the barges. Moreover, the Izmir and Kuşadasi ports have cruise vessel terminals and they expect to be called on by large cruise vessels when the tourism sector recovers after the pandemic. The 'Green shipping' concept is crucial for cruise vessels as they directly serve people. Getting ready for LNG fuelled cruise ships will make Turkish ports an attractive destination for these green concept vessels. Galata Port in Istanbul also could be on the list for these new-build LNG fuelled vessels.

Objective function provides a reference point to calculate the breakeven price for LNG bunker sales. Demand cases at 10% and 15% give the lowest breakeven prices which are 437 and 440 USD/mt respectively for Scenario I and 438 and 442 USD/mt

respectively for Scenario II. The lowest breakeven price was provided by Scenario III – 15% demand case at 418 USD/mt in parallel to highest demand and lowest fuel cost scenario. The LNG bunker price is a crucial decision for shipowners to invest in LNG fuelled vessels. It is also a critical stage for the supplier to achieve a profit margin. Bunker suppliers in Turkey work with very fine profit margins due to competition and the high logistics cost to deliver bunker to the final users. The High CAPEX required for LNG bunker vessels is not affordable by a single supplier or a shipowner. As was highlighted by the participants, the shipbuilding potential of Turkey could bring a CAPEX advantage for investors. With this in mind, a research and development process should be applied to develop LNG fuel tanks for larger vessels in order to reduce the building costs of LNG bunker barges and LNG fuelled vessels. Vessels working in the domestic trade, ferries, and Ro/Ro vessels have the potential to create demand in the LNG market as well as new job opportunities for the Turkish shipbuilding industry.

CONCLUSION AND RECOMMENDATIONS

The aim of this research is to investigate the small-scale LNG supply chain and to propose a model for LNG bunkering in Turkey. Five research questions were formulated which address the seven research objectives. The research employs inductive and deductive approaches, and utilises abductive reasoning with a pragmatic perspective. The analysis was carried out with triangulation strategy. Findings are grounded on theoretical framework with TCE and NT. Both qualitative and quantitative methods were used as a fully integrated mixed-method. A case study for Turkey was implemented in single-embedded structure. The study accomplishes its seven research objectives which are organised sequentially and each achievement provides ground for subsequent objectives. The study makes a significant contribution to small-scale LNG supply chain literature in which there are only a limited number of academic studies, by revealing challenges and proposing a model to cope with these challenges. At the first stage, the study collects data through semi-structured interviews with experts from different continents and participant observations which provide insight from experts and reflect different stakeholders' views in a holistic approach. The second stage utilises the MILP model as a decision support system at strategic and tactical levels while taking into account operational constraints. The model provides solutions for ship-to-ship LNG bunkering operations. The third stage analyses the outcomes of the first and second stage along with the semi-structured interviews in Turkey. The objectives of the studies and its theoretical contributions are summarised in the following sections.

- **The first research objective is to understand the small-scale LNG supply chain structure**

To achieve this objective, primary and secondary data sources were used. The primary data were collected through semi-structured interviews and participant observation on site in order to explore relatively new phenomena. The secondary data were obtained via the existing literature and sector reports such as DNVGL, Shell,

ABS etc. The literature covering LNG bunkering, LNG Supply Chain and Small/Mid-Scale LNG was reviewed.

LNG is a cryogenic liquid at normal atmospheric pressure and requires special handling processes throughout the supply chain. The four main components of the LNG supply chain are: 1- Exploration and production, 2- Liquefaction, 3- Shipping and 4-Storage and regasification (Mokhatab et al., 2013). Additionally, the small-scale LNG supply chain requires extension if it is to be used as fuel for transportation or industrial use. As its quantity is smaller than the conventional LNG supply chain, utilising it may require different characteristics than those used at a bigger scale. This 'extension' is reflected in operations, infrastructure, and the regulatory framework as well as in the market structure. The literature findings also indicate that in addition to the conventional participants of the LNG supply chain, new stakeholders will take part in the extended stage if it is to involve the delivery of LNG as a ship fuel (DMA, 2012; Wang and Notteboom, 2014; EMSA, 2017). In addition to the literature review findings, semi-structured interviews reveal that the small-scale LNG supply chain may involve new stakeholders. Apart from LNG carriers, shipowners of other types of vessels will participate in this leg of LNG supply chain. As the quantity is smaller, conventional LNG contracts, the spot market and pricing structure cannot be implemented in the same manner. Bunker suppliers are added to the distribution channel either by truck or barge in order to deliver LNG to the final users. Moreover, LNG terminals may be involved in back loading to smaller LNG carriers, bunker barges or to LNG fuelled vessels. Extended LNG operations require new technological improvements such as boil-off gas handling, onboard storage, or safety requirements. Technical service providers play an important part in this process to perform operations safely. Additional infrastructure requires additional standards, regulations, and legislations in order to handle LNG safely. These are provided by classification societies as well as international and national regulatory bodies. Therefore, the small-scale LNG supply chain stakeholders can be categorised under four main groups: 1- Shipowners, 2-Suppliers, 3- Technical service providers (TSP) and 4- Regulatory bodies (RB).

LNG bunkering is relatively new for the shipping industry, but LNG as a cargo has a history with a very clean safety record. The LNG industry applies the highest

industrial standards, and it is reflected in the entire supply chain. Small/mid-scale LNG is an extended part of the LNG supply chain and it involves different stakeholders. Therefore, transferring this experience into the small scale needs some adjustments in the operational, commercial and regulatory framework.

- **The second objective is to define the challenges of LNG bunkering development**

The second objective was fulfilled with the primary data gathered by the semi-structured interviews with experts, participant observation on site and secondary data obtained through a related literature review. The interviewees represent different continents such as America, Europe and the Far East, which was critical to gain a holistic insight into LNG bunkering. LNG has different dynamics in different continents in terms of supply, demand and pricing. TCE theory underpins this market mechanism and the commercial factors, which were defined as the most crucial challenge in LNG bunkering development. Problem orientation requires governance between markets and hierarchies (administrations)(Williamson, 2010). The nature of relations should focus on cost-efficiency. Shipowners and suppliers should take into account these theoretical lenses to identify framework of new supply chain system as small-scale LNG.

LNG bunkering operations are very limited across the world and reaching expert knowledge, and on-site experience was an important contribution of this research.

IMO 2020 regulations force the industry to look for compliance strategies. LNG as a ship fuel has great advantages in terms of compliance with the new regulations and also its availability across the world compared to the other alternative fuels. On the other hand, there are some drawbacks that the industry needs to tackle. These can be grouped under environmental, safety, operational, technical, regulatory framework and commercial considerations (Wang and Notteboom, 2014; Aymelek et al., 2015; Xu et al., 2015; Calderón et al., 2016; Schinas and Butler, 2016; Ge and Wang, 2017; Fevre, 2018). This study reveals subtitles of general challenges in detailed context such as standardisation, lack of transparency, and supply chain. The

research findings indicate that different stakeholders have different concerns according to their points of view: suppliers are not confident about demand, the shipowners' biggest challenge is the lack of infrastructure, poor technical standardisation is a barrier for TSPs, and RBs still need to work on improvements for worldwide implementations and take crew training as an important issue. Integrating different views in a holistic approach reveals that there are some crucial factors affecting LNG bunkering development.

LNG provides a significant contribution in the fight against air pollution as it has almost zero SO_x and PM content along with substantial mitigation to NO_x. On the other hand, overall CO₂ emission reduction is still arguable. Life cycle assessment studies reveal that LNG is not the final fuel to achieve decarbonisation targets, despite technological improvements on methane slip problem in engines. However, taking into account other alternative fuels and new technologies from an environmental perspective; it looks like the most promising alternative as it has global coverage, availability, and the technological and industrial experience in handling as a cargo. LNG as a marine fuel provides a transition pathway for zero carbon emission targets. LNG vessels have a very clean safety records over the years. Operational and technical experience in handling LNG could be transferred to the smaller scale to some extent. However, the quality of LNG at different locations, its methane number, and bunker measurement methods still need to be standardised. Safety concerns related to handling LNG is under discussion. The number of qualified crew for LNG bunker operation looks like an important barrier for shipowners. The lack of infrastructure is crucial for further development but world-wide coverage over the major shipping routes is in progress. A regulatory framework to handle LNG at larger scale, small/mid-scale industrial practices have been introduced by SGMF, IMO, EMSA and OCIMF. However, there are still different implications in global applications due to local legislation and different implementations by the classification societies. Commercial challenges are the most important factors in particular for suppliers and shipowners. High CAPEX requirements, price uncertainties, and a lack of transparency creates obstacles for newcomers to generate promising market from a business perspective. The missing link between shipowners and suppliers is critical for the development of LNG bunkering.

- **The third objective is to identify stakeholders' relationships in order to propose a pathway to cope with challenges in the LNG bunkering supply chain**

To accomplish this objective, primary and secondary data sources were used. Primary data were collected through semi-structured interviews. The participants represent different stakeholders of the LNG bunkering supply chain. The data obtained over these semi-structured interviews were evaluated with MAXQDA 18.1.1. software. The transcribed content was evaluated through the steps of coding, the creation of categories, and the generation of themes. The codes, categories and themes were analysed through Network Theory and TCE theoretical lenses which enables inter-organisational interactions as behavioural assumptions and transactions as primary domain of interests respectively (Halldorsson et al., 2007).

Analysing the categories and themes provided an insight into the connection between the defined challenges. It also revealed the relationships between the stakeholders and it allowed us to propose key approaches to overcome these challenges. Identifying the relations between the stakeholders and suggestions to overcome challenges in LNG bunkering is one of the significant contributions of this study to the small-scale LNG supply chain literature.

Collaboration is the key to overcome all the defined challenges relating to the supply chain, regulations, safety, operational and technical difficulties, commercial barriers, infrastructure, and environmental concerns. Collaborating among the actors of the supply chain is grounded to NT. *Clustering* provides commercial advantage as well as infrastructure development that could be utilised by shipowners, suppliers, and regulatory bodies. Strategic partnership for development of the supply chain components against market failure is assured through TCE theoretical lenses. *Standardisation* is required to cope with regulatory difficulties globally and, it is required to deal with safety issues from technical and operational perspectives. International organisations, classification societies, and policy makers are the key stakeholders in the management of standardisation. Methane number, quality of LNG also added commercial dimension to standardisation that is assured through efficient governance in TCE. Qualified crew to handle LNG as fuel are not available in

sufficient numbers and this shortage can lead to operational issues, technical concerns and put safety at risk. *Training* is another key approach to overcome these challenges to minimise risk and to maintain a good safety record. Regulatory bodies, flag states, classification societies and shipowners are the primary stakeholders to overcome these challenges through training. Joint training programs and investment in specific asset is a vital part of minimizing transaction costs. Shipowners seek flexibility in bunkering. This could be provided with alternative prices in challenging markets, alternative bunkering locations for operational issues and convenient design for technical constraints. Therefore, *flexibility* is another key approach that shipowners, suppliers and TSPs can act together to overcome commercial, operational and technical challenges. However, this creates theoretical contradiction. Long-term contracts and static characteristics of the TCE are critical for supplier side. This is the same for shipowner side as well in some segments. However, dynamic character is also needed as shipowners eventually require operational flexibility which is grounded to NT. LNG bunkering price is one of the most important elements for shipowners to calculate expenditures and it is also important to determine the critical levels for suppliers to maintain a profit margin. However, LNG bunkering prices are still very confidential between the suppliers and receivers, and markets seek for some reference price to cope with uncertainties and make proper calculations for pay-back time. Therefore, more *transparency* is needed in LNG bunker price for the market in order cope with this commercial challenge. Behavioural assumptions of NT in terms of personal trust, joint learning and transfer of knowledge provides theoretical lenses to explain transparency for supply chain development in small-scale LNG. Public interest is a strong argument to support initiatives. Developing clusters in some regions along with public opinion in green awareness brings green funds and substantial subsidies from authorities, which is what the industry needs to cover the high investment costs. *Public opinion* is one of the most important factors that provides the opportunity to deal with environmental concerns, infrastructure development at certain locations and commercial barriers. Figure 85 conceptualises the relationships between the stakeholders and the challenges by interlinking them with the key approaches which are required to overcome these challenges.

- **The fourth objective is to explore Turkey's bunkering dynamics**

The second stage of this study utilizes secondary data via regression analysis and a literature review in order to accomplish the fourth objective of the research. The secondary data obtained through industrial reports such as EMRA covering 2007-2019, UNCTAD 2020 reports, MOTI statistics database was analysed. A multiple regression method was utilised in order to understand the relation between Turkey's bunker sales and global economic variables, bunker prices, strait passages, port activities and marine traffic. Moreover, bunker delivery points and their weight in total deliveries were identified.

The Marmara Sea is the busiest region due to its significant port activities and the sea-traffic through the Istanbul and Canakkale straits. Other important port activities take place at Nemrut, Mersin and Iskenderun. These three ports handle more than 30% of port activities in terms of gross-tonnage. Another important shipping activity in Turkey is strait passage (MOTI, 2020c). The number of vessels passing through Istanbul and Canakkale is decreasing but their total tonnage is gradually increasing. An EMRA (2020) report indicates that Istanbul is by far the leading centre for bunker deliveries and it is followed by Kocaeli. The distribution of bunker deliveries according to region reveals the Marmara Sea as the centre. The Mediterranean and Aegean Sea share is slightly more than 5%(EMRA, 2020a).

The demand for shipping is a derived demand and is related with world economic variables. World seaborne trade, world GDP, Brent oil prices are substantial drivers for bunker (UNCTAD, 2020b). The biggest portion of Turkey's bunker deliveries take place in the Istanbul region. Therefore, strait passage statistics were evaluated along with economic variables to understand Turkey's bunker delivery dynamics. Among various multiple regression models; Turkey's bunker deliveries demonstrated a statistically meaningful relation to world seaborne trade and bunker price. Therefore, it was concluded that *Turkey's bunker deliveries are jointly influenced by world seaborne trade and bunker prices*. This finding provides a reliable framework to predict the future demand of Turkey's bunker deliveries.

- **The fifth objective is to predict the future demand of Turkey bunker sales**

To accomplish the fifth objective, secondary data were collected. The data were utilised through regression analysis and forecasting. Regression provides an important tool to understand the relation between variables and to understand the relationships of Turkey's bunker sales with economic variables (Koop, 2006). Firstly, regression analysis results were used as a framework and the ARIMA forecasting method was utilized in order to forecast Turkey's bunker sales in 2025. Secondly, industrial reports regarding LNG as ship fuel demand scenarios were analysed in order to provide a benchmark for potential LNG bunker demand in Turkey.

The findings of the fifth objective indicate that world seaborne trade and bunker price jointly influence bunker sales in Turkey. Explanatory variables, namely, world seaborne trade and bunker price time series data were evaluated through EViews ARIMA forecasting tool and both time series data were extended up to 2025. Based on a regression model, Turkey's bunker sales were forecasted up to 2025. In order to provide a benchmark for forecasting, global bunker sales' historical trend was compared with Turkey's sales. It was seen that Turkey's bunker volume accounts for 0.5% to 1% of global marine fuel sales. These findings were then used as a reference point for Turkey's LNG bunkering demand scenarios. The world LNG bunker demand scenarios of research centres were analysed and between 3.6% and 10% scenarios (Lloyd Register (2014), DNVGL (2019), IHS(2019), BCG (2019), IEA (2019), TOTAL (2019)), an average LNG demand forecast was estimated to 5% by the year 2025. This global LNG bunker volume was implemented at the same rate to Turkey's forecasted bunkering figure as the average scenario. Other demand assumptions were taken as 1%, 10%, the lowest and highest scenarios respectively. Finally, a fourth demand scenario of 15% was calculated. In this way, it was aimed to cover any missing volumes in EMRA report. In order to determine the breakdown of Turkey's bunker sales, EMRA reports covering January 2016-December 2019 data were taken as a reference and the Istanbul, Kocaeli, Tekirdağ, Izmir, Mersin, Hatay potential bunker volumes were calculated. These demand assumptions in terms of locations provide data for mathematical modelling.

- **The sixth objective is to evaluate the optimum barge size and capacities to be utilized according to the minimum cost scenario**

To accomplish this objective, a mathematical model was utilised. The data used in the model were acquired from industrial reports and expert views. Linear programming provides a valuable tool in economics, management and engineering as a decision support system. It aims to determine the optimum allocation of the limited resources subject to constraints. TCE theoretical lens provides cost-efficiency as primary domain of interest as minimizing transaction costs which require optimum allocation of limited sources.

Real-world problems often consist of integer variables, conversely, non-integer variables are not always possible. Mixed integer linear programming allows the use of both types of variables and overcomes the limitations of linear programming. It provides strategic, tactical and operational level decision support (Shapiro, 2001). Therefore, MILP was employed to solve the problem. The problem involves strategic and tactical level decisions in supply chain optimisation. The number of barges and their size, the optimum allocation of the barges and the distribution network are the decision variables. In the supply chain literature, the problem is generally discussed under the heading ‘Vehicle Routing Problems’ (Braekers et al., 2016). Small-scale LNG supply chain optimisation is very limited. These studies were usually designed with deterministic models, a heterogeneous fleet and providing solutions at the strategic and tactical level (Jokinen et al., 2015; Bittante et al., 2016, 2017; Bittante, Pettersson and Saxén, 2017, 2018). On the other hand, Deluster et al. (2018) evaluates small-scale LNG supply chain at operational and strategic levels as a location routing problem, which takes into account truck deliveries as well. This study’s focus point is ship-to-ship LNG bunker deliveries, which are the most common bunkering practices in the maritime industry. Therefore, this study differentiates from the other studies, while providing a strategic and tactical level decision support system, and also takes into account ship-to-ship operational level constraints. The model provides decision making tool concerning the minimum quantity to be transferred from the loading ports to the discharging locations, barges are banned from travelling if quantities are not sufficient until the fourth week of the period. Discharging and loading times below 1.5

hours are not permitted as it is not practical to perform mooring, hose connection, lining-up, safety precautions or safety meetings and so on in less than this time. Moreover, the model contributes to the decision-making literature in maritime business. The model was developed in terms of a voyage cost and a fixed cost perspective in shipping. Minimum cost scenarios provide the theoretical benchmark to determine *breakeven freight* for investment decisions in the LNG Bunkering field. Therefore, this problem can be defined as a ‘Multiple Period Maritime Fleet Size and Routing Problem’.

The problem was modelled to find the optimum number of barges and their size based on the demand scenarios for 2025. Two potential LNG terminals, namely, Marmara Ereğlisi BOTAŞ and Aliğa EGE GAZ were defined as the loading ports and Istanbul, Kocaeli, Tekirdağ, Izmir, Mersin and Iskenderun were determined as the bunkering locations based on EMRA reports, which provide historical time series data concerning conventional bunkering practices in Turkey. Arc-flow distribution was planned with a heterogenous fleet. Five different LNG bunker barges of Wartsila were chosen as the discrete variable, which range in size between 3k and 10k. The model enables split deliveries in multiple periods of the time horizon.

The mathematical model findings indicate that scenario I has a slight cost advantage over scenario II as the vast majority of the demand is concentrated in the Marmara Sea. 5k size barges provide the optimum solution for the 1% and 5% demand cases. However, the best scenario was found to be 3k and 5k barges together as the optimum solution. Breakeven freight is minimum in the Scenario III, M. Ereğlisi centred 15% case, in parallel to its highest demand and minimum travelling distance.

- **The seventh objective is to make recommendations for Turkey’s small-scale LNG and LNG bunkering development**

At the third and final stage of the study, the objective function was fulfilled by the outcomes of the previous stages and the primary data collected through semi-structured interviews with experts in Turkey, with the help of the theoretical approaches of transaction cost economy theory and network theory characteristics.

Interviewees were selected according to the template followed in the first stage. Shipowners, bunker suppliers, ports, terminals, shipbuilders, policy makers, classification societies, and technical service providers were contacted. The participants were grouped into four components: 1- Shipowners, 2-Suppliers, 3-TSPs, and 4- the RBs. The findings concerning the LNG bunkering supply chain in the global scale and Turkish perspective in LNG bunkering were analysed along with the findings of the mathematical model. In this stage, it was aimed to evaluate the mathematical model results as a decision support tool gain the insight of the experts in the Turkish maritime sector and make recommendations for Turkey's LNG bunkering and small-scale LNG supply chain.

The global coverage of the LNG bunker infrastructure on the main trade routes has been completed. Developments in the West Mediterranean region are also promising as Spain's LNG bunker deliveries increased 272% in 2020 compared to the previous year, including activities on the Atlantic Coast (Bunkerspot, 2021). Greece and South Cyprus have already invested in LNG projects and small-scale LNG not only for marine fuel but also for power production. LNG is not ultimate marine fuel solution to meet UN decarbonisation targets but it is ready and it has a fast-developing infrastructure across the world. Other important alternatives such as ammonia, methanol and hydrogen still need time to prepare infrastructure and overcome availability concerns. Arkas Bunker signed an agreement with Sumitomo Corporation for LNG bunkering (Arkas, 2021). BOTAŞ is planning to provide LNG as marine fuel in the second quarter of 2021 from Marmara Ereğlisi (Shipandbunker, 2020). One of the important Turkish shipowner has already ordered 10 LNG-ready vessels and expecting to receive first delivery in 2022 (R207). This is only known Turkish shipowner who invested in LNG-fuelled ships in large scale. Turkish shipyards have built numerous LNG fuelled, battery or hybrid driven vessels so far. For example, Tersan shipyard built 4 LNG-powered fishing vessel, 4 LNG-powered Coastal Passenger vessel, 5 battery-powered Ro/Ro Passenger vessels, 5 hybrid (gas and battery) powered Ro/Ro passenger & vehicle carrier for Norwegian shipowners so far (Tersan, 2021). Moreover, 3 battery powered passenger ship, 4 battery driven fishing boat, 2 battery driven renewable energy vessels were built in Cemre Shipyard. 2 fishing boats LNG-battery driven under construction and to be delivered in 2022

(Cemre, 2021). Other shipyards such as Sanmar, Kuzey Star, Safine shipyards have already built LNG-powered, battery-powered and hybrid ferryboats, tugs and fishing vessels (Portnews, 2020; Safine, 2021; Sanmar, 2021a). Turkish shipyard built one of the largest battery driven vessel (2000kwh) in the world as well. Turkey is also only country in the world who built hybrid powered fishing boats (R202) Turkish shipbuilding industry are not only building the vessels based on foreign design; but also developing their own designs. Moreover, Turkish shipbuilding industry is also exporting technology to Spain in electrical outfits to be used on the green concept ships (R201). Recently, Sanmar shipyard signed an agreement with Canada to build LNG fuelled 5 tug boats (Sanmar, 2021b). Despite these steps in LNG bunkering, it was observed that the LNG bunkering concept is not fully comprehended by the Turkish maritime industry. The high capital expenditure requirements for LNG fuelled vessels are the biggest barriers for shipowners. Safety concerns along with a lack of infrastructure and qualified crew requirements are also another issues to consider. Turkish bunker suppliers' demand concerns are not specific to the Turkish fleet as they provide service to all vessels conducting strait transits or calling on Turkish ports. The shipbuilding industry is able to build LNG fuelled vessels. However, they are not competitive compared to Far Eastern shipyards in this field as they still need to invest in research & development to develop tank designs and gain a competitive advantage. The big players of the world economy; Japan, Korea, China, Australia, Singapore, EU, USA and Canada are improving their LNG bunkering infrastructure. Not only LNG but also other alternative fuels are gaining momentum globally parallel to UN decarbonisation targets. A wait-and-see approach is usually inevitable due to the economic concerns of the Turkish shipping industry. Despite the aforementioned disadvantages of Turkey, the key outcomes of this research have been highlighted as recommendations for the Turkish maritime industry:

- ❖ In parallel to the findings of stage 1, *collaboration* is key for LNG bunkering development. Supply chain stakeholders; ports, terminals, shipowners, bunker suppliers, shipyards and policy makers should collaborate to overcome the current challenges of LNG bunkering development.

- ❖ Legislation to deliver LNG as marine fuel and small/mid-scale LNG operations has to be developed, customs requirements need to be updated to comply with safe LNG handling operations while taking into account the competitiveness of Turkey's bunker market. The regulatory framework, technical standards and legislation need to be ready before taking any high CAPEX required investment decision by all stakeholders.
- ❖ Global LNG bunkering supply chain development analysis indicates that high CAPEX investments have occurred via special subsidies, incentives and funds. Turkey should seek international funds which prioritise the environmental benefits of LNG, air pollution mitigation strategies and contributions to reduce CO₂ emissions.
- ❖ The Turkish shipbuilding industry has experience in building vessels in the green concept as well as in LNG fuelled vessels. However, building LNG fuelled vessels at a competitive price is critical mainly due to LNG tank design know-how. Cryogenic container manufacturing is available in Turkey (Aritas, 2021). Building the tanks for LNG fuelled vessels needs further research & development investment.
- ❖ Crew competency is an important barrier in LNG bunkering development not only in Turkey but also globally. The first LNG fuelled vessels were not even tanker and crew members conducted these operations after training in liaison with classification societies. IGF code set standards for LNG-fuelled vessels now. Turkey already have LNG handling experience. Number of the LNG fuelled vessels or LNG bunker barge will be limited in the near future, therefore training of countable crew members problem could be solved with cooperation of training institutes, shipowners and LNG industry in Turkey.
- ❖ The shipowner dimension is another critical point for small-scale LNG development. Turkey has an aging domestic fleet of ferries and Ro/Ro vessels (MOTI, 2021). The coaster fleet of Turkey plays an important part in Mediterranean and Black Sea trade. However, Turkey's competitive position in coaster trade is losing its position due to its aging fleet (Interview R216, 2020). Renewing the aging coaster fleet is a long-lasting

discussion in Turkey, but it has not been achieved to date due to a lack of funds, collaboration or strategic level maritime policies. Supporting shipyards with new orders enables them to invest in R&D. Renewing the coaster fleet with green concept vessels enlarges the market for the Turkish coaster fleet, particularly in EU ports (Cogea, 2017).

- ❖ Bunker suppliers need to see demand in order to invest in LNG bunkering and calculate their pay-back time. Local bunker demand at small quantities plays important role in setting up a market and allows it to grow up gradually. The domestic fleet renewal project is a strategic decision and requires the collaboration of all stakeholders.
- ❖ Regulatory pressure is the main motivation for the shipping industry to take initiative and invest in new designs, new fuels or new vessels. Emission Control Areas (ECAs) are an important driver of technologic improvement and investment decisions. IMO's plan to set new ECA in the Mediterranean and Black Sea could be an important driver to shift to environmentally friendly marine fuels.
- ❖ Green incentives could support ports and shipowners in line with environmental policies and regulations. At the same time, Turkey is an important country for tourism and the 'Green' concept is quite important for cruise shipping. Providing LNG bunkering facilities in Galataport, Istanbul, Izmir and Kuşadası could attract new-build, energy efficient and environmentally friendly ships to Turkish ports.
- ❖ LNG bunkering and small-scale LNG should be evaluated together in the Turkish perspective. Turkey's ambition to become an energy hub should consider the maritime energy concept at a strategic level as well. Recently discovered natural gas reserves in the Black Sea could support this ambition and provide a competitive small-scale LNG supply particularly in the Black Sea region.

LNG is one of the alternative fuels for the maritime industry and it is gaining momentum across the world. Other alternative fuels will emerge in the near future as well. Turkey should take strategic level decisions to be a leading country in shipping while using its know-how in the shipbuilding industry, manpower in shipping, fleet

size and growing port activities. The findings and recommendations of this study are in the LNG bunkering concept but similar arguments could be easily adapted to other alternative fuel supply chain developments. Turkey's ambition to become energy hub, despite being a net importer, is subject to using the resources cleverly and creating new opportunities rather than being just a follower.

THEORETICAL IMPLICATIONS

The study contributes to small-scale supply chain literature with several theoretical implications. LNG bunkering and small-scale supply chain literature is very limited as it is relatively new phenomena. The study firstly contributes to small-scale LNG supply chain literature by defining challenges and important consideration for future development. Some studies in the literature address this problem, however, researches are limited with one country, or with a one stakeholder perspective, or with one segment of the shipping. (Wang and Notteboom, 2014, 2015; Aymelek *et al.*, 2015; Xu, Testa and Mukherjee, 2015; Calderón *et al.*, 2016; Ge and Wang, 2017; Jafarzadeh *et al.*, 2017; Gucma *et al.*, 2019). This study encompasses different supply chain stakeholders from different regions through semi-structured interviews and bring a holistic insight to the phenomenon. Moreover, the study also contributes to knowledge by bringing real-time practitioners' experience in this relatively new issue in shipping and provides comprehensive framework for further research. Findings of the study contribute to the literature; since, in addition to underlining challenges, also propose key approaches to how to cope with these challenges and which stakeholders need to take part at this stage.

Another stage of the study is mathematical modelling. Mathematical modelling is widely used in supply chain optimisation literature. Applications in small-scale LNG supply chain optimisation is very limited (Jokinen *et al.*, 2015; Bittante *et al.*, 2017; Bittante *et al.*, 2018; Deluster *et al.*, 2018). The studies take into account two-echelon deliveries and incorporate with truck deliveries or satellite terminal deliveries. This study contributes to small-scale supply chain literature in shipping while focusing only ship-to-ship deliveries which are the most common bunkering activities in the maritime industry. In addition to strategic and tactical level constraints, this study adds

important operational constraints to provide solution for the problem as close as possible to real-time scenarios. The model also contributes to maritime business literature by providing ground for breakeven freight calculation.

Another novelty of this study is the methodology and theory that is grounded to research. The lack of methodological flexibility in logistics and supply chain management research has been criticized, as has the inability to use additional approaches that may be more suitable for hypothesis generation and investigation of dynamic, complex phenomena. Supply chain management analysis has historically focused heavily on quantitative approaches like surveys, experiments, and mathematical models (Golicic and Davis, 2012). This study encompasses qualitative and quantitative methodology. Small-scale LNG supply chain is relatively new and complex issue in shipping literature. The mathematical model findings at the second stage are considered as strong decision support tool. However, the method cannot provide stand-alone solution for the research questions and objectives. Synthesizing expert views through semi-structured interviews with mathematical model findings provide robustness of this study in relatively new and complex supply chain problem.

Small-scale LNG in shipping context is relatively new consideration in the supply chain literature. This study utilised TCE and NT in order to underpin theoretical framework of small-scale LNG supply chain. Behavioural assumptions and unit of analysis characteristics of the small-scale LNG supply chain is supported by NT. On the other hand, time dimensions and nature of the relations are explained through TCE. This study also brings a hybrid approach to problem orientation and primary domain of interest characteristics of small-scale LNG supply chain theory. Hybrid governance between markets and hierarchies of TCE is supported by collaboration among the actors (NT) in order to provide theoretical ground for problem orientation. Primary domain of interests are underpinned with investment specific assets that is grounded to TCE. However, in small-scale LNG supply chain is not satisfactory and it should be grounded to 'personal contacts' and 'sharing information' (NT) as well. This study contribute to small-scale LNG supply chain with literature by utilising two different theories in sequential and hybrid approach.

IMPLICATIONS FOR PRACTITIONERS

The key approaches, which are revealed after the analysis, could be practical guidance to cope with the present difficulties for suppliers, shipowners, ports and the other industrial actors who are already in LNG bunkering business or for those willing to enter. Main implications for shipowners, suppliers and ports are summarised as follows.

This study contributes to the shipping industry by analysing LNG bunkering development with different perspectives and provides a holistic approach for the overall supply chain. The challenges for LNG bunkering have been identified. Thematic links between the challenges and the stakeholders assist in practical applications for managers and practitioners. The key approaches of the model priorities are how to cope with the existing challenges, recognize responsible stakeholders and explain how they are interlinked. Collaboration is key factor to overcome challenges. The link between the shipowners and suppliers is missing. Shipowners and suppliers should consider that the relationship between two parties assists in overcoming some commercial obstacles. More transparency in LNG bunkering pricing is recommended in this perspective. Suppliers' long-term agreement plans in order to see sufficient demand for the future is an important concern for the shipowners as they seek flexibility not only in time span for bunker contracts but also in availability in different locations to gain operational and commercial independence. Another key implication should be clustering in order to reduce commercial risk for both sides and to develop infrastructure in designated regions.

This study also contributes to investment decisions in LNG bunkering for shipowners and suppliers as it provides a decision support model at the strategic and tactical level. The research findings indicate that the optimum barge sizes are 3k and 5k according to the demand scenarios. This study comprises the OPEX and CAPEX values of the related barges and calculates voyage cost as well. This study provides a commercial framework for shipowners and suppliers. Also, it calculates the breakeven freight for LNG bunkering shipments in 16 different scenarios. Shipowners and suppliers should consider this crucial limit to calculate the pay-back time of their investment, determine profit margins and to provide a benchmark to compare the LNG

option with other alternative fuels. The model presents a comprehensive tool as a feasibility study for shipowners and suppliers. It can also be generalised for global implications for any small-scale LNG supply chain fleet size and routing problem with different data sets.

The ports are vital part of the small-scale LNG supply chain. Not only regulatory pressure but also public pressure takes important role over port management. Providing service for alternative fuels is critical for sustainability targets of the ports. Therefore, port managements should consider investing in ‘green’ concepts. LNG in trucks and ISO containers could be operational in small/mid-size ports. The large ports should take into account ship-to-ship operations. Simultaneous operations supported by detailed risk assessment is crucial for LNG bunkering developments at ports. Providing service for alternative fuels is a essential for cruise terminals. In Turkey case, Istanbul, Kusadasi, Izmir and Galataport should consider LNG bunker service in order to attract ‘green’ concept cruise vessels and gain competitive advantage against other alternative ports in the region. LNG terminals plays pivotal role in infrastructure developments and being part of the joint ventures should be considered to reduce the risk and invest in high CAPEX required business.

IMPLICATIONS FOR POLICY MAKERS

This study could also be benefited by policymakers as it identifies the weak points in the regulatory framework and provides suggestions on how to improve them. This study points out that regulatory framework is a substantial driver for LNG bunkering development. LNG as a marine fuel is an alternative fuel to minimise shipping related air pollution and for shipping CO₂ emission mitigation strategies. International regulatory bodies in shipping play a crucial part in the LNG bunkering supply chain. The regulatory framework should be standardised not only for the technical specifications of barges and LNG fuelled vessels but also for bunkering operations, bunker delivery notes, methane numbers and the quality of the LNG. All these factors affect investment decisions for the stakeholders and could be organised by strong regulatory framework and effective follow-up systems. Environmental pressure and public opinion are another strong drivers for alternative fuels and the

green perception which can be achieved by a strong regulatory framework planned by the policy makers. IMO, SGMP, SIGTTO, IACS, IAPH should react in harmony to overcome the operational, technical and commercial obstacles which are already experienced and potentially will be experienced in the future as LNG bunkering business get mature over the years.

The third stage of this study focuses on Turkey's case. It was highlighted that Turkey should develop legislation to use LNG as marine fuel, revise custom regulations to comply with the safe handling procedures of LNG and update marine traffic control regulations for port activities and strait passages. Establishing technical standards for LNG bunkering is necessary to provide a safe, reliable investment atmosphere for potential entrepreneurs. The 'collaboration' theme has a different dimension in Turkey's case. Turkey has a very well-developed shipbuilding industry capable of adopting new technologies but struggling with a lack of finance and sustainable order lists. Bunker suppliers are working within very limited profit margins and the high CAPEX required for investment is not realistic. Shipowners are on the edge of profit margins and can barely manage the running cost of the aging fleet. Therefore, the industry needs strong support from the government that could orchestrate stakeholders with incentives, subsidies and guarantees as part of strategic maritime and energy policies. Ministry of Energy and Natural Resources, Ministry of Environment and Urbanisation, Ministry of Trade, Ministry of Transport and Infrastructure and Energy Market Regulatory Authority are crucial regulatory bodies and policy makers in that should be take part to develop convincing structure for not only for LNG bunkering but also for other alternative fuels in shipping. The regulatory body should shape its strategic plans not only for commercial perspective but also public welfare as shipping related activities has substantial negative effects on public health. Eliminating air pollution over the highly populated cities by incentives provided to shipping industry, could pay back at long-term as reducing the pressure on public health system.

LIMITATIONS OF THE RESEARCH

This research has some limitations to be emphasized. At the first stage of the study a total of twenty interviews were evaluated, and all of them were conducted during and after the LNG Bunkering Summit in Amsterdam January 2019. LNG bunkering is a relatively new subject in bunkering; therefore, historical data is very limited, and operational experience is still infancy.

The demand forecast was carried out until 2025 as the historical time series data is limited and statistically, it is not possible to make more long-term forecasts. EMRA annual bunker sales data have been available since 2007. Therefore, forecasting was restricted till 2025 rather than extending time horizon till 2030 in order to provide statistically meaningful prediction. EMRA data content is changing over the years and it was recommended to follow same table number over the years for consistency. Therefore, total bunker sales volume of Turkey was taken as less than actual figure. However, this handicap was compensated with additional demand case scenario (15%).

The mathematical model was developed in terms of some operational assumptions to make the problem possible to solve with MILP. Assumptions is required for MILP implications as integrating all real-life components could bring substantial complexity and extend problem solving time dramatically without giving appropriate solutions. Therefore, weather and sea conditions, the Canakkale Strait passage and potential traffic restrictions were ignored. Speed was taken as stable as indicated in technical specifications of the barges. Moreover, voyage cost items such as port expenses, agency fees, anchor dues, and light dues were ignored as they are relatively small expenses compared to fuel costs and do not have priority in the bunker suppliers' agenda. The model is covering running cost and fuel cost of the vessels which represents the vast majority of the expenditure in a ship management. Operational expenditures and capital expenditures were obtained from an LNG consultant. These costs could differ according to the shipowners, the working region of the barges and the shipyards of the barges.

Another limitation is sampling. There are 19 respondents for the semi-structured interviews in Turkey. Ship-to ship LNG bunkering operations have not been

performed in Turkey, yet. Shipowners and supply experts in Turkey are inexperienced in this field and they shared their views based on their theoretical knowledge. Unlike their counterparts in the first stage of the study, shipowners and suppliers have no real-world experience in LNG bunkering. Global implication of the mathematical model is possible with different data sets; however, evaluation of the results has been carried out in Turkey context which is drawback of the study.

This study's theoretical framework was underpinned through TCE and NT. Different theories in supply chain organisation such as Agency Theory, Resource Based view, Resource Dependency Theory, and Relation Exchange Theory could bring different approaches to small-scale LNG supply chain phenomenon.

RECOMMENDATIONS FOR FUTURE RESEARCH

Bunkering is vital part for any ship management activity along with crewing. LNG as marine fuel's price assessment could be carried out, forecasting could be utilised.

The mathematical model could be enlarged with larger supply chain problems. Additional operational parameters could be added to base MILP model.

The problem also could be designed as two-echelon supply chain network and propose a solution for truck transportation as well. Further extension could be via satellite terminals in distribution network as receiving depots.

One another future research direction could employ simulation techniques that provide application of the model and further improvements to tackle with uncertainties.

Optimum LNG bunkering location determination could be exciting research direction that involves operational and technical constraints.

Another research direction could be focusing LNG bunkering operation with different methodology and theoretical frame. Qualitative studies that explore operational experience of LNG bunkering is an interesting research direction that has very limited studies in the literature. Other aspects such as economic, technical and operational approaches still need to be addressed in the small-scale LNG literature.

This study employed semi-structured interviews as qualitative research method. Small-scale LNG and LNG bunkering could be explored with Delphi method by surveying a panel of experts as well. Another data collection method could be Focus group study which brings group of experts in a room and provide feedback for related phenomenon.

Similar study could be conducted for other alternative marine fuels such as hydrogen, ammonia and LPG. Comparative study could provide another decision tool for shipowners, suppliers and other stakeholders in the maritime industry.



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APPENDIX 1: Semi-Structured Interview Questions I

Dear Sir/Madam,

This research was prepared as part of Dokuz Eylul University, Institute of Social Sciences, the Department of Maritime Business Administration PhD program, and it's titled as " Small-scale LNG Supply Chain: LNG Bunkering Modelling for Turkey, " doctoral thesis under supervision of Assoc. Dr. Gül Denктаş Şakar.

Your answers will only be evaluated within the scope of the doctoral study, your name/company details will be kept confidential. Thank you very much for your contribution and support to this research.

Mehmet Doymuş, PhD candidate
Dokuz Eylul University
Maritime Faculty

- 1- What are the main challenges for LNG bunkering development?
- 2- What do you think about regulatory framework for handling LNG bunker?
- 3- How do you determine safety standards for LNG bunkering handling?
- 4- What are the operational difficulties of performing Ship to Ship operations as cargo calculations, mooring, hose connection, boil-off gas or compatibility?
- 5- What are the differences between cargo measurement of large LNG carriers and ship to ship LNG bunker transfer?
- 6- What do you think about LNG price, contracts and LNG bunkering pricing?
- 7- How does your port encourage and facilitate the use of LNG bunkering?
- 8- What are the main challenges for LNG bunkering development?
- 9- How do you define your environmental strategy?
- 10- How do you organize regulatory framework for handling LNG bunker?
- 11- How do you determine safety standards for STS LNG bunkering?

- 12- What are the risks of LNG bunkering operations?
- 13- What are the criteria for bunkering location selection?
- 14- How do you benefit from collaboration with other ports?
- 15- How did you take investment decision in LNG fuelled vessels as shipowner?



APPENDIX 2: Multiple Regression Results

Bunker price historical data (1991-2020) Automatic ARIMA forecasting

Automatic ARIMA Forecasting
Selected dependent variable: DLOG(R38)
Date: 04/08/20 Time: 15:22
Sample: 1991 2020
Included observations: 29
Forecast length: 0

Number of estimated ARMA models: 49
Number of non-converged estimations: 0
Selected ARMA model: (5,0)(0,0)
AIC value: 0.826190053566

Estimation of bunker price

Dependent Variable: DLOG(R38)
Method: ARMA Maximum Likelihood (OPG - BHHH)
Date: 04/08/20 Time: 15:24
Sample: 1992 2020
Included observations: 29
Convergence achieved after 57 iterations
Coefficient covariance computed using outer product of gradients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.034471	0.082907	0.415778	0.6816
AR(1)	0.056150	0.208544	0.269249	0.7902
AR(2)	-0.400929	0.182262	-2.199744	0.0386
AR(3)	0.157575	0.431591	0.365102	0.7185
AR(4)	-0.280266	0.337231	-0.831081	0.4149
AR(5)	0.510528	0.353253	1.445219	0.1625
SIGMASQ	0.076440	0.016229	4.710127	0.0001
R-squared	0.395241	Mean dependent var		0.018248
Adjusted R-squared	0.230307	S.D. dependent var		0.361818
S.E. of regression	0.317431	Akaike info criterion		0.826190
Sum squared resid	2.216774	Schwarz criterion		1.156227
Log likelihood	-4.979756	Hannan-Quinn criter.		0.929554
F-statistic	2.396353	Durbin-Watson stat		2.032444
Prob(F-statistic)	0.061964			

World seaborne trade time series data (1970-2018) Automatic ARIMA forecasting

Automatic ARIMA Forecasting
 Selected dependent variable: DLOG(ST)
 Date: 04/08/20 Time: 14:24
 Sample: 1980 2018
 Included observations: 38
 Forecast length: 0

Number of estimated ARMA models: 25
 Number of non-converged estimations: 0
 Selected ARMA model: (0,0)(0,0)
 AIC value: -3.64989223537

Dependent Variable: DLOG(ST)
 Method: Least Squares
 Date: 04/08/20 Time: 12:36
 Sample (adjusted): 1981 2018
 Included observations: 38 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.028828	0.006085	4.737718	0.0000
R-squared	0.000000	Mean dependent var		0.028828
Adjusted R-squared	0.000000	S.D. dependent var		0.037509
S.E. of regression	0.037509	Akaike info criterion		-3.702524
Sum squared resid	0.052055	Schwarz criterion		-3.659429
Log likelihood	71.34795	Hannan-Quinn criter.		-3.687191
Durbin-Watson stat	1.580200			

Regression-Data set of bunker sales between 2007-2018 were used.

Dependent Variable: BUN
 Method: Least Squares
 Date: 04/08/20 Time: 17:46
 Sample (adjusted): 2007 2018
 Included observations: 12 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-1058588.	1225666.	-0.863683	0.4102
WST	189.8258	112.1653	1.692376	0.1248
BPR	1773.980	889.9998	1.993236	0.0774
R-squared	0.359425	Mean dependent var		1419122.
Adjusted R-squared	0.217075	S.D. dependent var		413964.4
S.E. of regression	366288.4	Akaike info criterion		28.67255
Sum squared resid	1.21E+12	Schwarz criterion		28.79377
Log likelihood	-169.0353	Hannan-Quinn criter.		28.62767

F-statistic	2.524935	Durbin-Watson stat	1.308807
Prob(F-statistic)	0.134762		

Regression-Data set of bunker sales with dummy variables

Dependent Variable: BUN
Method: Least Squares
Date: 04/06/20 Time: 16:38
Sample (adjusted): 2007 2018
Included observations: 12 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-1313848.	578803.6	-2.269938	0.0529
D1	-778326.5	136318.4	-5.709620	0.0004
BPR	1625.855	419.8365	3.872592	0.0047
WST	237.4126	53.46386	4.440618	0.0022
R-squared	0.873778	Mean dependent var		1419122.
Adjusted R-squared	0.826444	S.D. dependent var		413964.4
S.E. of regression	172457.8	Akaike info criterion		27.21489
Sum squared resid	2.38E+11	Schwarz criterion		27.37653
Log likelihood	-159.2894	Hannan-Quinn criter.		27.15505
F-statistic	18.46005	Durbin-Watson stat		1.666075
Prob(F-statistic)	0.000592			

Bunker Deliveries KPSS Test Results

Null Hypothesis: BUN is stationary
Exogenous: Constant
Bandwidth: 0 (Newey-West automatic) using Bartlett kernel

	LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic	0.156335
Asymptotic critical values*:	
1% level	0.739000
5% level	0.463000
10% level	0.347000

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	1.57E+11
HAC corrected variance (Bartlett kernel)	1.57E+11

KPSS Test Equation
Dependent Variable: BUN
Method: Least Squares

Date: 04/10/20 Time: 18:30
Sample: 2007 2018
Included observations: 12

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1419122.	119501.2	11.87537	0.0000
R-squared	0.000000	Mean dependent var		1419122.
Adjusted R-squared	0.000000	S.D. dependent var		413964.4
S.E. of regression	413964.4	Akaike info criterion		28.78460
Sum squared resid	1.89E+12	Schwarz criterion		28.82501
Log likelihood	-171.7076	Hannan-Quinn criter.		28.76964
Durbin-Watson stat	1.224342			

Bunker Price KPSS Test Results

Null Hypothesis: BPR is stationary
Exogenous: Constant
Bandwidth: 1 (Newey-West automatic) using Bartlett kernel

	LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic	0.214874
Asymptotic critical values*:	
1% level	0.739000
5% level	0.463000
10% level	0.347000

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	16273.56
HAC corrected variance (Bartlett kernel)	24373.30

KPSS Test Equation
Dependent Variable: BPR
Method: Least Squares
Date: 04/10/20 Time: 18:30
Sample: 2007 2018
Included observations: 12

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	398.3333	38.46315	10.35623	0.0000
R-squared	0.000000	Mean dependent var		398.3333
Adjusted R-squared	0.000000	S.D. dependent var		133.2403
S.E. of regression	133.2403	Akaike info criterion		12.70184
Sum squared resid	195282.7	Schwarz criterion		12.74225
Log likelihood	-75.21104	Hannan-Quinn criter.		12.68688
Durbin-Watson stat	0.955497			

World Seaborne Trade KPSS Test Results

Null Hypothesis: WST is stationary

Exogenous: Constant

Bandwidth: 2 (Newey-West automatic) using Bartlett kernel

	LM-Stat.
Kwiatkowski-Phillips-Schmidt-Shin test statistic	0.496457
Asymptotic critical values*:	
1% level	0.739000
5% level	0.463000
10% level	0.347000

*Kwiatkowski-Phillips-Schmidt-Shin (1992, Table 1)

Residual variance (no correction)	1024579.
HAC corrected variance (Bartlett kernel)	2447578.

KPSS Test Equation

Dependent Variable: WST

Method: Least Squares

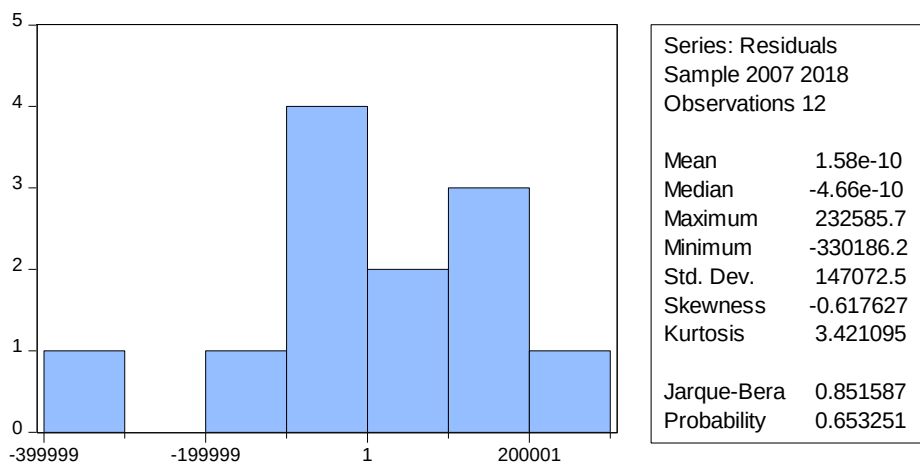
Date: 04/10/20 Time: 18:29

Sample: 2007 2018

Included observations: 12

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	9329.998	305.1942	30.57069	0.0000
R-squared	0.000000	Mean dependent var		9329.998
Adjusted R-squared	0.000000	S.D. dependent var		1057.224
S.E. of regression	1057.224	Akaike info criterion		16.84434
Sum squared resid	12294943	Schwarz criterion		16.88474
Log likelihood	-100.0660	Hannan-Quinn criter.		16.82937
Durbin-Watson stat	0.116696			

Histogram Normality



VIF Multicollinearity

Variance Inflation Factors
Date: 04/10/20 Time: 18:42
Sample: 2007 2018
Included observations: 12

Variable	Coefficient Variance	Uncentered VIF	Centered VIF
C	3.35E+11	135.1694	NA
D1	1.86E+10	1.249608	1.041340
BPR	176262.7	12.44150	1.157334
WST	2858.384	101.5737	1.181630

Heteroskedasticity Test: Breusch-Pagan-Godfrey

Heteroskedasticity Test: Breusch-Pagan-Godfrey

F-statistic	1.344273	Prob. F(3,8)	0.3269
Obs*R-squared	4.021819	Prob. Chi-Square(3)	0.2591
Scaled explained SS	2.163824	Prob. Chi-Square(3)	0.5391

Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 04/10/20 Time: 18:43
Sample: 2007 2018
Included observations: 12

Variable	Coefficient	Std. Error	t-Statistic	Prob.

C	-3.52E+10	1.03E+11	-0.339969	0.7426
D1	-3.19E+10	2.44E+10	-1.308620	0.2270
BPR	-73764546	75004022	-0.983475	0.3542
WST	9611598.	9551347.	1.006308	0.3437
R-squared	0.335152	Mean dependent var	1.98E+10	
Adjusted R-squared	0.085833	S.D. dependent var	3.22E+10	
S.E. of regression	3.08E+10	Akaike info criterion	51.40127	
Sum squared resid	7.59E+21	Schwarz criterion	51.56290	
Log likelihood	-304.4076	Hannan-Quinn criter.	51.34142	
F-statistic	1.344273	Durbin-Watson stat	1.808471	
Prob(F-statistic)	0.326935			

Date: 04/10/20 Time: 18:44

Sample: 2007 2018

Included observations: 12

Autocorrelation	Partial Correlation	AC	PAC	Q-Stat	Prob
. .	. .	1 0.001	0.001	3.E-05	0.996
. *	. *	2 0.089	0.089	0.1320	0.936
. * .	. * .	3 -0.125	-0.127	0.4252	0.935
. ** .	. ** .	4 -0.273	-0.286	1.9883	0.738
. * .	. * .	5 -0.089	-0.078	2.1782	0.824
. .	. *	6 0.062	0.110	2.2868	0.892
. *** .	. *** .	7 -0.354	-0.453	6.5057	0.482
. .	. * .	8 -0.002	-0.183	6.5058	0.591
. .	. *	9 -0.010	0.074	6.5115	0.688
. .	. .	10 0.047	-0.036	6.6999	0.753
. *	. * .	11 0.154	-0.191	10.670	0.471

Breusch-Godfrey Serial Correlation LM Test

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.069212	Prob. F(2,6)	0.9339
Obs*R-squared	0.270604	Prob. Chi-Square(2)	0.8735

Test Equation:

Dependent Variable: RESID

Method: Least Squares

Date: 04/13/20 Time: 18:52

Sample: 2007 2018

Included observations: 12

Presample missing value lagged residuals set to zero.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-162273.8	792510.3	-0.204759	0.8445
D1	5687.071	180349.2	0.031534	0.9759

BPR	-23.58598	525.6201	-0.044873	0.9657
WST	19.30216	80.24074	0.240553	0.8179
RESID(-1)	0.112249	0.673025	0.166782	0.8730
RESID(-2)	0.252752	0.679402	0.372021	0.7227
R-squared	0.022550	Mean dependent var	1.58E-10	
Adjusted R-squared	-0.791991	S.D. dependent var	147072.5	
S.E. of regression	196879.0	Akaike info criterion	27.52542	
Sum squared resid	2.33E+11	Schwarz criterion	27.76787	
Log likelihood	-159.1525	Hannan-Quinn criter.	27.43565	
F-statistic	0.027685	Durbin-Watson stat	1.664977	
Prob(F-statistic)	0.999418			

World Seaborne Trade Forecasting

Automatic ARIMA Forecasting
Selected dependent variable: DLOG(ST)
Date: 04/10/20 Time: 23:10
Sample: 1980 2018
Included observations: 38
Forecast length: 0

Number of estimated ARMA models: 25
Number of non-converged estimations: 0
Selected ARMA model: (0,0)(0,0)
AIC value: -3.64989223537

Dependent Variable: DLOG(ST)
Method: Least Squares
Date: 04/10/20 Time: 23:03
Sample (adjusted): 1981 2018
Included observations: 38 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.028828	0.006085	4.737718	0.0000
R-squared	0.000000	Mean dependent var		0.028828
Adjusted R-squared	0.000000	S.D. dependent var		0.037509
S.E. of regression	0.037509	Akaike info criterion		-3.702524
Sum squared resid	0.052055	Schwarz criterion		-3.659429
Log likelihood	71.34795	Hannan-Quinn criter.		-3.687191
Durbin-Watson stat	1.580200			

Bunker Price Forecasting

Automatic ARIMA Forecasting
 Selected dependent variable: DLOG(R38)
 Date: 04/08/20 Time: 15:22
 Sample: 1991 2020
 Included observations: 29
 Forecast length: 0

Number of estimated ARMA models: 49
 Number of non-converged estimations: 0
 Selected ARMA model: (5,0)(0,0)
 AIC value: 0.826190053566

Dependent Variable: DLOG(R38)
 Method: ARMA Maximum Likelihood (OPG - BHHH)
 Date: 04/08/20 Time: 15:24
 Sample: 1992 2020
 Included observations: 29
 Convergence achieved after 57 iterations
 Coefficient covariance computed using outer product of gradients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.034471	0.082907	0.415778	0.6816
AR(1)	0.056150	0.208544	0.269249	0.7902
AR(2)	-0.400929	0.182262	-2.199744	0.0386
AR(3)	0.157575	0.431591	0.365102	0.7185
AR(4)	-0.280266	0.337231	-0.831081	0.4149
AR(5)	0.510528	0.353253	1.445219	0.1625
SIGMASQ	0.076440	0.016229	4.710127	0.0001
R-squared	0.395241	Mean dependent var		0.018248
Adjusted R-squared	0.230307	S.D. dependent var		0.361818
S.E. of regression	0.317431	Akaike info criterion		0.826190
Sum squared resid	2.216774	Schwarz criterion		1.156227
Log likelihood	-4.979756	Hannan-Quinn criter.		0.929554
F-statistic	2.396353	Durbin-Watson stat		2.032444
Prob(F-statistic)	0.061964			
Inverted AR Roots	.75 -.63+.67i	.29-.85i	.29+.85i	-.63-.67i

APPENDIX 3: Semi-Structured Interview Questions-II

KÜÇÜK ÖLÇEKLİ LNG TEDARİK ZİNCİRİ, TÜRKİYE İÇİN LNG BUNKERING MODELİ GELİŞTİRİLMESİ İÇİN YARI YAPILANDIRILMIŞ GÖRÜŞME FORMU

Sayın İlgili,

Dokuz Eylül Üniversitesi, Sosyal Bilimler Enstitüsü, Denizcilik İşletmeleri Yönetimi Anabilim dalında, ‘‘Küçük-ölçekli LNG Tedarik Zinciri: Türkiye için LNG Bunkering Modellemesi’’ konulu doktora tez çalışması, Doç. Dr. Gül Denктаş Şakar danışmanlığında yürütölmektedir.

Bu çalışma ile IMO 2050 hedefleri paralelinde alternatif yakıtlardan biri olan LNG’nin, Türkiye’de tedarik zincirinin oluşturulmasına yönelik bir model önerisi ortaya koymak hedeflenmiştir. Uzakdoğu, Baltık Denizi, Kuzey Avrupa, Kuzey Amerika ve Batı Akdeniz’de kurulan ve gelişmekte olan LNG gemi yakıtı ikmal tedarik zincirleri ile bağlantılı olarak Doğu Akdeniz ve Karadeniz bölgesi için Türkiye önem arz etmektedir. Bu bağlamda yurtdışında bulunan LNG tedarik zincirindeki paydaşlar ile görüşmeler yapılarak bu bölgelerde tedarik zincirinin nasıl kurulduğu incelenmiş ve bu bilgilerin aktarımı ile Türkiye için küçük ölçekli LNG/LNG yakıt ikmal modeli geliştirilmesi hedeflenmiştir. Görüşme çıktıları ve endüstriyel veriler ışığında ‘karışık tamsayı doğrusal programlama’ yöntemi ile minimum maliyet hedefiyle optimum barç sayısı, kapasitesi ve dağıtım kanalı hesaplanmıştır. Çıkan sonuçların Türkiye dinamikleri ile pekiştirilmesi için yerel uzman görüşlerine başvurulması planlanmıştır.

Siz değerli uzmanımızın görüşlerine ihtiyaç duyduğumuz bu çalışma ile Türkiye’de gemi yakıtı olarak LNG’nin gelişiminin irdelenmesi ve matematiksel modelleme ile elde edilen sonuçların değerlendirilmesi amaçlanmaktadır. Sorulara vereceğiniz cevaplar sadece doktora çalışması kapsamında değerlendirilecektir, isminiz ve bağlı bulunduğunuz kurum gizli tutulacaktır. Bu araştırmaya yapacağınız katkı ve desteğiniz için çok teşekkür ederiz.

Mehmet Doymuş
Öğr.Gör., Uzakyol Kaptan

YARI YAPILANDIRILMIŞ GÖRÜŞME SORULARI

- 1- LNG'nin gemi yakıtı olarak kullanılmasını nasıl görüyorsunuz?
- 2- Türkiye'nin LNG bunkering potansiyeli hakkında görüşleriniz nelerdir?
- 3- LNG'nin gemi yakıtı olarak kullanılmasının önündeki teknik engeller sizce nelerdir?
- 4- LNG ile çalışan gemilerin Türk tersanelerinde inşa edilmesini ve Türk tersanelerinin rekabetçiliği açısından nasıl değerlendirirsiniz?
- 5- LNG ile çalışan gemilerin bunker operasyonları ile ilgili emniyet standartları nasıl olmalıdır?
- 6- LNG ile çalışan gemilere yatırım yapma kararının verilmesini maliyet, çevre, regülasyonlar gibi unsurlar nasıl etkiliyor?
- 7- LNG ile çalışan gemilerin bunker operasyonları ile ilgili emniyet standartları nasıl olmalıdır?
- 8- Liman olarak LNG'nin gemi yakıtı olarak kullanılmasını nasıl yorumluyorsunuz?
- 9- Türk denizciliğinin LNG ile çalışan gemilere yatırım kararını maliyet, çevre, regülasyonlar gibi unsurlar nasıl etkiliyor?

GERÇEKLEŞTİRİLEN SENARYOLARA İLİŞKİN BİLGİLENDİRME:

Tedarik zinciri, kapasiteleri 3000 ila 10000 cbm arasında değişen 5 ayrı LNG bunker barç modeli ile geliştirilmiş ve 3 ayrı senaryo altında değerlendirilmiştir. 3 ayrı senaryo, 2025 yılında Türkiye'de gerçekleştirilmesi beklenen yakıt ikmallerinin %1, %5, %10 veya %15'lik kısmının LNG olarak yapılması tahminlerine göre kurgulanmıştır. Minimum maliyet fonksiyonuna göre barçların sefer süresince yaptıkları yakıt giderleri, OPEX ve CAPEX maliyetlerini dikkate alarak optimum sonuçlar bir aylık periyod için hesaplanmıştır. Barçların hızları sefer boyunca sabit ve maksimumda alınmıştır. Dış etkenler, akıntı, rüzgar, hava durumu, boğaz geçişi, liman maliyeti gibi faktörler problemin sadeleştirilmesi için dikkate alınmamıştır. OPEX ve CAPEX değerleri uzaman görüşü ile yaklaşık olarak alınmış, dolayısıyla farklı işletmelerde ve farklı sözleşmelerde maliyet değerleri farklı olabilecektir. Yakıt maliyeti için referans olarak BOTAŞ 2020 LNG satış fiyatı alınmıştır.

Senaryo 1: Marmara Ereğlisi Botaş LNG terminali çıkışlı olarak İstanbul, Tekirdağ, İzmit, İzmir, Mersin ve Iskenderun talep noktalarına dağıtım planlanmıştır. Değişik yakıt talep miktarlarına göre (1%,5%,10%,15%) sırasıyla 5000cbm/5000cbm/10000cbm/3000 ve 5000cbm kapasiteli barçlar optimum sonucu vermiştir.

Senaryo 1 Sonuçlar

LNG Talep Miktarı	Optimum Barç Sayısı ve Kapasitesi	Min Maliyet- (OPEX+CAPEX+ Yakıt Maliyeti) usd
1%	1 / 5000 cbm	726960,6
5%	1 / 5000 cbm	731852,8
10%	1 / 10000 cbm	816397,9
15%	2 / 3000 cbm ve 5000 cbm	1296467,0

Senaryo 1'e ilişkin;

- Marmara Ereğlisi çıkışlı olarak LNG bunkering operasyonlarının gerçekleştirilebilmesi için gerekli olan altyapı ihtiyaçları nelerdir?
- Marmara Denizi'nde yatırım planlaması için hangi paydaşlar bir araya gelmelidir?
- Boğaz geçişlerini, demir sahalarını, yakıt ikmal bölgelerini, deniz trafiğini ve liman potansiyellerini dikkate alarak senaryo sonuçlarını nasıl değerlendirmektesiniz?
- Barç sayı ve kapasitesi ile ilgili görüşleriniz nelerdir?

Senaryo 2: Ege Gaz Aliğa terminali çıkışlı olarak İstanbul, Tekirdağ, İzmit, İzmir, Mersin ve İskenderun talep noktalarına dağıtım planlanmıştır. Değişik yakıt talep miktarlarına göre (1%,5%,10%,15%) sırasıyla 5000cbm/5000cbm/ 10000cbm/3000 ve 5000cbm kapasiteli barçlar optimum sonucu vermiştir.

Senaryo 2 Sonuçlar

LNG Talep Miktarı	Optimum Barç Sayısı ve Kapasitesi	Min Maliyet- (OPEX+CAPEX+ Yakıt Maliyeti) usd
1%	1 / 5000 cbm	726880,0
5%	1 / 5000 cbm	749875,8
10%	1 / 10000 cbm	834729,4
15%	2 / 3000 cbm ve 5000 cbm	1337784,0

Senaryo 2'ye ilişkin;

- Aliğa çıkışlı olarak LNG bunkering operasyonlarının gerçekleştirilebilmesi için gerekli olan altyapı ihtiyaçları nelerdir?
- İzmir Bölgesinin LNG bunkering gelişiminde avantajları nelerdir?
- Boğaz geçişlerini, demir sahalarını, yakıt ikmal bölgelerini, deniz trafiğini ve liman potansiyellerini dikkate alarak senaryo sonuçlarını nasıl değerlendirmektesiniz?
- Barç sayı ve kapasitesi ile ilgili görüşleriniz nelerdir?

Senaryo 3: Bu senaryoda Marmara denizindeki talepler M.Ereğlisi BOTAŞ terminalinden yapılan ikmaller ile, diğer talepler Ege Gaz Aliğa terminalinden yapılan ikmallerle karşılanmıştır. Marmara Ereğlisi çıkışlı olarak talep miktarlarına en uygun barçlar sırasıyla 3000cbm/5000cbm/6500cbm/10000cbm olarak belirlenmiştir. Ege Gaz çıkışlı olarak İzmir, Mersin ve İskenderun talep noktaları değerlendirilmiş ve optimum çözüm tüm talep değerleri için 3000cbm kapasiteli barç olmuştur.

Senaryo 3 Sonuçları

LNG Talep Miktarı	Optimum Barç Sayısı ve Kapasitesi Marmara	Min Maliyet- (OPEX+CAPEX+ Yakıt Maliyeti) usd	Optimum Barç Sayısı ve Kapasitesi Aliğa	Min Maliyet- (OPEX+CAP EX+ Yakıt Maliyeti) usd
1%	1 / 3000 cbm	551682,0	1 / 3000 cbm	562835,1
5%	1 / 5000 cbm	707096,3	1 / 3000 cbm	562835,1
10%	1 / 6500 cbm	735867,2	1 / 3000 cbm	562835,1
15%	1 / 10000 cbm	793022,2	1 / 3000 cbm	562835,1

Senaryo 3'e ilişkin;

- Barc sayı ve kapasitesi ile ilgili görüşleriniz nelerdir?
- Boğaz geçişlerini, demir sahalarını, yakıt ikmal bölgelerini, deniz trafiğini ve liman potansiyellerini dikkate alarak senaryo sonuçlarını nasıl değerlendirmektesiniz?
- Küçük ölçekli LNG tedarik zinciri gelişimini, Marmara Denizi, Ege, Akdeniz ve Karadeniz için nasıl değerlendirirsiniz?