Erasmus University Rotterdam

MSc in Maritime Economics and Logistics

2013/2014

LNG import terminal efficiency in Europe

by

Luca Oprinsen

Acknowledgements

I would like to express my gratitude to those who have supported me during this research. Foremost, appreciation goes out to Prof. Dr. Michele Acciaro, who has invested large portions of time and effort in guiding me throughout the complete research period. I would also like to thank the people at Shell, particularly Paul Fitton, for indicating gaps in LNG import terminal knowledge. Furthermore, my parents deserve a thank you for their moral and financial support. Last, but certainly not least, I would like to thank my girlfriend Eline, for her endless love and care, despite my energy being diverted towards finishing this thesis.

Abstract

LNG demand is increasing in Europe and an import infrastructure is required to meet these demands. In developing this infrastructure the performance of LNG import terminals has to be maintained. Research on LNG terminal efficiency is limited, even though it can provide valuable information towards the further development of the LNG infrastructure. The following study has provided a way for terminals to benchmark terminal efficiency. In seeking explanation for the differences encountered, lessons are learnt about sources of inefficiency. The study has focussed on European LNG import terminals, but the methods used can be implemented in a wide variety of settings. The relative efficiencies of LNG import terminals in Europe have been measured by implementing a DEA, performed using the OSDEA software. The DEA variant chosen in this case was the output oriented variable (increasing) returns to scale model measuring technical efficiency by using unloading, regasification and storage capacity as inputs and surface area and capital costs as outputs. The outcome of the analysis has indicated that eight out of the 15 included terminals are deemed inefficient. Inefficiency scores vary from 1.055 to 1.443 indicating certain terminals should be able to increase their levels of output with up to 44.3 percent. Slacks have indicated that especially unloading capacity is falling behind. Findings have shown how terminals with high output levels and capital costs tend to score more efficiently. Due to high unloading, storage and regasification capacities terminals are capable of dealing with uncertainties and, therefore, manage to achieve higher levels of efficiency. The explanation for the high capital costs of efficient terminals is found in their equipment. In striving for efficiency these terminals invest in expensive equipment. This equipment composes a large part of the capital costs and, therefore, more advanced terminals require higher capital costs. The efficiency analysis, however, proved incapable of dealing with external factors like construction delays. Further research might incorporate means of coping with these factors. The future trends of the gas and LNG market have to be kept in mind, however.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

Abbreviation	Description
BCC	Barnes, Charnes & Cooper
BCM	Billion Cubic Meters
BM^3	Billion Cubic Meters
CCR	Charnes, Cooper & Rhodes
CO_2	Carbon Dioxide
CRS	Constant Returns to Scale
CSV	Comma Separated Values
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DRS	Decreasing Returns to Scale
EIA	Energy Information Administration
EPM	Engineering & Project Management
FOB	Free-On-Board
FSRU	Floating Storage & Regasification Unit
GBS	Gravity Based Structure
GDEA	Generalised Data Envelopment Analysis
GECF	Gas Exporting Countries Forum
GHG	Greenhouse Gas
GIE	Gas Infrastructure Europe
GLE	Gas LNG Europe
GRS	Generalised Returns to Scale
HFO	Heavy Fuel Oil
IEA	International Energy Agency
IFO	Intermediate Fuel Oil
IRS	Increasing Returns to Scale
JCC	Japanese Crude Cocktail
LNG	Liquefied Natural Gas
M^3	Cubic Meter
mBtu	million British thermal units
MDO	Marine Diesel Oil
MPSS	Most Productive Scale Size
Mtoe	Million tonnes of oil equivalent
NBP	National Balancing Point
NIRS	Non-Increasing Returns to Scale
NO_x	Nitrogen Oxide
OECD	Organisation for Economic Cooperation and Development
OSDEA	Open Source DEA
OSV	Offshore Supply Vessel
RTS	Returns To Scale
SBM	Slack Based Model
SFA	Stochastic Frontier Analysis
SO_x	Sulphur Oxide
STS	Ship-To-Ship
TEU	Twenty-foot Equivalent Unit
TPS	Terminal-Pipeline-Ship
TTS	Truck-To-Ship
US	United States
VRS	Variable Returns to Scale
€M	Million Euro

1 Introduction

1.1 Problem statement

1.1.1 Background

"Europe plans more import terminals" (Pfeifer, 2012). This 2012 Financial Times header indicates the essence of current *liquefied natural gas* (LNG) developments in Europe.

Global energy demands have been increasing and are predicted to continue doing so for the next couple of decades (Energy Information Administration, 2013; International Energy Agency, 2013). In meeting these demands a shift from currently dominant fuels towards new fuels is expected (Exxon Mobil, 2014). One of these fuels is *natural gas*. Natural gas, due to its versatility, affordability and low levels of emissions, is predicted to become the second largest energy source globally. Until recently, gas was not seen as a possible global energy source due to the inability to transport it over long distances. This has changed with the introduction of LNG and the associated supply chain (Figure 1).

Figure 1, Simplified LNG supply chain (Author).

LNG makes it possible to store or transport gas over long distances (Shell, 2014). These characteristics make global trade of LNG possible, thereby integrating the formerly separated market of gas (Neumann, 2008). Possibilities of storing and transporting LNG, together with its environmental qualities and relatively low price compared to other maritime fuels, have also sparked the interest of the maritime sector (Acciaro, 2014). Due to these characteristics LNG is seen as a future *bunker fuel* for shipping (Adamchak & Adede, 2013).

The increasing demand for LNG and especially gas have resulted in competition around the energy source (Ratner, Belkin, Nichol, & Woehrel, 2013). European countries in particular are, therefore, increasing the focus on the security of their supply (Bilgin, 2009). As gas is mainly supplied by non-European countries like Russia and some Middle Eastern countries, these supplies are subject to instability and political risk (Weisser, 2007). To overcome these risks Europe is trying to diversify its supplies. LNG, not bound to pipeline networks and thus third party influences, makes this supply diversification possible.

The Ukraine crisis has increased the rate in which, especially Central and Eastern, European countries are developing an LNG infrastructure (Kaare, Koppel, & Leppiman, 2013). This infrastructure, mainly consisting of LNG import (*regasification*) terminals, reduces their pipeline dependence. In addition, these countries and others less dependent on (Russian) gas, can reap the benefits of this clean and relatively cheap energy source. As the header introducing this chapter indicates, the amount of European LNG import terminals is, therefore, rapidly increasing (International Gas Union, 2013).

In developing the LNG infrastructure, knowledge about terminal performance is important. LNG import terminals are known to be *capital intensive* (Grabau, 2013), but *economies of scale* have provided a way of coping with these costs (von Hirschhausen & Neumann, 2008). However, to accomplish these scale economies, high levels of efficiency should be met. If these efficiency levels are met, economies of scale can take away some of the (financial) risk in expanding the LNG infrastructural network. For this reason it is important to gain insight in the efficiency of LNG import terminals in Europe.

1.1.2 Statement of the problem

Currently, no research has been dedicated to measuring efficiency among European LNG import terminals. Research on terminal efficiency could provide valuable insights for the further development of the European LNG infrastructure. Simultaneously, inefficiencies could be identified, indicating where the existing infrastructure could improve. Similar research has been implemented in comparable industries (Ruggiero, 2007), leading to valuable information on possible improvements. Expanding this type of research towards the LNG import terminal industry could lead to comparable benefits.

This thesis could initiate the abovementioned research by measuring LNG import terminal efficiency in Europe. By comparing the efficiency of European terminals, a benchmark for further developments can be established. Knowledge on inefficiencies makes it possible for existing terminals to improve and future terminals to avoid these sources of inefficiency.

For this reason the following research question is suggested:

Are there substantial efficiency differences among LNG import terminals in Europe, and if so, how can they be explained?

Answering this question requires measuring efficiency levels in European LNG import terminals. If efficiency differences are identified, seeking explanation for them could provide valuable information for existing and future LNG import terminals.

1.2 Research objectives

1.2.1 Purpose of the study

This study aims at assessing and comparing efficiency among LNG import terminals in Europe. By benchmarking *relative efficiency*, LNG terminals might be able to learn from each other. Assessing efficiency, however, is not straightforward. Efficiency depends on, among others, the type, location and inputs and outputs of a terminal. Therefore, comparing the efficiency of LNG import terminals is a challenging task.

However, similar efficiency measurements and benchmarking methods have been implemented in all sorts of other settings. These studies have proven that, despite the complexity of such comparisons, methods to measure relative efficiency do exist. By imposing similar methods on LNG import terminals in Europe the first steps towards efficiency benchmarking in this sector can be made.

1.2.2 Research design

As European LNG import terminals are the units under evaluation in this study information about these terminals has to be gathered. Because the population of terminals in Europe is relatively limited (Gas LNG Europe, 2014), all terminals can be included in the study without posing limitations on data collection. More challenging is the collection of primary data on these terminals, as information regarding performance is often confidential due to its commercial value. Data on these terminals will, therefore, mainly originate from *secondary sources*. Databases containing performance-related information on LNG import terminals exist, and can be used as input for the analysis required to benchmark relative terminal efficiency.

Measuring efficiency is dependent on a wide set of inputs and outputs. *Data envelopment analysis* (DEA), a linear programming technique, has been developed to handle these variables. As mentioned before, this technique has been implemented in a wide variety of sectors, and has proven its capabilities there. For these reasons it is decided to use this technique in measuring relative efficiency among LNG import terminals in Europe.

The outcome of this analysis can be used in benchmarking the efficiency of LNG import terminals. Any variations in efficiency can be highlighted and can provide information as to where to improve efficiency, or prevent inefficiency. Thus, apart from indicating possible efficiency differences, the analysis can indicate the sources of these inefficiencies.

1.2.3 Assumptions, limitations and scope

The choice for the DEA requires the researcher to select one of the many varying models it encompasses. Choices with regard to variables, orientation, efficiency and returns to scale determine the outcome of the model. The outcome of the model is, therefore, subject to the researchers assumptions and interpretations. Certain data can be constructed in different ways, requiring assumptions to indicate what is chosen. Examples of such assumptions are *capital costs* that only include construction costs and costs of further expansions and offshore terminals with a surface of 1.5 hectares.

There are also limitations to each study as a result of the researcher's possibilities or the instrumentation used. In this case the data availability is restricted as it is commercially sensitive in nature. A large part of the available data requires payments and financial limits thus restrain the possibilities as do the time constraints. There are also limitations as to what the instrumentation can provide. A DEA for example does not indicate *absolute efficiency* scores. Scores are relative to other terminals, and these, therefore, change when including or excluding certain terminals. A further limitation is that the methodology, when using a small dataset, is easily *over-specified*. For this reason certain variables might have to be excluded, even when they have added value. The calculations, when done by using *OSDEA software*, also lack transparency. Thus, whilst the software poses benefits, like time savings, it also has its limitations.

Although the problem often spans further than the research question posed, a choice has to be made as to which part of this problem is addressed. Research has to be scoped in this sense. In this study the focus is solely on European LNG import terminals. Furthermore only operational terminals are addressed, as these are deemed most relevant towards answering the research question. No further attention will be granted to the LNG supply chain and the effect inefficiencies have on profitable LNG trades.

1.3 Structure of the thesis

The structure of this thesis will be designed to work towards answering the research question in a structured and logical manner. It will start with introducing the theoretical foundation upon which the thesis is built. A review of past and present literature related to this research question will be discussed, as well as literature introducing the methodology used. After reading this literature review the reader should be able to understand the problem or gap this thesis is trying to (partially) fill. Following the literature review is the methodology chapter. Data collection and analysis are critical in answering the research questions. As the findings and thus conclusions, are dependent on the methodology chosen, this requires serious attention. Apart from clearly indicating which data collection and analysis methods are used, and why, the measurements and assumptions that have to be made are discussed. In establishing *credibility* the chapter will finalise with indicating the limitations and ethical considerations. The outcome of the collection and analysis, discussed in the methodology, will be presented in the results. The results contain the findings that relate to the research question. The following discussion contains reflections on the significance of the findings towards answering the research question. After the discussion the key points in answering the question should be clear. The final chapter, the conclusion, will restate the major findings and formulate an answer to the research question. With this answer contributions, or implications, towards existing theory and practice will be discussed. Recommendations for further research will be made, based on the limitations of the current study and speculations of future trends. In doing so the researcher indicates what is not covered and where the study stands within the larger problem it is embedded in. After these recommendations the study should be finalised.

This introduction indicates the background of the problem researched. The problem should be clear and the design of the study, in filling the gap, is introduced. The following chapters are the embodiment of these proposals.

2 Literature review

2.1 Introduction

The increasing gas demand, and the role LNG has been fulfilling in making this possible, has resulted in the growth of LNG imports. The amount of LNG import terminals, and the types and elements included in these terminals, have followed this trend. For these reasons, gaining knowledge about its performance and which aspects are key in this is of growing importance. In this, the question if there are any substantial efficiency differences between these terminals, could provide insight. The explanatory factors behind these possible efficiency differences could help in addressing focus areas for further development of these terminals. In reaching this goal the first step is to explore the literature on this subject and related topics. Through exploring this literature, the key elements in this discussion and the gaps therein, can be highlighted. Research could help in filling these gaps, but, therefore, it is important to discuss what is known and unknown about the topic.

The literature review will discuss how the demand for energy is increasing on a global scale. It is believed that natural gas will become one of the most important fuels in meeting this demand. However, there are threats that might make it troublesome to meet this demand. If gas manages to overcome these threats LNG is believed to play a major role in meeting energy demands. LNG makes trading natural gas on a global scale possible. This is increasingly important as nations want to secure their supply, and decrease single source dependence. For that reason countries are investing in an LNG infrastructure to make importing possible. The amount of LNG import terminals will increase in rapid pace. As different countries and different sectors, like the maritime sector, have different LNG demands the types of terminals are varying. In order to manage the costs of these terminals it is important that they operate as efficiently as possible. However, there is not much known about LNG import terminal efficiency. Using known methods, like DEA, efficiency differences can be distinguished and more can be learnt from these differences.

The search for literature originated from the research dilemma discussed in the introduction and was done according to search and selection procedures proposed by Blumberg et al. (2011). Following the dilemma, an initial search for key terms and events was done through reading books, articles and newsfeeds and by discussing the topic with people employed in the business. The outcome of this initial search was used as input for more intense and structured search among academic journals and books, mainly in the Google Scholar database. The documents that this search produced, often included references to other useful sources. Eventually a sizeable information pool was created of which only a proportion could be used. Through the evaluation and selection procedures mentioned earlier, this pool was reduced to the literature actually used for this review.

The resulting literature review will initiate by discussing the increasing energy demand, and the position of gas in this. This will be followed by a discussion of LNG's role in supplying this demand. LNG import terminals, the infrastructure necessary to make LNG trade possible, will be highlighted as key in this. Once more is clear about these terminals, their efficiency can be questioned. It is discussed how DEA can contribute to this. The review will be concluded by a summary and a discussion on the relevance of the literature discussed.

2.2 Topics

2.2.1 Energy demand

Energy demand increasing

Primary energy consumption has been increasing steadily during the past years. Since 2003 the total consumption has increased from 9,943 to 1,2730 *million tonnes of oil equivalent* (Mtoe) per annum in 2013, meaning an increase of 28 percent (BP, 2014). Asia Pacific and Europe/Eurasia (for explanation of regions see Appendix 1) are the largest consummating areas, whilst the US and China are main consumers. Primary energy mainly consists of oil, coal and natural gas, together good for 86 percent of total energy consumed. Renewable energy sources, nuclear energy and hydroelectricity have experienced relatively larger consumption increases, but still only represent the remaining 14 percent. Coal is the dominant fuel in Asia Pacific, as gas is in Europe/Eurasia and the Middle East. All other regions mainly consume oil.

When looking at the future, these demands are predicted to increase. There are multiple projections made (Energy Information Administration, 2013; Exxon Mobil, 2014; International Energy Agency, 2013). Depending on the assumptions included in the models, like economic development, demographics and the time periods, these projections differ (Lightfoot, 2007). The *US International Energy Agency* (IEA) is projecting a one-third increase by 2035, whilst the *Energy Information Administration* (EIA) is predicting a 56 percent increase by 2040. *Exxon Mobil* also projects for 2040, but with a 35 percent increase it is closer to IEA's prediction. The share of fossil fuels will decrease, whilst natural gas will surpass coal as the second largest source, together accounting for 60 percent of the demand. Renewables and nuclear energy will meet 40 percent of the growth in demand. Emerging countries like China and India will become the most demanding, in oil and coal respectively. America will meet most of its energy needs with domestic resources, whereas the Middle East will become a major energy consumer.

Growing population, urbanisation and welfare growth will change energy demands in the commercial and residential sectors (Exxon Mobil, 2014). The combined energy demands are expected to grow by 30 percent (in 2040) here, with a shift towards electricity and natural gas as fuel. Regarding the transportation sector, especially the demand for energy by commercial transportation will grow. Increased economic activity and the resulting movement of goods will drive demand up by 70 percent. Efficiency is improving here too, and especially diesel and gas will grow in use. The industrial sector will be stimulated by urbanisation and welfare gains, as infrastructure and consumer goods will be in demand. The heavy industry and the chemicals sector will be the most energy demanding, whilst they move from coal towards oil and natural gas as a main resource. The power generation sector will be the largest in growth, with an energy demand increase of 90 percent. Electricity will account for the largest part of energy needs by the residential, commercial and industrial sectors. As a result of tighter environmental standards, in developed countries, the dominant source for electricity will become natural gas.

Growing population and expanding economies are often named as the main causes of this increasing demand (Kumar et al., 2011). This is illustrated by the 2 billion people increase of the global population and the 130 percent larger economy stated as key figures in Exxon Mobil's 2040 projection (Exxon Mobil, 2014). Growing urbanisation further drives this demand for energy, due to higher incomes, industrial levels and households compared to rural areas. Other economic factors often named are *gross domestic product* (GDP) per capita and energy prices (Gately & Huntington, 2002). Income increases result in higher demand, but the response to price changes play a softening role in this. Recently attention has also been paid to the effect of *non-economic factors* like demographic, structural, technological and temperature change on energy demand (Huang, 2011). Growing GDP, urban areas and industrial sectors will result in a higher demand, whilst higher energy prices and the development of service economies and technological innovation will do the opposite. As welfare increases, energy efficiency will improve thus this growth is slowing down.

Literature on the global energy demand indicates how present growth levels are likely to continue or even intensify. Apart from a shift in consuming and producing countries, there will also be a shift away from current dominant fuels towards energy sources like natural gas and renewables. These sources will especially become dominant in the industrial and power generation sectors, the largest growing sectors when looking at energy demand. Although growing population and expanding economies are regarded the main stimulants of this increasing demand, other economic and non-economic factors and their effects have also been discussed. Among the major growing energy sources is natural gas, the demand for this fuel will be discussed in more detail below.

Natural gas demand increasing

From the previous paragraph it becomes apparent how natural gas is making its way up. Since 2003 the consumption of natural gas has increased from 2344 to 3020 Mtoe, an increase of nearly 29 percent in the last 10 years (BP, 2014). With 3020 Mtoe in 2013 natural gas accounted for 23 percent of total fuel consumption worldwide. North America and Europe/Eurasia are the largest consumers, accounting for nearly 60 percent of global consumption. However, oil is still the dominant energy source in North America. In the Middle East gas has overtaken oil as the dominant fuel in 2013.

As described earlier, gas will increase in popularity, mainly due to its versatility, affordability and low emissions (Exxon Mobil, 2014). Natural gas is predicted to grow at a staggering speed, surpassing coal as the second largest energy source by 2025. Especially non-OECD (Organisation for Economic Cooperation and Development) countries show great growth potential. New sources of gas, often named *unconventional gas,* have been found or have become economically viable to produce. The Middle East and Russia contain the most *conventional gas*, whilst North America is rich in unconventional gas. Although North America and Russia are the largest producers, the geographically spread nature of gas will result in more regions increasing their production.

Natural gas is the fastest growing fossil fuel due to multiple aspects (Energy Information Administration, 2013). As it is environmentally less damaging than other fossil fuels, sectors under stringent *greenhouse gas* (GHG) emission regulation by their governments prefer low carbon intensive gas as energy source. Power plants also prefer gas due to the low capital costs and favourable *heat rates* for energy generation. As natural gas resources are abundant and diversifying, through shale gas extraction in the US and Russian Arctic exploration for example, it is only improving its position compared to other energy sources. To make these resources available around the world LNG functions as a linkage between regional gas markets, thereby accommodating the trade of natural gas worldwide.

Shale gas extraction in the US and the role of LNG in world natural gas trade will be discussed in more detail below. In the literature discussed above it is underlined that natural gas is becoming the second largest energy source worldwide. It is becoming the dominant fuel in multiple regions, especially growing in non-OECD countries. The main reasons for this growth are its versatility, affordability and low emissions.

Shale gas

Shale gas is found within deposits trapped in shale rocks, which are the source and reservoir of this unconventional gas (Jarvie, Hill, Ruble, & Pollastro, 2007). With *horizontal drilling* and (hydraulic) *fracking* methods this gas can be extracted. The introduction of these two techniques made extraction technically viable, and shale gas production increased from one to 20 percent of US gas production between 2000 and 2009 (Stevens, 2010). At the same time favourable geology, taxation and a vibrant service industry further made shale gas extraction feasible. Currently the extraction methods and their impact on the environment are gaining attention. The conditions the US experienced and the (societal) pressure shale gas extraction is under now, pose a barrier for the development of shale gas outside the US.

Before the extraction of shale gas, LNG imports were expected to expand and result in investments in ever larger import (regasification) plants. Consequently investors in LNG have lost considerable amounts of money and the US is suffering from a dramatic under-utilisation of *regasification capacity* (Meagher, 2010). This over-capacity is not restricted to the US however. Demand decreases, due to the recession, a fall-back in pipeline throughput and the commissioning of plants that were under construction have created global over-supply of LNG capacity (Hulbert, 2010). In addition to and partially as a result of this under-utilisation, gas prices have been falling (Stevens, 2010). Although falling oil prices, to which LNG is linked in certain markets, explain some of these price decreases, other factors like gas price competition in Europe also play a role. A result of the over-capacity and falling gas prices is the growing uncertainty in the gas value chain and the restraining effect this has on investment levels. This is a risk as gas demand is expected to increase and the uncertainty might delay the necessary projects. The low gas prices also pose a threat to more expensive renewables, as the price difference becomes too large to cover the environmental benefits.

Literature thus indicates how shale gas extraction has made its appearance in the previous decade, as a result of favourable geological, economical and regulatory circumstances. A negative effect of this gas extraction has been the under-capitalisation of regasification capacity in the US. Simultaneously, there has been a global over-supply of capacity, eventually leading to uncertainty in the gas value chain. This uncertainty forms a threat to growing gas demand and the necessary projects to facilitate this growth.

2.2.2 LNG

Role of LNG in world natural gas trade

LNG is natural gas that has been cooled down to -162 degrees Celsius (Shell, 2014). It shrinks a factor 600 and becomes a non-toxic and clear liquid. These new characteristics make it possible to transport and store the liquid. LNG can be regasified, when it is closer to its destination, thereby making it economically attractive to deliver gas at distant markets (Exxon Mobil, 2014). About 15 percent of global demand for gas, in 2040, is expected to be met by gas imported as LNG. LNG as trade product will help balance the supply and demand of gas. Especially Asia Pacific, due to increased energy demand, and Europe, due to a decline in local production, will demand LNG.

As the demand for gas is increasing, prices are in upward movements and competition is increasing. LNG supports the trade of natural gas worldwide, thereby integrating the formerly split market (Neumann, 2008). LNG has only recently been interconnecting markets, diverting shipments to countries with the highest *spot prices* (current price at which LNG is bought or sold for immediate payment and delivery). LNG can be traded as long as the price differentials only reflect transportation costs. Currently there are export (*liquefaction*) terminals and import (regasification) terminals on both side of the trade, enough vessel capacity to facilitate the trade and regulatory regimes in place making the trade possible. This has resulted in substantial LNG trade (Appendix 2 and Appendix 3) although spot trading is not at its full potential. LNG trade and especially the role of pricing therein will be discussed in more detail later.

LNG has made exporting gas to distant markets economically attractive and can thereby balance out supply and demand. It supports global trade and interconnects formerly segregated markets. As long as the circumstances are right gas can be traded according to spot prices.

LNG as maritime bunker fuel

Despite lacking availability and investments therein, LNG is seen as one of the future shipping fuels (Acciaro, 2014). The two main drivers giving LNG its market potential are the capability to comply to emission regulation and the low price of the fuel compared to other possible fuels (Adamchak & Adede, 2013). LNG offers compliance to current and future *sulphur oxide* (SO_x) and *nitrogen oxide* (NO_x) level requirements. In addition, possible future regulation of *particulate matter* and greenhouse gasses do not form a direct threat as LNG emits considerably less of these compared to other fuels. When looking at the price of LNG a distinction has to be made between certain markets. In the US and, to a smaller extent, in Europe the price of LNG is lower than *heavy fuel oil* (HFO), *marine diesel oil* (MDO) and *intermediate fuel oil* (IFO). In Asia and the Pacific LNG is priced somewhere between MDO and IFO. LNG as bunker fuel, however, shall require investments in infrastructure increasing general LNG prices. Nevertheless LNG is likely to be competitively priced compared to other fuels.

LNG as fuel has been used on LNG carriers for decades and more than 10 years on small ships, like ferries and *offshore supply vessels* (OSV). In order to propel a ship LNG should be safely contained, processed and bunkered (Harperscheidt, 2011). Regarding storage, LNG has the disadvantage of taking up more volume than fuel oil for the same energy content. Currently LNG is contained in *Type C Tanks* (IMO IGC code). The processing of LNG as fuel, can differ according to design parameters of ships. One important factor is the *operating pressure* and how this relates to storage volumes. For large volumes, maintaining high operating pressure increases costs significantly. Therefore, small tanks can be pressurised, whilst larger tanks will require compressors. *Two-stroke* engines require another system due to the high pressure required. In order to prevent damage or accidents a combination of technical and procedural measures have to ensure safety. Crew training and several safety systems, developed as a result of decade-long experience with LNG operations, are key in this. Finally, bunkering is an essential aspect of LNG propelled shipping. Currently there are three main types of bunkering solutions (Danish Maritime Authority, 2012): *ship-to-ship* (STS) bunkering at sea or quay, *truck-to-ship* (TTS) bunkering and *terminal-to-ship* (TPS) through pipeline. Using containerised bunkers is also an option, but this has not been developed and implemented as much as the previous.

Literature thus indicates that LNG is an attractive fuel for shipping due to its environmental qualities, and capability to comply to regulation, and generally low price, making it attractive among other fuels. Technically, using LNG as fuel is already rather developed. Containment, processing and bunkering of the fuel is possible in multiple manners.

LNG pricing

The pricing structure of LNG is still widely discussed and unclear (Royal Haskoning DHV, n.d.). LNG prices originate from imports and exports (Maxwell & Zhu, 2011). A large part of LNG is imported from countries, with large gas reserves and limited end markets, like Qatar and Russia. For these countries exporting LNG is a way of earning from their resources. Exporting is viable when a desired return of equity is earned, meaning that returns sufficiently cover costs (of the value chain). LNG contract prices can be priced *free-on-board* (FOB) or *ex-ship*. Ex-ship is the downstream price minus the costs of the value chain. FOB contracts price LNG at the export terminal, excluding shipping and insurance costs. There is a shift from ex-ship contracting to FOB contracting, as the latter provides the buyer with more flexibility. Producers have the choice to send spot shipments to the market that provides the highest *netback* (remainder, after costs and return on equity are subtracted). These netbacks are influenced by *downstream* gas prices and other factors like (the decrease in) shipping and liquefaction costs. Producers used to sell through long-term contracts in order to guarantee minimum purchases, so that the lender would be willing to invest in the LNG projects making this trade available. Nowadays there is a shift towards short-term contracts, like the earlier discussed FOB contracts, as transport costs are declining and the amount of suppliers (exporters) are increasing (Jensen, 2004).

<u>Gas Prices</u>

The price of LNG is thus mainly composed of the downstream gas prices and the costs of the value chain (Acciaro & Gritsenko, 2014). Global gas prices are complex and, therefore, widely discussed. Gas prices can be *oil price linked* or priced through *gas-to-gas competition* (Kingma, Lijesen, & Mulder, 2002). With oil price linkage, gas prices are linked to the prices of alternative (oil based) fuels according to the *netback market value concept*. This linkage was created to prevent any inventive to switch to the other fuels. Movements in the oil price were passed on to the consumers through the producers. This method could be maintained as gas suppliers had monopolistic positions (within their country). Under gas-to-gas competition this linkage is obscure and gas is traded at market hubs at spot rates. Demand and supply determine the price of gas, meaning that gas prices increase if supply is low or when demand is high.

Gas trade is concentrated around the three main gas markets (Siliverstovs, Hégaret, Neumann, & Von Hirschhausen, 2005) Europe, North America and Asia (mainly Japan and South Korea). The main importers are Europe (from Russia by pipeline, and Algeria and the Middle East by LNG shipments) and Asia (from Australia and the Middle East by LNG shipments), whilst North America has moved towards becoming an exporter due to the shale-gas revolution (BP, 2014).

In North America gas prices derive from spot pricing at the *Henry Hub*. This market pricing is based on supply and demand fundamentals and therefore make long-term contracts unfeasible (Rogers & Stern, 2014). In Europe the *UK National Balancing Point* (NBP) follows similar principles. However, gas pricing in continental Europe differs. Although long-term oil indexed contracts prevailed, the 2008 recession and the changing energy market resulted in a shift towards competitive *hub-based pricing* (Stern, 2007, 2009). Currently there is a *hybrid price* market, consisting of the *German Border Import Prices*, which represent the remaining European long-term oil priced contracts, and the UK NBP hub price (Stern & Rogers, 2011). In Asia gas pricing has its origins in Japan, as the first LNG importer in the region (Rogers & Stern, 2014). When others followed the *Japan Crude Cocktail* (JCC) pricing principle was already established and, therefore, adopted. Until the Fukushima nuclear disaster in 2011 (which increased LNG demand and, thus, price) the LNG import prices of the countries were similar, which meant that basing their price on the Japanese price was reasonable. Global gas prices are, thus, (mostly) benchmarked by the US Henry Hub, the UK NBP, the Average German Import and the Japan LNG price.

Until 2008 these prices followed similar paths, as can be seen in Figure 2, ranging between $ 6.01 and $ 8.05 (per million *British thermal units*, or mBtu) on average in 2007 (BP, 2014). After that prices started deviating more, with European and Asian (Fukushima disaster) prices increasing and US prices decreasing (shale-gas revolution). This deviation led to a 2013 spread, of $ per mBtu average that year, between $ 3.71 (US Henry Hub) and $ 16.17 (Japan LNG).

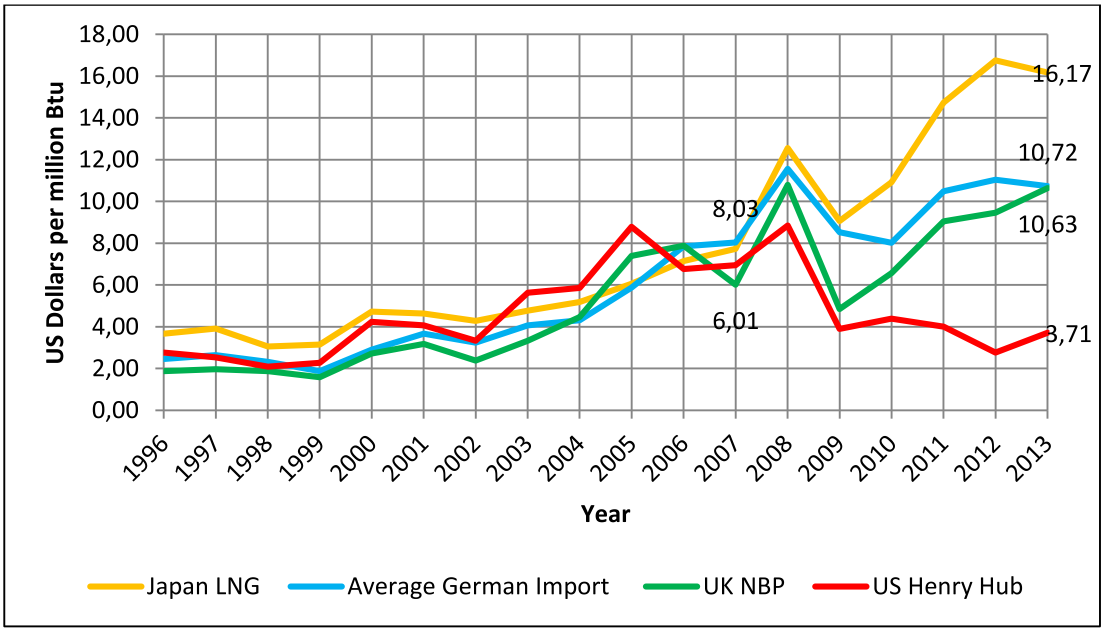


Figure 2, Global natural gas prices (BP, 2014).

Transport Costs

The costs of LNG are thus determined by the price of the gas at the market and the costs made. These costs mainly consist of liquefaction and transportation costs towards bunkering facilities, before the gas can be used or bunkered (Acciaro & Gritsenko, 2014). There is a wide range of possibilities regarding the supply chain of LNG, which differs between the LNG supply chain towards natural gas (energy) markets and for the supply chain for bunkering purposes.

The 'normal' LNG value chain consists of five steps, namely: gas exploration & production, liquefaction, transportation, regasification and sales (Ruester & Neumann, 2006). There are four main price components in this (Energy Information Administration, 2003), being the costs made by gas production (15-20% of the costs), the export terminal (30-45% of the costs), LNG shipping (10-30% of the costs) and the import terminal (15-25% of the costs). The supply chain for LNG as bunker fuel is more complex, and is extended after LNG reaches the import terminal or when gas reaches the national gas grid (Danish Maritime Authority, 2012). LNG can be directly bunkered from the import terminal or from an *intermediary terminal*. Trucks and *bunker/feeder vessels* transport LNG between these terminals, but the intermediary terminal can also receive LNG that has been liquefied after having been transported through the gas grid. This maritime LNG supply chain thus adds multiple price components to the four mentioned earlier. Costs are added at the terminals, the liquefaction plant and the distribution between these and towards the end users. Costs added at the terminals mainly consist of handling (loading and unloading) and regasification costs**.** Distribution costs depend on the distance towards the end user, the method of distribution and the volume transported (European Shortsea Network, 2013).

The effect of distance (and, therefore, time) on costs is relatively straightforward, namely higher distances result in higher costs due to fuel and personnel. The method of distribution and the volume transported have to do with economies of scale. If LNG is distributed by truck, the costs compared to the volume transported increase significantly (Acciaro & Gritsenko, 2014). Regarding the volume transported, the amounts needed to fuel a vessel are much lower than the quantities supplied to the energy markets (European Shortsea Network, 2013). This also negatively effects economies of scale and, therefore, increases costs. Fortunately the fleet of LNG carriers is increasing and the infrastructural costs of LNG terminals are decreasing, to counteract this cost increase.

The LNG market is changing and more competition, flexibility and short-term contracts are becoming the standard. The price of LNG is composed of downstream gas prices and the added costs due to the value chain. These downstream gas prices are increasingly being determined at market hubs, but since 2008 they differ largely among the three largest regions. Transport costs depend on the supply chain, for example if it is flowing towards bunkering facilities the costs will increase along with the increasing complexity. In addition the economies of scale, which characterise the current LNG value chain, dissolve when it is moved or handled in the small amounts required by the bunkering industry.

Security of energy supplies

Discussion on the security of energy supplies, especially in Europe, has been resurfacing lately (Stern, 2002). The demand for energy is rising, as a result of emerging economies and competition for energy sources is increasing (Ratner et al., 2013). In Europe especially natural gas demand has been increasing, increasing the stress on *supply security* (Bilgin, 2009).

There are multiple threats putting European gas supplies at risk. The most pronounced is that demand for gas is increasing dependence on imports from suppliers outside Europe, and although there is a wide variety of sources available, Europe currently relies on only a few of them (Weisser, 2007). Europe mainly relies on gas from the Middle East and Russia and is, therefore, subject to the risks that arise from their instability and political power. The appearance of the *Gas Exporting Countries Forum* (GECF), which resembles a cartel, and therefore, might result in collusion between these partners, only weakens the position of dependent (European) industrialised countries (Costantini, Gracceva, Markandya, & Vicini, 2007). Another risk is the fragmented European energy market and the resulting demand and supply imbalance. This creates instability for exporting countries and the multi-billion investments, needed for the liquefaction plants, are therefore having more troubles getting financed. As a result, the infrastructure, that is required to increase along with the demand, is unable to provide these supplies.

As Europe realises the pressure on gas supply, security solutions are being sought. In first instance solutions are being sought in international policies. It is important that Europe establishes a clear strategy and policy regarding gas security (Correljé & van der Linde, 2006; Weisser, 2007). As the abovementioned risks are unevenly distributed across EU member states, it is likely, however, that thoughts about such a policy will differ, making it challenging to implement such tools (Le Coq & Paltseva, 2009). The cooperation between Europe and other importing regions, often developing countries, could increase their negotiation power towards exporting countries, with whom more cooperation should be established too (Costantini et al., 2007). The final solution is a diversification of supply. As a result of the cooperation, as mentioned above, Europe could decrease barriers towards links with Caspian and (new) Middle Eastern countries (Bilgin, 2009). Countries like Azerbaijan, Turkmenistan (both Caspian) and Iran and Iraq (both Middle East) could be incorporated in the supply system. North Africa, despite its instability, and Central Asia, which requires establishment of lengthy pipelines, are also named as alternative sources by Ratner et al. (2013). These authors continue by underlining how LNG can provide help in this diversification process. Transporting LNG by ship makes the Middle Eastern and Central Asian countries accessible and reduces the dependence on pipeline transport. An increase in LNG importing countries, and terminals, is a result of this diversification.

Literature indicates how gas supply security has become an important topic for European countries. The increasing demand, and the competition for gas supplies is accompanied by risk, predominantly due to source dependence. Policy initiatives and relational efforts are being made to improve the position of importing countries. To decrease dependence, Europe is putting an effort into diversifications of its supply. LNG could become an important part of this.

LNG replacing gas

Recently the Crimea dispute between Russia and Ukraine has intensified the discussion on Europe's dependence on, predominantly, Russian gas (The Economist, 2014). Western countries' economic sanctions towards Russia have resulted in their response to disrupt gas supplies. Under the excuse of unpaid

Ukrainian gas bills Russia threatened to stop gas flows towards Ukraine, a key gas transit route for Europe.

Europe has been trying to reduce these risks by liberalising the energy market. The *Third Energy Package* implemented by the *European Commission* in 2007 (European Commission, 2011) aimed at increasing competition and integrating the European gas (and electricity) market. The *2009 Gas Directive* (European Commission, 2009) continues to increase transparency and interconnectivity. Where a connected market used to be opposed, in fear for lower prices, the gas supply security issues are now resulting in more cross-border connections. An integrated market makes it possible to provide the countries dependent on Russian gas with gas from the west (Chazan, 2014). This gas can originate from existing stocks or new LNG supplies.

Especially eastern European (Baltic) countries are investing in LNG terminals in order to secure supplies, as they are not yet connected to this European gas network (Kaare et al., 2013). However, the Fukushima disaster has led a to diversion of 'European' LNG towards Japan, as they simply pay more (Rogers & Stern, 2014). To prevent having to join this LNG price increase, the remaining possibilities are to further diversify the European supply sources.

Europe has found new suppliers in Nigeria, Egypt, Trinidad & Tobago and Qatar. The US has also helped, not with supplies from their newly won shale gas, but by decreasing imports and thereby freeing up LNG supplies for the European market (Cunningham, 2013). Shale gas has even been mentioned as source in Europe, but this has not proven to be economically or socially feasible so far.

Thus, before LNG can provide an alternative to Russian gas the price differences between Europe and Asia have to be dealt with. Where the dominating idea is to address new supply sources, other countries believe that investing in an LNG infrastructure could mitigate the upward pressure on prices.

More importing countries

Europe has been importing LNG since 1964, when the United Kingdom imported the first ever exported LNG from Algeria (Tusiani & Shearer, 2007). France signed a similar deal a year later. Libyan LNG reached Europe in 1971 where it entered the Italian and Spanish market. It took another 16 years before Belgium followed and Turkey started importing in the '90s. These six countries are also the oldest and currently still the largest LNG importers in Europe (BP, 2014). New countries like Greece and Portugal followed just after the millennium change and northern European countries like Norway, Sweden and the Netherlands followed several years later. Together these countries only import seven percent of European imports, whilst Spain alone imports nearly 30 percent. Qatar and Algeria account for nearly all of these imports.

Partially as a result of the described LNG supply tensions more European countries are planning to construct LNG terminals. Central and Eastern European countries like Bulgaria, Croatia, Estonia, Lithuania, Latvia, Poland, Romania and Ukraine have LNG import terminals planned to weaken this dependence (Cunningham, 2013). In addition to these terminals there are also plans to construct terminals in less Russian dependent countries like Ireland and Denmark. Thus the dependence on

Russian gas is stimulating the development of European terminals, but factors as the fuels cost and environmental qualities must not be forgotten.

It took nearly 50 years to establish the currently existent LNG network, but the increasing gas demand and the Russian supply issues are likely to stimulate a much faster development of a LNG network in Eastern Europe.

2.2.3 LNG import terminals

Increasing number of import terminals

As more and more countries are switching to gas as their main source of energy they turn to LNG to meet this demand (International Gas Union, 2013). This trend logically results in an increasing amount of LNG terminals worldwide. In 2013 the amount of terminals online had passed 100 to reach 103 terminals in total. Regardless of the current developments in Eastern Europe the amount of terminals is also increasing in the rest of Europe. At the beginning of 2014 there were a total of 25 LNG import terminals in Europe (Gas LNG Europe, 2014). The Netherlands, Belgium, Greece and Portugal still have the terminals they started with, but all other countries have expanded their import capacity by establishing new terminals. Spain has expanded towards six terminals and the United Kingdom currently has four. France and Italy both have three terminals whilst Turkey has two. How the amount of currently existing LNG import terminals in Europe developed can be seen in Figure 3.

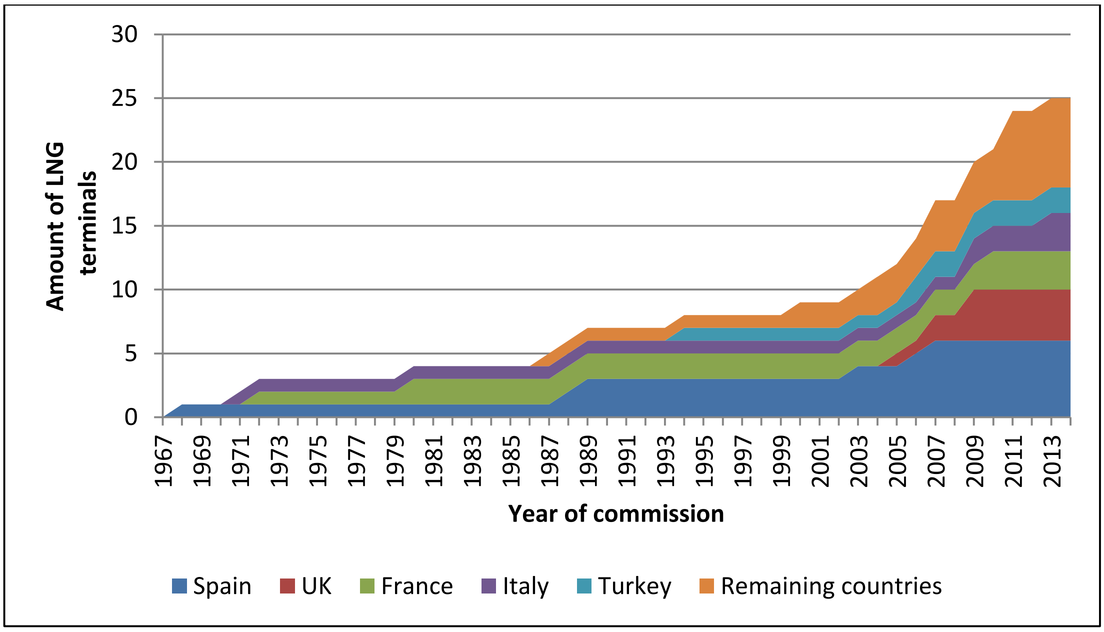


Figure 3, Development of current European import terminals (Author).

Numbers show that not only the global amount of LNG importing terminals is increasing but that a similar trend is happening in Europe. Currently 25 terminals are operational and there are a handful under construction to add to this. Especially countries in Central and Eastern Europe are developing terminals to decrease their dependence towards Russian gas.

Diverse import terminals

The technology of LNG terminals has also been developing resulting not only in more efficient terminals but also in complete new types of terminals. In Europe currently five types of LNG regasification terminals can be distinguished (Gas LNG Europe, 2014). The first distinction can be made with regards to scale. The *Danish Maritime Authority* (2012) defines three scales of LNG import terminals: *large-, medium- and small-scale*. They only appoint these scales according to a terminal's *storage capacity* and the size of vessels they can receive (Appendix 4). In literature, however, scale distinctions are often limited to large- or small-scale terminals. When looking at European terminals this makes sense as there is only one terminal (Brunnviksholme LNG) that fits the medium-scale description (Appendix 5). Among the LNG importing countries there are also those who require only limited amounts of LNG. For these countries, small-scale terminals could better suit their needs. These terminals can regasify LNG and send out gas into the pipeline, but they can also offer small-scale services like bunkering of vessels, trucks or trains (Gas LNG Europe, 2013). They are not downscaled versions of the larger terminals, but innovatively designed to match the needs whilst remaining economically viable (Andrieu, 2013).

Another distinction that can be made, is whether the terminal is located onshore or offshore. The abovementioned terminals are considered onshore. A more recent development is the design and construction of offshore regasification terminals. These offshore terminals come in two forms (Tugnoli, Paltrinieri, Landucci, & Cozzani, 2010; Wijngaarden, 2004): *gravity based structures* (GBS) or *floating storage and regasification units* (FSRU). GBS are prefabricated concrete caissons, already containing storage tanks and regasification equipment, that are lowered onto the seabed. The deck of the structure is above sea level and also functions as breakwater for the (un)loading vessels. FSRU are converted LNG carriers, or barges, that contain vaporisation equipment on deck. Gas can be sent out directly through a *riser* and a *sealine* for natural gas. An FSRU is *turret-moored* to its location and is capable of withstanding all weather conditions. When necessary, the unit can uncouple the *mooring lines* and change its location, making it geographically flexible. An addition to the FSRU technology has been the *Energy Bridge*, developed by *Excelerate Energy*. Where a regular FSRU remains offshore and delivers gas through subsea pipelines, Excelerate's FSRU can receive LNG offshore and regasify this onboard before mooring at bay and delivering high pressure directly into the gas grid (J. Cook, 2006).

Europe is home to all the above mentioned terminals (Gas LNG Europe, 2014). There are three small-scale LNG regasfication terminals in Scandinavia, two in Norway and one in Sweden. The United Kingdom has the only Energy Bridge in Europe, located in Teesport. Italy commissioned a GBS in 2009 and added a FSRU to their terminals in 2013. The remaining 19 import terminals can be regarded as large-scale terminals, according to the categorisation of the Danish Maritime Authority (Appendix 4).

Along with the growth of the amount of terminals has come a development of different types of terminals. Each terminal is engineered to accommodate the needs of importing countries. Small-scale terminals are fit for receiving small quantities of LNG, and performing other tasks like bunkering, and are mostly employed in Scandinavian countries. There are also offshore terminals, in multiple forms, that are more evenly distributed across Europe. These new types of terminals give countries more choice in what to develop. However, they come at high costs.

Capital costs

Capital costs, the costs made in order to construct or expand plants or terminal, are composed of multiple aspects. Regarding LNG terminals these costs are composed mainly of construction, equipment and bulk materials (Songhurst, 2014). For liquefaction terminals half of the costs are dedicated to the liquefaction equipment. With regasification terminals the largest part of costs are dedicated to the storage tanks (Energy Information Administration, 2003). Up to 50 percent of the total costs can be dedicated to storage tanks, depending on the tank type. Another major cost contributor are the *marine facilities*. The costs in marine facilities are largely determined by the jetty head and trestle, possible breakwater(s) and any dredging required. Construction costs, which represent the largest part of the remaining costs, are mainly driven by plant location, man hours required, labour costs and productivity. *Bulk materials* are surprisingly expensive for LNG terminals as they require large amounts of stainless steel, to cope with the cryogenic conditions of LNG, and come at high prices. Further costs made are *engineering and project management* (EPM) and owners' costs, both for engineering and managing the projects.

The capital costs of LNG regasification terminals can vary from 100 million dollars to two billion dollars, depending on the factors introduced above. Not only these terminals, but the LNG and natural gas market in general are known to be very capital intensive (Grabau, 2013). It is the sector's responsibility to introduce measures to cope with these high costs.

2.2.4 Efficiency

Relevance of terminal efficiency

Economies of scale throughout the LNG value chain and in the natural gas industry are providing a way to cope with these costs. The capital intensity, or costs per unit, are decreasing as a result of these economies of scale (von Hirschhausen & Neumann, 2008). This in its turn is decreasing (financial) risk and, therefore, creating possibilities for the market to expand. A similar role could be appointed to terminal performance. Although performance and economies of scale are closely related, the former does not always imply the latter. Nevertheless, increasing performance would result in more (or similar) production at lower costs. High terminal performance could, thus, indirectly support the infrastructure expansion. In developing the LNG import market, knowledge about the performance of different terminal types is also of importance. Gaining knowledge about performance, or underperformance, can provide insights in ways to improve the current infrastructure.

Efficiency is an important measure to cope with the high capital costs that characterise the industry. Economies of scale and high performance rates in LNG terminals could contribute to this. In order to gain insight in terminal performance, and how this can be improved more knowledge about terminal efficiency should be gathered.

Import terminal efficiency

Performance measurement can be distinguished into multiple categories: effectiveness, efficiency, quality, timeliness, productivity and safety (TRADE, 1995). The choice for one of these measurements depends on the focus of the measuring party. LNG importing terminals operate through a highly complicated and technologically sophisticated process (Tusiani & Shearer, 2007). Large capital investments are made to ensure that the terminals are capable of handling as much LNG as possible with as little inputs as possible (Danish Maritime Authority, 2012; Grabau, 2013). In this case efficiency will be a good performance measurement, as efficiency measures the capability of a process to produce a certain level of outputs at minimum input levels.

For customers interested in developing LNG import terminals, efficiency of existing terminals could serve as a benchmark, thereby helping to decide what type of terminal to develop. For the existing LNG infrastructure, efficiency measurements could provide insights in areas of improvement. Unfortunately, the amount of literature or studies on LNG import terminal efficiency is near to none. In contrast, other sectors have been employing these types of measurements. The performance or efficiency of ports (Roll & Hayuth, 1993), container terminals (Tongzon, 2001) and airports (Gillen & Lall, 1997) have been measured and compared with each other. As the efficiency of these units are dependent on a wide variety of factors, most of these comparisons employ the method of DEA. A similar efficiency measurement could possibly be applied to LNG import terminals as well.

Measuring efficiency is a suitable performance measurement of LNG import terminals and can be used in decisions about terminal development. Efficiency comparisons among terminals can be undertaken using DEA. However, before implementing such an analysis it is important to understand the context in which these terminals operate. LNG is part of the complex and changing gas industry and, therefore, the efficiency of LNG terminals should be related to this market.

Gas market efficiency

As the demand for natural gas as energy source has been increasing in the last couple of years, policy makers are concerned about the use of scarce sources by this industry (Hawdon, 2003). The gas market has integrated and opened up and competition is increasing as a result of that. Simultaneously privatisation, liberalisation and deregulation of gas markets have further changed the sector. Thus questions are asked whether these changes negatively influence the efficiency of the industry, in terms of resource utilisation and the containment of costs for example. Efficiency in the gas market is negatively influenced by a wide variety of factors (Newbery, 2000). High and often unclear costs, of production and investments in infrastructure, are at the basis of this. As a result a situation exists in which producers prefer long term contracts to recover these costs (and averse risk). Europe, however, has managed to overcome most of these obstacles. Northern European gas, and later Russian gas, supplies and the introduction of LNG, to ensure new sources, are among the reasons why it seems as if Europe has managed to increase efficiency. However, whilst competition is increasing it is the question if these efficiency improvements will take place equally throughout the European continent. Earlier research indicates that only true competition, and same levels of deregulation across related regions, will result in these improvements (Waddams Price & Weyman-Jones, 1996). Thus, despite the possibilities for high levels of efficiency it is possible that efficiency differences will exist among European countries, or possibly even terminals.

There are multiple barriers for efficiency in the natural gas market. The European market has, due to particular circumstances, managed to overcome most of these. The privatisation of the gas market in most countries has only increased efficiency further. However, questions are asked whether these levels of efficiency have increased at a same rate throughout the European countries. Measuring terminal efficiency and comparing these could provide insight in this.

2.2.5 Data envelopment analysis

Development of DEA

Before efficiency was introduced to performance measurement, financial output performance was leading in performance measurement (Kumbhakar & Lovell, 2000). The first production functions followed later, as a response to the incapability of these measurements to include varying levels of efficiency. It was assumed that all inputs and outputs were used in an efficient manner, but in fact producers were inefficiently solving their optimisation problems (Cobb & Douglas, 1928). These inefficiencies resulted in the introduction, by work of Koopmans (Koopmans, 1951), of *production frontiers* in this field of research. He focussed on efficiency and believed that this meant that producers could not improve their inputs or outputs, without messing up the remaining inputs and outputs (Cooper, Seiford, & Zhu, 2011). After work by Debreu (1951) and Shephard (1953), on the distance of producers from the frontiers, Farrell (1957) was the first to empirically employ these measures of *technical efficiency*.

It took another 20 years before Farrell's *piecewise-linear convex hull approach* to frontier estimation was picked up (Coelli, 2008). Only when Charnes, Cooper and Rhodes introduced the term data envelopment analysis or DEA, in 1978, frontier estimation really took off. DEA is a *non-parametric*, statistics without probability distributions, mathematical programming approach to such estimations. The model uses a *radial measure of efficiency* to find points on an efficiency frontier that use the same inputs or outputs. Moving along this radial towards the (efficient) frontier indicates increasing efficiency (Portela, Borges, & Thanassoulis, 2003). Charnes, Cooper & Rhodes created a model (CCR, according to their names) which was input oriented and assumed *constant returns to scale* (Charnes, Cooper, & Rhodes, 1978). Since the CCR model introduced in 1978 there have been a great number of altered DEA models introduced (Cooper, Seiford, & Tone, 2007).

It falls outside the scope of this literature review to discuss all these models and the determinants leading to, and distinguishing, the models. The most common models, and the model relevant for this thesis, along with their determinants will be discussed in more detail at in sections 3.6 and 3.7.

Advantages of DEA

DEA could be a method of measuring and comparing the relative technical efficiency of LNG import terminals. There has been no prior research (to my knowledge) on LNG import terminals, or any LNG terminal whatsoever, that has implemented the DEA as measure of gaining insight in their efficiency. This is peculiar as over 2000 articles have been published on DEA since its introduction in 1978 (Cooper et al., 2011), applying its methods in a wide variety of settings (Ruggiero, 2007).

The foremost reason of applying the DEA is that it is able to incorporate multiple inputs and outputs simultaneously when measuring technical efficiency (Bhagavath, 2006). Through the comparison of the relative efficiency scores among a set of units, lessons can be learnt from units that are *slacking* (inefficiently using inputs or outputs). However, it is important that the right choices are made in setting up the model, as the DEA is sensitive to measurement error, sample size and the specification of inputs and outputs.

In measuring the relative technical efficiency of LNG import terminals, and the reasons for slack in inefficient terminals, more might become clear as to which European terminals are efficient and why. For the same reasons DEA has been employed in (related) industries, as will be discussed below. With knowledge on the origin of inefficiencies, similar units are able to incorporate this knowledge in their current or future operations.

Despite the extensive amount of literature and the clear benefits of DEA as method of measuring relative technical efficiency, no such research has been done on LNG (import) terminals. If this, as in related sectors, would have been done, more could have become clear about efficiency differences. The explanations for these differences could be valuable information for these units themselves or the complete sector. The following paragraphs will indicate, through examples from the (related) maritime and energy sector, how DEA can provide valuable information for DMUs (decision making units) and policy makers.

Application DEA in practical maritime problems

The benefits of using DEA in measuring relative efficiency has resulted in the methodology being applied in all sorts of sectors (Ruggiero, 2007). For these same reasons the methodology has also been applied in the maritime sector. Roll & Hayuth (1993) were the first to apply DEA for the measurement of relative efficiency among ports. They used hypothetical *cross-sectional data* from financial annual reports to indicate the usefulness of this method for port performance analyses. Without having large amounts of data the DEA is capable of providing useful information with regards to port organisation and management. DEA has been implemented, in various ways, in port related practical problems ever since (Panayides, Maxoulis, Wang, & Ng, 2009).

The first DEA measuring relative port efficiency with actual data (Poitras, Tongzon, & Li, 1996) used container related variables like TEU (twenty-foot equivalent unit) handled per year and the frequency of ship calls. It also recognised varying returns to scale among these terminals, and the effect this had on efficiencies. Similar work shortly followed (Martinez-Budria, Diaz-Armas, Navarro-Ibanez, & Ravelo-Mesa, 1999), now also taking historic efficiency movements into account by using time series data. The DMUs were also categorised, thereby making it possible to relate efficiency differences to the DMU’s categorisation. A couple of years later Tongzon (2001) compared Australian ports with other international ports. During this research, which used the *additive model* (*variable returns to scale*) for the first time, it became clear that small sample sizes could lead to over-specification of the DEA. The balance between the amount of DMUs and inputs/outputs, indicates how the structure of the DEA largely determines the outcome. As ports were increasingly becoming privatised DEA was implemented to measure if ownership structure and port efficiency were related (Valentine & Gray, 2001). The categorisation, as introduced in earlier research (Martinez-Budria et al., 1999), was also to divide ports according to their ownership structure. In further researching the effects of privatisation a *Malmquist index* was used to analyse total productivity, divided into technical efficiency and technological change (Barros, 2003). The study showed that autonomy made no significant difference and that location and scale were more important. In the following years of maritime studies, it became apparent that DEA could provide more information, slacks could indicate reasons for efficiency for example (Barros & Athanassiou, 2004), and that DEA models could be tuned to overcome certain limitations (Barros, 2006). In 2004, Park & De (2004) had also examined the possibility of introducing a four-stage DEA model. Instead of focussing on general efficiency, they distinguish four efficiency stages. Strengths or weaknesses of a port, if appointed to one of these stages, are easier to stimulate or improve. It was around the same time that the focus of efficiency measurements shifted from ports in general to (container) terminals. As terminals are believed to be highly dynamic the DEA was extended with the *window analysis* in order to show movements in efficiency levels over time (Cullinane, Song, Ji, & Wang, 2004). In a study expanding the research on privatisation and efficiency (Valentine & Gray, 2001) towards container terminals, it appeared that this window technique solved misrepresentative efficiency scores due to random events like equipment failure (Cullinane, Ji, & Wang, 2005). *Stochastic frontier analysis* (SFA), the *parametric benchmarking methodology*, results were also compared to DEA efficiency scores. When looking at the relative technical efficiency of container terminals, the efficiency scores of DEA and SFA proved to be rather similar (Cullinane, Wang, Song, & Ji, 2006). The basis of port and container terminal efficiency measurements having been provided by these studies, many more similar studies followed in recent years.

The focus of the early port efficiency measurements was clearly oriented towards seaports and container terminals. In a similar way as focussing on container terminals, instead of the port in general, research was also moving towards *dry bulk* terminals (de Oliveira & Cariou, 2011). In comparison with containers dry bulk is more diverse, making it more challenging to find relevant inputs and outputs to perform a single DEA. A further contribution of this 2011 study is that it aggregated these terminals at a country level, making comparisons among countries possible. The main finding indicated that inefficiencies in bulk terminals are predominantly related to scale. Haralambides & Gujar (2012) further extended relative efficiency measurements to *dry ports*. These ports, due to road and rail transportation, contribute significantly to atmospheric pollution. In measuring their efficiency these negative side effects should, therefore, be included. To realise this, a new ‘Eco-DEA’ is developed which takes CO_2 (*carbon dioxide*) emissions into account. The efficiency levels of dry ports are significantly different when also addressing these *transport externalities*. It must not be forgotten that DEA was being implemented in all sorts of industries. Regarding the maritime sector shipping firms, for example, were also being evaluated (Lin, Liu, & Chu, 2005). Non-financial indicators, which counted as the principal efficiency measures at the time, are untrustworthy and often difficult to gather. Financial indicators were introduced to DEA as financial data is more trustworthy, as it is audited, and more easy to collect.

DEA has, thus, been implemented for practical problems in the maritime sector since 1993. The first studies used these methods to measure (general) port performance. Container and bulk terminals followed in the use of DEA, as it had proven to provide useful outcomes. For the same reasons dry ports and shipping companies have also employed these efficiency measurements. Adaptations to the original DEA methodology were made in order to provide insights in efficiency changes over time (Malmquist indices and window analysis), incorporate externalities (Eco-DEA) and improve outcomes (by including financial indicators). Although different in inputs and outputs, LNG import terminals differ only slightly from ports and terminals. With further adaptations DEA could, therefore, provide similar outcomes for efficiency measurements of LNG import terminals.

DEA in the energy sector

Along with the application of DEA in maritime related practical problems, the methodology was also being implemented in the energy industry. Since the oil crisis in 1973, and the growing concern about the environment in the ‘80s, research has been focussing on the energy industry (Zhou, Ang, & Poh, 2008). At the time when the energy sector was being deregulated in the late ‘80s, DEA was making its way into scientific research. DEA, therefore, was introduced into energy studies and a great deal of such research has followed since. Zhou et al. (2008) discuss 100 publications related to this field, from the period between 1983 to 2006. A relevant selection of these publications will be discussed below.

The first studies, undertaken in the late ‘80s, primarily focussed on the relative efficiency of electricity generation plants and coal mines. Probably the first in this respect (Färe, Grosskopf, & Logan, 1983), used the *Farrell measure* (Farrell, 1957) and adapted this in order to provide extra information about sources of inefficiencies. Looking at electric plants in Illinois, the study indicated that (the earlier discussed) regulation does not necessarily contribute to efficient operations and even levels of performance across plants. The same methods were used in a study measuring the productive efficiency of Illinois strip mines (Byrnes, Färe, & Grosskopf, 1984). The largest contributor to inefficiencies was any deviation from the optimal scale of production. A later study on electric generation plant regulation (Färe, Grosskopf, & Logan, 1985) made a comparison between public and private plants based on six efficiency measurements: *overall efficiency, allocative efficiency, overall technical efficiency, purely technical efficiency, scale efficiency* and *congestion*. In most cases public plants score more efficiently. Byrnes et al. (1988) use three of these efficiency measurements when comparing productivity differentials between unionised and nonunionised coal mines in the US. They also compare the outcomes with outcomes of a *statistical regression*, and find that there are no significant differences, only with regards to the amount of information on the sources of inefficiencies. In a second study on Illinois electric plants, a Malmquist productivity index is used to measure changes in technical efficiency and technology over time (Färe, Grosskopf, & Yaisawarng, 1990). Technological regress in that period resulted in decreasing efficiency levels. Furthermore, it was concluded that variations in efficiency are closely related to productivity growth. Thompson et al. (1995) use a case of Illinois coal mines to illustrate how profit ratios and technical efficiency measures need to be treated separately. Technical efficiency and maximum profit ratio are shown to be independent from each other. DEA analyses have also been used outside US, like in Kulshreshtha & Parikh’s study of efficiency and productivity in opencast and underground coal mines in India (Kulshreshtha & Parikh, 2002).

During the ‘90s DEA made its way to other parts of the energy sector. Especially electricity distribution utilities were subject to a large amount of efficiency measurements, once again due to the deregulation in the energy sector. One of the first of these was a study by Weyman-Jones (1991), which compared efficiency among privatised electricity distribution boards in England and Wales. Knowledge on potential efficiency gains was important as the boards had just been privatised, and the study could provide insights for the new regulatory regime. Many similar studies have followed since. A study by Hjalmarsson & Veiderpass (1992), for example, shows how the Malmquist index was also used to measure efficiency differences over time in this field of study. In the period between 1970 and 1986 the productivity of these distribution utilities appeared to have grown, due to *economies* *of density*. Similar studies have been implemented in Turkey (Bagdadioglu, Waddams Price, & Weyman-Jones, 1996) and Norway (Førsund & Kittelsen, 1998), again indicating that productivity has grown as a result of deregulation. A shift of the *technology frontier* is added to the explanations. Jamasb & Pollitt (2003) are the first to create an international efficiency benchmark for electricity distribution utilities, as they believe national energy regulators have a shortage of information due to increasing amounts of international mergers. The study also discusses the variation in methods used for distribution utilities and the problems each of these methods are known to have. As quality has become important in post-reform distribution networks Giannakis et al. (2005) contribute, although only focussing on the United Kingdom, to electricity distribution network efficiency measurements by adding quality aspects into DEA. Technical efficiencies are measured and productivity change over time is captured using Malmquist indices. The results show how service quality improvements have led to increased productivity in the electricity distribution networks.

Privatisation of nuclear power plants proved to be somewhat more troublesome (Pollitt, 1996). High capital costs and environmental risk had delayed privatisation proposals, in the United Kingdom, until 1995. The US and Japan had succeeded in this years before. For this reason, an international sample of public and private plants was used to indicate the effects of ownership on performance. Pollitt initiates with DEA and submits the outcomes to a *Tobit analysis*. The outcome indicates that there is little difference in performance between public or private plants, and that inefficiencies can mainly be tackled by lowering employment levels. In the years after the millennium DEA in the energy sector moved its focus towards heat plants. District heating markets were one of the latest in the energy market to move towards liberalisation. Rączka (2001) measured technical efficiency of heat plants in Poland. By implementing a Tobit model the factors influencing these efficiency levels were identified. Government intervention seemed to decrease efficiency, whereas coal quality and capital utilisation increased efficiency. Most importantly, public heat plants performed better than privatised ones. Agrell & Bogetoft (2005) expand this research to Denmark, the country with the most developed district heating network in Europe. Technical and economic efficiency are measured through a DEA, and inefficiencies are related to governmental, market and managerial influences. Especially governmental action proves to influence efficiency, thereby indicating the importance of fitting regulatory measures. No direct regulatory measures are recommended, however. Following research (Munksgaard, Pade, & Fristrup, 2005) further stresses the importance of fitting regulatory measures, especially due to the near monopolistic structure in district heating markets. The ongoing liberalisation provide possibilities of increasing efficiency in these heating plants, as was already indicated by Agrell & Bogetoft (2005). The study suggests a combination of *cost-of-service pricing* with benchmark regulation, based on efficiency scores, in order to stimulate incentive schemes.

DEA had also been used to measure relative efficiency of petroleum and gas companies. In one of the first of these studies, petroleum companies were measured for their *productive efficiency* (Thompson, Lee, & Thrall, 1992). By imposing DEAs for each year, over a seven-year time period, differences in efficiency between certain years were distinguished. According to the findings recommendations for policy, regarding petroleum companies, were made. A later study (Thompson, Dharmapala, Rothenberg, & Thrall, 1996) added *assurance region methods* to this analysis in an attempt to measure overall efficiency, rather than technical efficiency. These methods resulted in less fully efficient companies and a lower efficiency overall. Adding the assurance region methods made it possible to measure minimum and maximum profit ratios, which showed that there was profit potential for a large number of companies. Kashani (2005*b*) uses DEA, SFA, Malmquist indices and regression analysis to measure the effect of different regulatory regimes on the efficiency of petroleum companies in Norway. Most inefficiencies were related to the inputs used, and when regulation pushed the use of domestic goods and services these inefficiencies were higher. As this movement to domestic inputs was part of Norwegian policy goals, the study concludes that the regulation has been successful but that it has come at certain (efficiency) costs. The exact same methods were employed in a study measuring petroleum companies in the United Kingdom (Kashani, 2005*a*). The findings are in line, and further support the conclusions of the Norwegian study. As mentioned before, similar studies covered the effects of privatisation in the gas industry too. One of these studies measured technical efficiency of regions in the British gas industry, before and after privatisation (Waddams Price & Weyman-Jones, 1996). As so many before, Malmquist indices were used to show how productivity grew after the introduction of privatisation. Stimulating in this was the clear regulatory measures that were paired with the privatisation. Despite privatisation, more competition between regions could have further improved efficiency. In light of the recent expansion of the gas industry DEA is also employed to provide insights in the use of scarce resources (Hawdon, 2003). DEA is used to measure the efficiency of individual countries in their use of resources. The study encounters problems as the economies of scale are inadequately defined in this industry, and as it is difficult to distinguish clear explanations for efficiency changes over time. It does support, on a global scale, the findings of previous studies that privatisation has led to increased efficiency.

Research in the energy sector has, just as in the maritime sector, shown the benefits of using DEA for practical problems. An oil crisis, growing environmental concerns and, especially, the privatisations taking place since the ‘80s have stimulated the use of DEA in the energy sector. Before 1990 energy generation plants and coal mines were the primary focus of efficiency measurements. Research becoming familiar with these techniques soon spread to electricity distribution facilities, district heating utilities and even nuclear electricity generation plants. Furthermore, petroleum and gas companies have also been evaluated by using DEA. DEA methods were often adapted to improve the outcomes, for example by including Tobit analyses or assurance region methods. These studies, both in the maritime and energy sector, give an indication of the advantages of DEA. The same methods can be used to measure relative efficiency among LNG import terminals.

2.3 Summary literature review

Predictions show how current growth levels in global energy demand are likely to continue or even intensify. It is expected that there will be a shift from current dominant fuels to new energy sources. Natural gas is, therefore, likely to become the second largest energy source worldwide, due to its favourable characteristics, showing great growth potential especially in non-OECD countries. Although some believe the shale gas revolution could help in this, others only see it contribute to uncertainty in the natural gas value chain. More uniformity exists on the role of LNG. Foremost, LNG has made transporting gas over long distances possible, thereby supporting global trade and the connection of formerly segregated markets. In addition, LNG is believed to be an attractive future fuel for shipping, due to its environmental qualities and generally low price. Pricing of LNG in general has proven to be rather complex. The price is believed to consist of market prices of gas and the additional costs of the value chain. Gas prices are more frequently being determined at market hubs, but still differ widely per region. As the demand for gas is increasing and more competition for this fuel has arisen, nations are focussing on the security of energy supplies, especially in Europe. By diversifying supply sources, partially through the use of LNG, source dependence can be overcome. In that sense LNG is helping in replacing gas dependence towards (near monopolistic) suppliers like Russia. The amount of LNG importing countries has therefore increased. The network of LNG import terminals, the required infrastructure for these imports, is increasing as a result. There is a financial risk tied to the expansion of the LNG infrastructural network as terminals have proven to be capital intensive. LNG demand fluctuations can put investments in these costly terminals at risk but by lowering the capital intensity of the terminals part of these risks can be anticipated. Economies of scale have proven to lower the capital intensity of these terminals, thereby providing a method of coping with these high costs. Increasing outputs and lowering average costs simultaneously can result from improved terminal efficiency. Since the demand for terminals is increasing terminal efficiency can thus provide a way of coping with the financial risk involved. Measuring efficiency among these terminals could indicate which ones contribute to this risk. Lessons can be learnt from their inefficiencies, but so far no such research has been done. Relative technical efficiency measurements and comparisons have been implemented, by means of DEA, in the related energy and maritime sector. Imposing similar analysis on LNG import terminals could provide useful insights in efficiency and simultaneously function as a benchmark for the industry.

3 Methodology

3.1 Introduction

This chapter will introduce the methodology used in this research. First a choice for a certain research design, in relation to others, is discussed. The needs of the study have to be clear and a research design is chosen accordingly. The quality of the chosen methodology will be identified using research literature. Once a choice is made the instrumentation and materials used shall be discussed.

Secondly, the population and sampling methods used in this study will be addressed. A target population is identified, from which a representative sample will be taken. The choices regarding this population and sampling method shall be discussed.

This is followed by the data collection, which describes the way data is gathered. This method depends on the design chosen. The procedures followed are specified, indicating when and why certain choices regarding collection are made. Because the theoretical foundation, discussed in the literature review, and the actual information gathered never entirely suit, it is indicated where the collected information is modified to the theoretical concepts. This increases the *validity* of the study.

This part is followed by the data analysis, methods used to analyse and process data, and how this works exactly. It is made clear why this approach is appropriate. As there is never a perfect fit between data and methodology, assumptions made in order to be able to implement methodology are also indicated.

Limitations regarding the sample/population, measurements and analysis techniques are discussed in the following section. It is discussed where methodology or implementation problems exist and how this can affect the validity of the outcomes. The steps taken to reduce these limitations are posed here.

The last sections discuss the evaluation criteria and how this research manages to cope with these. It also acknowledges ethical risk in the study and presents how it can be ensured that these risks are minimised.

After summarising the research design, the conclusion links the problem statement to the strategies chosen during this chapter. Furthermore, the reader is prepared for the next chapter.

3.2 Research design

In choosing a fitting research design the books of Bryman (2008) and Blumberg et al. (2011) were used. The design has to be structured in such a way that research can effectively answer the research question posed. In this case the relative efficiency of European LNG import terminals has to be measured, after which an attempt can be made to explain any possible differences therein. The following structure will support the research in the best possible way.

3.2.1 Philosophy

"Research is based on reasoning (theory) and observations (data or information)" (Blumberg et al., 2011, p. 16). The way these relate is determined by the *research philosophy*, which can be either *positivistic* or *interpretivistic*. This research is positivistic, implying that a researcher is independent and looks at the world as an external and objective object. It is observed in a *quantitative* way, reducing it to simple elements, in order to develop knowledge. In this study the researcher is objective, stands free of what he is examining and the world is observed by collecting objective facts. It only focuses on one element of a much larger picture.

The role of theory determines whether the research is *deductive* or *inductive* (Bryman, 2008). This research is deductive, indicating that research is initiated by a theory and that observations are used to measure this theory. In this study research follows the deductive process of constructing hypotheses (or hypothesis) around a certain theory. Data collection will result in findings related to these hypotheses, supporting or rejecting them. The outcome of these hypotheses can be used in evaluating, and if necessary revising, the existing theory.

Related to these aspects is the research strategy, which can be quantitative or *qualitative*. Quantitative research is often based on measurement, through quantification of data. Qualitative research is less focussed on quantification and more on general observation. In this study research combines both strategies. This research although mainly quantitative, is likely to use some qualitative aspects, making it a mixed methods research. Most data will be quantitative in form and the methods applied will also. However, additional qualitative information might be gathered in the form of unstructured interviews for example.

3.2.2 Design

Blumberg et al. (2011) discuss a set of descriptors which distinguish the research design. These descriptors will be discussed and related to this research.

The first aspect is the degree of *research question crystallisation*. There are two options, being *exploratory* or *formal*. This research is a formal study, as it aims at illustrating a current situation and setting up a hypothesis around this. A hypothesis is constructed in order to identify efficiency differences. Findings can contribute to knowledge of the current situation, regarding LNG import terminals.

The second aspect is the method of data collection. Data can be collected through *monitoring*, *communicating* or by using *archival sources*. This research uses archival sources. The researcher does not collect data, but uses readily available data. More about data collection will be discussed in 3.4.

The third aspect is the power the researcher has to control variables. This is determined by the choice for an *experimental* or *ex-post facto* design. This research has an ex-post facto design, implying that the researcher is not able to manipulate or influence the variables. Doing so would produce biased results. In this case the variables, which will be discussed later, consist of constant data. A choice which of these could (!) change, has to be made, but they are not actually changed.

The fourth aspect is the purpose of the study. Studies can aim at describing the current situation or at explaining relationships among variables. For this research this is hard to say. In first instance more has to become clear about efficiency, and differences herein between terminals. Once these are clear it is examined why these differences exist, by looking at the included variables. It, therefore, seems as if aspects of both methods are incorporated into this research.

The fifth aspect is the time dimension. There are cross-sectional and *longitudinal* studies. This research is cross-sectional, indicating that the study is carried out at one point in time and, therefore, does not indicate changes over time. The observations made, or the data used, is representative for the current state of affairs.

The sixth aspect is the *topical scope* of the research. The depth of the study is influenced by the choice for a *case* or *statistical study*. This research actually uses both. In first instance a statistical, and broad, study will be done to measure and compare LNG import terminal efficiency in a quantitative manner. No samples, but the complete population of European import terminals will be included. Once the hypothesis is tested and evaluated, a simplified case study can be added. First efficiency differences will try to be determined by looking at the variables included in the model. However, a case study might be able to provide additional relevant information that is not apparent from the statistics.

The final aspect is the environment in which the research takes place. This environment can be real, manipulated or artificial. This research consists of simulations, in which artificially created models represent actual situations. The mathematical model of the DEA is used to measure relative technical efficiencies. These efficiencies are representations as they don't measure absolute efficiency.

In summary, the research philosophy is deductive and positivistic in nature. It will be a formal study, collecting data from archival sources. The researcher is not able to influence the variables and the measurements are made at one given point in time. The purpose of the study is a mix of descriptive and causal elements. It will start with a statistical study, using mathematical simulations (DEA) to test the hypothesis. In determining the explanatory factors behind possible efficiency differences a (very basic) case study can be applied.

3.3 Sampling design

The research question posed, tries to measure relative terminal efficiency among LNG import terminals in Europe. This question will make inferences about a collection of subjects, in this case LNG import terminals (Blumberg et al., 2011). The scope of terminals included has been discussed in the introduction and is limited to European LNG import terminals. For these reasons, the *population* of this study will be the collection of all LNG import terminals in Europe. Quantitative data often takes *samples* as these can be representative for the complete population. Doing so saves time and money and can simultaneously increase the accuracy of the results. There are multiple methods of doing such samples, of which the convenience sampling methods is chosen in this case. The method is easy and fast in use, but is also less reliable than many other methods. The reason for this method is that there are (only) 25 operational LNG import terminals in Europe (Gas LNG Europe, 2014), making samples unrepresentative for the entire population. The whole population can be included in the study, but certain terminals (due to data unavailability for example) will probably need to be excluded. Choices as to which terminals to include are, therefore, based upon matters of convenience.

It must also be noted that the research question, and the methods used to answer this, do not seek general conclusions. The study aims at analysing the relative efficiency of specific LNG terminals. The methods, which will be discussed below, describe a group of specific (European) terminals and findings are therefore not representative for other LNG import terminals (in the US for example).

3.4 Data collection

3.4.1 Collection process

To measure the relative efficiency of LNG import terminals DEA will be implemented. This model measures relative efficiency among a set of units based on similar sets of inputs and outputs (Coelli, 2008). Inputs and outputs, which in this case are not necessarily related to the production process (W. Cook, Tone, & Zhu, 2014), must, therefore, be collected. Although DEA is capable of including qualitative data (Golany & Roll, 1989), the information required in this case will consist of quantitative data. Due to the commercially sensitive nature of input and output data regarding LNG import terminals, the methods of collection and access to data will be restricted.

Although there are multiple sources that provide information on LNG import terminals, most of which require payments, the databases of *Zeus Intelligence* and *GLE* (Gas LNG Europe) are chosen. Zeus Intelligence has a database called the *World LNG Trade Database*. This database contains information on liquefaction plants, regasification plants, shipping fleets, industry participants and other related information (Zeus Intelligence, 2014). Fortunately *GIE* (Gas Infrastructure Europe), together with its subdivision GLE, have developed multiple (freely accessible) maps and datasets containing data on transmission pipeline capacities, storage locations and capacities, LNG terminals (including small-scale terminals), current levels of gas supplies and new LNG services (bunkering for example). As the name suggests this data only focuses on the European LNG market (Gas LNG Europe, 2014).

GLE's LNG map and dataset can be used for this research. Through information provided by GLE members the dataset contains, otherwise inaccessible information, about existing, planned and LNG terminals under construction in Europe. For each terminal it indicates *maximum hourly capacity*, *nominal annual capacity*, LNG storage capacity, number of tanks, maximum ship class size receivable, number of jetties, sea depth alongside, *maximum sendout pressure* and information on additional services (like reloading). It also indicates planned expansions and how these will influence figures. This data can provide useful insights into the outputs of LNG import terminals in Europe. To do the same for inputs, more information is needed, however.

In order to add to the data available in the GLE datasets, a subscription to the Zeus Intelligence database is made. This database also provides valuable information on LNG import terminals. The information on capital costs and further details regarding equipment and capacity/utilisation rates is especially valuable towards collecting information for the DEA.

3.4.2 Secondary data

Advantages of using *secondary data* are, that one does not need to collect data and thus saves time and that it is often of good quality, as it is mostly gathered by well-known institutions (Blumberg et al., 2011). However, the accessibility of such sources is often restricted by payment. The main disadvantage of secondary data is that it is not gathered for the purpose the research will use it for and, therefore, it needs to be modified. The data can be insufficient to answer the question posed, it can address alternative units of analysis and it might be outdated.

In collecting data for the DEA the GLE dataset and the Zeus Intelligence dataset provided secondary information regarding LNG import terminals. Using these databases saved time and contained information that would otherwise be inaccessible. Unfortunately the GLE dataset alone proved to be insufficient towards conducting the analysis and, therefore, the costly Zeus Intelligence database had to be addressed.

3.4.3 Secondary sources

Secondary data can originate from multiple sources in a wide variety of types. According to Blumberg et al. (2011) these forms can be distinguished by their origin and form. Data can be internally or externally gathered and can be in written or electronic form.

The databases used in this research are both electronic secondary sources. The GLE dataset is in a *Microsoft Excel* file, whilst the Zeus Intelligence data is presented in a *web-based dropdown menu*. Combining these two sources is troubled by the fact that data is presented in two different ways. Effort has to be put into creating a uniform dataset. The data is collected by institutions, both of which are external to the current research. Both sources are not the result of prior studies, but more a means of informing interested parties. However, as the Zeus Intelligence database requires a payment it can be seen as a commercial source.

Concluding, in measuring relative efficiency among LNG import terminals in Europe, secondary sources will provide the larger part of the data. These secondary sources contain information otherwise inaccessible and too time-consuming to collect. There are multiple sources for relevant information, but the larger part of them requires payments. The GLE dataset is an exception to this, but the information provided is not sufficient to run a DEA on. Therefore a subscription to the Zeus Intelligence database was established. This database added to the information from the GLE database, especially regarding the inputs for the DEA. Unfortunately effort had to be put into creating a uniform dataset containing information from both sources.

3.5 Measurements

3.5.1 Quality concession

The databases used in this research contain vast amounts of information about LNG import terminals. In determining the efficiency of these terminals, by using a DEA, not all of this information will be used. It is, therefore, important to distinguish which data to consider and which not. When preparing the actual analysis a more thorough data selection will take place, but prior to this, as much (possibly) related information as possible is gathered. Appendix 6 includes a list of variables that resulted from this initial search. The collection of these variables is subject to the researcher’s interpretation of what is relevant for the measurement of terminal efficiency.

In addition, the datasets alone were insufficient and, therefore, had to be merged. This merged dataset had to be constructed manually, by importing data from both datasets. To maintain comparability the information used for each variable was extracted from the source containing the most complete data on this variable. Multiple sources, containing their own set of assumptions and methods of measurement, will decrease the quality in the data used. Appendix 7 indicates which sources were used for each variable.

For certain variables, like *surface area* and capital costs, even after merging the two datasets, information was scarce. Additional secondary sources had to be addressed in order to complete the database. This further decreases the quality of the database. Using multiple sources for capital costs increases the possibility that the figures adding up to these costs are calculated in different ways. For surface area, which seems more straightforward, similar issues exist, however. Despite quality compromises, data on these variables was collected and included in the dataset. As both have a substantial amount of sources these are addressed in Appendix 8.

Through secondary sources and measurement tools it was possible to gain knowledge about the surface area of all terminals. Data on capital costs proved more troublesome. There are multiple reasons that could account for this. The information can be commercially sensitive, it can be too complex to calculate into one single figure, it is not deemed important for the public (possibly when a terminal is not state-owned) or it is only partially available. The last reason was encountered multiple times, information about certain expansions was available whilst data on earlier investments was not. For a combination of these reasons, despite all possible efforts to collect the information from any source possible, the data on capital costs could not be completed. Fortunately this was only the case for a small set of terminals, and, therefore, these terminals were excluded from the dataset. Appendix 9 indicates which data was obsolete and which terminals were excluded as a result.

3.5.2 Assumptions

Apart from these concessions a set of assumptions was made regarding the remaining data, some more straightforward than others. As the research focuses on LNG import terminals in Europe, data was logically only collected on European (only relevant for the Zeus Intelligence database) import terminals. Because the research wants to get an overview of the efficiency (differences) of current European terminals, data was only collected on existing and operational terminals. Data was also available for planned, or terminals under construction, but this was less relevant and also often incomplete. Especially data on capital costs is not available before completion.

The capital costs variable was assumed to consist of investments in the building, or expansion, of a terminal. These costs have been discussed in the literature review, but due to their confidential nature they are (mostly) not specified to that detail. For this reason investment costs are often stated as lump sums, and these are used as input for this analysis. After construction, and between expansions, costs are also made in maintaining or improving the terminal in smaller aspects, like dredging, but for the sake of calculation (and data availability reasons) these costs were not incorporated into capital costs. There were also differences in the currency the investments were stated in. In order to make the data comparable this was all converted into Euros. And to keep currency rates in mind, the historical conversion rates (X-Rates, 2014) of (1 January) of the year the terminal was commissioned were used.

Measurement of surface area, despite coming from multiple sources, is relatively straightforward. In the cases of the offshore terminals some assumptions must be made, however. For these terminals the surface area is measured by the dimensions of the vessel or pontoon they are built upon. However, the Energy Bridge uses a land connected jetty to unload gas at Teesport (J. Cook, 2006), whilst the FSRU and GBS are moored to the seabed and have subsea pipes running from them (Tugnoli et al., 2010; Wijngaarden, 2004). These connections are excluded from surface area calculations, for ease of calculation, just as jetties are excluded from the land based terminals. The surface area of the offshore terminals is assumed to be 1.5 hectare, an average size estimate, from which size differences are minimal (Marine Traffic, 2014; Waters, Mueller, Hellen, & Hurst, 2007).

The final decision was to exclude small-scale terminals from the dataset. The technology in these terminals is believed to be structurally different from the other terminals in the dataset, that comparing these would be like comparing apples and pears. As a result, despite being import terminals, these are excluded from the efficiency measurements.

Thus, in first instance as much information as possible regarding LNG import terminals, is collected. The inclusion of variables is subject to the researchers choice of what is deemed relevant. In addition, multiple sources have to be combined to construct a complete dataset. Merging of data has the risk of including similar data measured in different ways. Especially data on surface area and capital costs proved to be difficult to measure. Multiple resources were, therefore, addressed, adding to this abovementioned risk. In addition a set of assumptions was made. Data was only collected about operational European LNG import terminals, not including small-scale terminals. Measurements of capital costs were also simplified to construction and expansion investments. Finally, some assumptions regarding the surface area of offshore terminals were necessary.

3.6 Data analysis

Since the CCR model was introduced in 1978 a great number of altered DEA models have arisen (Cooper et al., 2007). It falls outside the scope of this thesis to discuss all these models individually. Therefore the determinants leading to, and distinguishing the models will be discussed. The vast amount of models can be distinguished by the type of inputs and outputs, the orientation, the efficiency and the *returns to scale* (RTS). The most common models will be addressed, and the choice for the model relevant for this thesis will be discussed in the following assumptions section.

3.6.1 Inputs and outputs

The variables in DEA exist of input or output factors. One of the befits of the DEA is that it can measure efficiency when using multiple inputs and outputs, without having to weigh each variable (Charnes et al., 1978). However, this makes the analysis sensitive to the variables selected (Madhanagopal & Chandrasekaran, 2014). There are no predetermined methods of selecting variables and this degree of freedom has given rise to a vast array of variable selection methods.

Although researchers would prefer including as many variables as possible, this is not recommendable. It is believed (Golany & Roll, 1989) that twice the sum of the number of inputs (s) and outputs (m) should not exceed the number of decision making units, or DMUs, (n). This is indicated as $n \geq 2 * (s + m)$. There is some discussion about this as others (Banker, Charnes, Cooper, Swarts, & Thomas, 1989) believe that three times the sum of $(s + m)$ should not exceed (n), indicated as $n \geq 3 * (s + m)$. Although there is no imperative or statistical reason behind this empirical rule, it is imposed as it is believed that discriminatory power decreases with an increase of variables (W. Cook, Tone, et al., 2014). This loss in discriminatory power will eventually result in a (too) high number of DMU's being regarded as efficient, thereby making the analysis less relevant. In addition to this empirical rule, it is difficult to find available data on all these variables, especially with a large number of DMUs. Including irrelevant variables, excluding relevant ones and the resulting misspecification of DMUs have a large impact on the outcome of the analysis (Galagedera & Silvapulle, 2003).

As mentioned before, there are multiple selection methods to prevent these problems. The selection of relevant variables can be done according to their contribution to efficiency (Pastor, Ruiz, & Sirvent, 2002), their *statistical significance* (Ruggiero, 2005), the removal of highly correlated variables (Jenkins & Anderson, 2003) and many more (Edirisinghe & Zhang, 2007; Madhanagopal & Chandrasekaran, 2014; Morita & Avkiran, 2009; Morita & Haba, 2005).

Among the relevant and right amount of variables, a distinction can be made between *standard*, *non-discretionary* and *non-controllable* variables. Standard is perhaps the incorrect naming of this category of variables, but it originates from the fact that they are controllable and discretionary and thus standard compared to the other two categories. Apart from the variables that are internal to the (production) process, there are also contextual (controllable) variables which are external but may affect the efficiency nevertheless (Banker & Natarajan, 2008). Categorical variables, which come in the form of a predefined set of discrete values, which require special DEA models also exist (Banker & Morey, 1986*b*). An extension of these types of variables are ordinal variables, which are ranked in a specific order, and also need special treatment (W. Cook, Kress, & Seiford, 2014).

Apart from standard variables there are also non-controllable variables. These are variables that cannot be controlled and often indicate the impact of the operating environment (H. Yang & Pollitt, 2009). It extends traditional thinking by understanding that inefficiencies can also be caused by factors that lie outside the reach of DMUs. These external variables thus influence the capability of DMUs to increase outputs and decrease inputs (Medina-Borja, 2002). They do not however, count towards the efficiency score of the DMUs, and are not allowed to have *non-zero slacks* (excess input or shortage in output after the proportional change in the input or the outputs).

Finally, there are the non-discretionary variables. These variables are also non-controllable, *exogenously fixed* and they do not contribute towards efficiency scores (Lotfi & Jahanshahloo, 2007). The major difference with non-controllable variables is that non-discretionary variables are allowed to have non-zero slacks. As it is believed that these variables, together with discretionary variables, do actually influence a DMU's outputs (Ruggiero, 2004), there are proposed methods of incorporating these variables.

When incorporating the inputs and outputs into a DEA model, it must be decided discretely which type of variables they are and how this determines which model should be used.

3.6.2 Orientation

Efficiency is measured through a wide array of DEA models, as discussed before. These models can roughly be divided into oriented (input or output oriented) and non-oriented. The orientation of a model determines if inputs, outputs or both are changed in order for a DMU to move towards the efficiency frontier. The oriented models will be discussed first, followed by the non-oriented model.

Oriented models can be either *input* or *output oriented*. The orientation determines how observed units, or DMUs, are valued compared to the efficiency boundary. DEA originates out of a input reducing, currently named input oriented, environment (Coelli, 2008). An input oriented DEA determines how a DMU could efficiently decrease its inputs whilst keeping outputs constant (Pascoe, Kirkley, Greboval, & Morrison-Paul, 2003). In output oriented DEAs an inefficient DMU is made efficient through an increase of outputs, whilst the inputs are held constant. Therefore, output oriented models are similar to production functions, which follow similar optimisation characteristics (Fare, Grosskopf, & Lovell, 1994).

The third possibility is *non-oriented* DEA models. Where oriented models change inputs or outputs, non-oriented models can change both simultaneously (Portela et al., 2003). Determining whether the input or output factors are going to be changed when seeking efficiency seems unrealistic, as often both sides have to be adapted (Chambers & Mitchell, 2001). Non-oriented DEAs provide more freedom to seek efficiency in such a manner and are, therefore, deemed more realistic. However, actually moving towards this efficiency frontier is more troublesome in this setup.

Choosing an orientation thus depends on the variables you want to increase or decrease in the goal of moving towards efficiency. The importance of choosing the correct orientation is questioned, as it is proven that choices will only affect the efficiency scores lightly (Coelli & Perelman, 1999).

3.6.3 Efficiency

DEA measures the efficiency of DMUs relative to each other. Each DMU is compared to the best practice frontier of the group (Ruggiero, 1996). However, efficiency is a wide concept of which there are multiple variants related to DEA. The most common variants will be discussed, after which an indication of the efficiencies relevant for choosing the correct DEA model will be presented.

Bhagavath (2006) and Sherman & Zhu (2006) clearly distinguish and discuss most common variants of efficiency. The most commonly used measure of efficiency is technical efficiency (Khai & Yabe, 2011). Technical efficiency as developed by Farrell (1957), represents the ability of a DMU to transfer physical inputs into outputs. It hereby ignores scale differences, and only compares efficiency according to *best practice*. Absolute efficiency represents best practice, meaning that inputs are optimally utilised towards producing outputs. Best practice is indicated as being 100 percent technically efficient, whilst lower levels are indicated as a percentage of best practice. Technical efficiency is measured according to the BCC model, by Banker, Charnes & Cooper (1984). Efficiency is influenced by technology, production processes, management and the scale of the DMU. Scale efficiency is another commonly used measure. Scale refers to the size of DMUs, or their operations, and indicates if it is possible to increase efficiency as a result of scale optimisation. If a DMU is scale efficient, any alteration to its size will decrease its efficiency. As with other efficiencies these DMUs will be on the efficiency frontier. With scale efficiency this is somewhat more complex, as returns to scale (which will be discussed in more detail later) play a role along this frontier (Ruggiero, 2011). The *most productive scale size* (MPSS) indicates the technical efficiency of DMUs along the constant returns to scale frontier (Banker et al., 1984). Scale inefficiency refers to DMUs on variable returns to scale (increasing or decreasing) frontiers not being optimally efficient. Scale efficiency thus measures the distance to the most efficient scale size, under constant returns to scale. This is measured by the ratio of aggregate efficiency, efficiency under constant returns to scale (which is the CCR model), over technical efficiency, efficiency under variable returns to scale according to the BCC model (Emrouznejad, 2012*a*). As there are often multiple inputs and outputs involved in DEA, inefficiencies can also result from the wrong mix or proportions of inputs. This has to do with the allocative efficiency of DMUs. The price of inputs (given) is added to the equation, as technically efficient DMUs can still be inefficient if their mix of inputs does not minimise their costs, for producing their outputs. Finally there are also measures of price or cost efficiency. DMUs are cost efficient when they are both technically and allocatively efficient. By multiplying these two efficiencies one can determine the cost efficiency (in percentage) of a DMU.

In choosing the correct DEA model there are, however, two efficiencies, or inefficiencies: *technical* and *mixed*. Technical efficiencies have been discussed before, and can be improved by changing either the inputs or outputs, depending on the orientation. Mixed efficiency was introduced by Tone (2001) with the *slack based model* (SBM). The difference with mixed efficiencies is that mixed efficiencies can only be improved by changing the mix of the multiple inputs and outputs, whilst these proportions do not need to be changed in case of technical inefficiencies.

3.6.4 Returns to scale

Constant returns to scale

The DEA models initiated by Farrell (1957) and established by Cooper et al. (1978) measured efficiency among DMUs under constant returns to scale. Under constant returns to scale, a proportionate increase in inputs results in similarly proportionate increases in output levels. Twice as many inputs should thus result in twice as many outputs. The goal of a DEA is to create a frontier on, or under, which all DMUs lie. In order to understand a DEA the mathematics of a constant returns to scale (CRS) model will be discussed (Coelli, 2008). In such a DEA there are K inputs and M outputs for each DMU (n). For the DMU_i these are indicated as vectors x_i and y_i. The DEA is continued in ratio form, creating a ratio of outputs of inputs. This is indicated by $(u'y_i)/(v'x_i)$, where u and v are vectors of output weights of outputs and inputs respectively. The optimal weights can be calculated with the following mathematical programming problem:

$$max_{u,v}\ (u'y_i)/(v'x_i)$$

Subject to:

$$(u'y_j)/(v'x_j) \leq 1, j = 1,2, \dots , N$$

$$u, v \geq 0$$

In finding the maximised DMUs two constraints are imposed. One in which all efficiency measures should not exceed one and the other, to narrow the number of solutions, is $v'x_i = 1$. This creates a new problem, which is known as the *multiplier form*:

$$min_{\theta,\lambda}\theta$$

Subject to:

$$-y_i + Y\lambda \geq 0$$

$$\theta x_i - X\lambda \geq 0$$

$$\lambda \geq 0$$

An envelopment form can be created, using the *duality* in linear programming, which contains fewer constraints and is easier to solve. It produces θ, the efficiency score for DMU_i. This value has to be 1, being technically efficient, or lower (Farrell, 1957). To collect information on θ for each DMU this process has to be repeated.

Variable returns to scale

In a situation of variable returns to scale an increase in inputs results in non-proportional changes in output levels. In expansion to earlier DEA models, Banker et al. (1984) developed a model capable of measuring efficiencies under such returns to scale. The *variable returns to scale* (VRS) model has to include scale efficiencies, as DMUs are not all operating at optimal scale (Coelli, 2008). This can be done by including a convexity constraint to the CRS model:

$$min_{\theta,\lambda}\theta$$

Subject to:

$$-y_i + Y\lambda \geq 0$$

$$\theta x_i - X\lambda \geq 0$$

$$\lambda \geq 0$$

And now also:

$$N1'\lambda = 1$$

This creates an area that surrounds the DMUs more restrictively than the CRS model, therefore giving efficiency scores at least as high as the CRS ones.

Increasing and decreasing returns to scale

Variable returns to scale can be subdivided into *increasing returns to scale* (IRS) and *decreasing returns to scale* (DRS). If a DMU increases its inputs proportionally and this is followed by a greater (or less) than proportionate increase in outputs this happens under increasing (or decreasing) returns to scale. In order to determine whether the DMUs are operating under increasing or decreasing returns to scale multiple steps have to be added to the problems mentioned under CRS and VRS (Coelli, 2008). In first instance scale inefficiencies can be recognised by comparing the outcomes of a CRS and VRS model. The difference in the outcomes can be appointed to scale inefficiencies, thereby setting the difference apart from the technical efficiencies of the DMUs. However, this does not determine under which returns to scale the DMUs are operating. A second step, adding a *non-increasing returns to scale* (NIRS) model to the calculations can help in this. The VRS model is adapted by removing:

$$N1'\lambda = 1$$

and implementing:

$$N1'\lambda \leq 1$$

The technical efficiency scores of this model are compared with the VRS outcomes to determine whether a DMU is under increasing or decreasing returns to scale. If the scores are the same this means they are under decreasing returns to scale, if they differ increasing returns to scale exist.

Whether the models are input or output oriented does not affect the frontier they produce, this stays the same resulting in similar efficient DMUs. The technical inefficiencies, of non-efficient DMUs, will differ under VRS, however. As mentioned before, the choice of orientation only has minor effect on the scores (Coelli & Perelman, 1999).

Generalised returns to scale

The final, and most recently introduced, returns to scale is the *generalised returns to scale* (GRS). This GRS was implemented in the *generalised DEA* (GDEA) by Yun et al. (1999, 2001). This model can be incorporated into all basic models. The model makes it possible to measure efficiency whilst taking various preference structures of decision makers into account (Yun, Nakayama, & Tanino, 2002). The admissible range permitted for returns to scale can be controlled by values L and U (Cooper et al., 2007), in the case:

$$0 \leq L \leq 1, U \geq 1$$

This indicates that returns to scale can decrease by proportions from zero to one and increase by proportions larger than one. The convexity constraint introduced in the BCC model can thus be relaxed.

Only small amounts of literature have been produced regarding the generalised returns to scale, and the accompanying models. Nevertheless it should not be excluded in determining which model to choose.

3.6.5 Additional models

In choosing the correct model to structure a DEA there are thus three choices that have to be made: the orientation, the efficiency and the returns to scale. Keeping these choices in mind, there are nearly 40 possible models that become available (Appendix 10). These models eventually stem from the five basic DEA models, namely: CCR, BCC, SBM, non-discretionary and non-controllable models. The CCR and the BCC have already been discussed and are, therefore, excluded from the following part discussing the (remaining) basic possible DEA models.

Slack based model

The CCR and BCC model are both radial, or oriented, keeping either inputs or outputs fixed whilst changing the other. The additive model, attributed to Charnes et al. (1985), is non-oriented and allows simultaneous movements. The focus lies on input and output slacks, which the CCR and BCC model do not take into account. Slacks, as mentioned before, are excess input or shortage in output after the proportional change in the input or the outputs. A pitfall of this additive measure is that it only focuses on the sum of slacks, which in most cases does not say anything about inefficiency of DMUs (W. Cook & Seiford, 2009). The additive model only indicates which DMUs are efficient or inefficient and it is unable to present any depth in these inefficiencies.

The slack based model, introduced by Tone (2001), adds to the additive model by satisfying properties as unit invariance and monotone regarding slacks. In addition, the slack based model is able to cope with input or output orientation, even though it is originally a non-oriented measure. The model seeks to maximise profit instead of the maximum ratio (output over input), the other models seek. Despite this alternative focus, an advantage of the model is that it can adapt to different returns to scale, or as mentioned, orientations.

The slack based model thus has the advantage that it can function as non-oriented and that it can determine mixed efficiency, both under multiple returns to scale, thereby being very flexible. The downside is, that it is not capable of indicating the levels of inefficiencies of DMUs.

Non-discretionary and non-controllable models

As mentioned before, non-discretionary and non-controllable variables are not under direct control of management (W. Cook & Seiford, 2009). In order to account for such variables alternative DEA models have been established.

Ruggiero (2007), who is actively involved in establishing and modifying these models, discusses how these models followed each other. The first model to allow non-discretionary variables was by Banker & Morey (1986*a*). Ruggiero (1996) introduced a modified version of this, excluding production impossibilities. According to others (Muñiz, Paradi, Ruggiero, & Yang, 2006; Syrjänen, 2004) this model improved estimations of technical efficiency. In order to cope with the inclusion of multiple non-discretionary variables, *multi-stage models* were developed (Ray, 1991). Also to this multi-stage model alternatives were provided, again by Ruggiero (1998), reducing the amount of information required. Further extensions of this multi-stage model were produced by Muñiz (2002), focussing on excess slacks, and Yang & Paradi (2006), using a *handicapping function*, but the multiple stage model by Ruggiero seemed to perform best (Muñiz et al., 2006).

When using these models a distinction between non-discretionary and non-controllable has to be made. Sometimes variables (input or output) have to remain at a fixed level, and comparisons are only to be made between DMUs at these same level, such variables are called non-controllable (W. Cook & Seiford, 2009). The formulas differ from non-discretionary variables, but the methods used remain the same.

In choosing the correct model to use the inclusion of non-discretionary or non-controllable variables has serious effect on the form of the model. A large range of alterations to DEA have been developed, since Banker & Morey introduced possibility to include these variables. Each with their own (dis)advantages (H. Yang & Pollitt, 2009).

3.6.6 OSDEA

There are multiple DEA software available that can do the mathematical calculations towards measuring relative efficiency. One of these is *Open Source DEA* (OSDEA), a free DEA application (Open Source DEA, 2014). The latest version *OSDEA GUI 0.2* can solve the problem, as long as the data is uploaded in *comma separated values* (CSV) format and the abovementioned choices are made. After indicating the variables (and what type they are), orientation, efficiency and returns to scale the software automatically indicates which model is suitable and produces the solution if requested to do so. The solution consists of efficiency scores (objectives), *projections*, *lambdas*, *peer group*, slacks and *weights*. The website provides walkthroughs and background information to get acquainted with the software.

In conclusion, since the introduction of DEA a wide variety of models has been developed. The structure of a DEA model is determined by the variables included, the orientation, the efficiency and the returns to scale. Variables can be standard or non-discretionary or non-controllable. In addition it must be determined whether they are regarded as inputs or outputs. The orientation of a DEA can be input, output or non-oriented. This depends on the variables that are changed in order to move towards efficiency. There are two forms of efficiency, technical and mixed. Where technical changes inputs or outputs, mixed changes the proportion between these. A very important aspect of DEA is the returns to scale of the DMUs. These can be constant, variable (increasing or decreasing) or generalised. From five basic models, nearly 40 versions of these can be distinguished according to the abovementioned factors. OSDEA software can be used to solve the DEA, as long as the right data is uploaded and the settings are chosen according to the researchers needs.

3.7 Methodological assumptions

The previous section has indicated which methodology will be used, what its characteristics are and what choices have to be made in selecting the right DEA model. In this section a choice shall be made according to decisions of each of the four (variables, orientation, efficiency and returns to scale) aspects mentioned before. Based on facts or assumptions each aspect will be discussed, eventually leading to a choice in model.

3.7.1 Variables

From the data collected during the data collection it must be determined which variables are incorporated into the DEA. This is a two-step process, as the first is to determine which variables are included and the second is to indicate whether these are inputs or outputs. In addition any non-discretionary or non-controllable variables must be distinguished. Keeping the empirical rule in mind, that the amount of variables (times two or three) should not exceed the number of DMUs, the amount of variables should best be kept at a low (Banker et al., 1989; Golany & Roll, 1989).

The amount of DMUs accounted for in this DEA equals 15. This means that the amount of variables should not exceed seven. However, as this rule is not statistically grounded this amount is more an indicator than a constraint. Knowing this is the first step, deciding which variables to include, can be made. In determining what to incorporate, it should be kept in mind if, and how, a variable influences efficiency. It is also questioned whether multiple variables are not too strongly correlated, as this would mean that it scores double towards efficiency. The second step is to determine if these variables are used as inputs or outputs in the DEA. Inputs and outputs are not necessarily related to a production process, but are used in measuring efficiency (W. Cook, Tone, et al., 2014; Cooper et al., 2011). In this case inputs should be minimised, whilst outputs should be maximised. Undesirable factors, like pollution, should also be minimized and thus treated as input. The final step is to determine if any of the variables are non-controllable or non-discretionary. These variables, often indicating the exogenously fixed impact of the operating environment, can cause inefficiencies but as they cannot be controlled they do not count towards the efficiency scores. The chosen variables in this DEA are not exogenously fixed and can all be controlled by decision makers. All variables are thus discretionary. A detailed explanation of the chosen variables, how they are distinguished as inputs and outputs and why they are all discretionary is described below.

Inputs

Surface area is measured in hectares. Surface area measures the surface on which LNG import terminals are developed. This area predominantly consists of space for storage tanks, regasification equipment, piping, other facilities and unused space (for safety reasons or potential expansions). This variable is included as proxy for environmental and safety exposure. Terminals present risks and pollute to the environment surrounding them. Risks are leakages and fires for example, whilst pollution can consist of noise or light pollution for example. The surface area constrains a terminal in its size and room for development, in this sense the area should be maximised. But as proxy for environmental and safety exposure surface area should be minimised, as larger terminals present more risks and higher levels of pollution. For this reason the variable is included as an input. Although the area to which a terminal is constrained is determined during the development and construction phase, and, therefore, is rather fixed in its nature, the variable can be seen as discretionary. The variable is not externally determined and although often set in the past, management is able to influence this input. Acquiring or selling ground could be an example of this.

Capital costs are measured in millions of Euros. The literature review already indicates that capital costs are the costs made in order to construct or expand plants or terminal. Regarding LNG terminals these costs are composed mainly of construction, equipment and bulk materials. With regasification terminals the largest part of costs are dedicated to the storage tanks, however, marine facilities are also a large contributor. Capital costs are included as they indicate how much financial inputs are invested in the construction or expansion of an LNG import terminal. Costs will increase when the size of the terminal increases and more expensive equipment and materials have been used. Although higher capital costs can lead to scale benefits, generally speaking terminal developers want to keep these costs at a minimum. Terminals that produce a certain level op outputs and have required less capital costs to do so can be deemed efficient. For this reason capital costs are included as an input. Capital costs are mostly set before construction or expansions, but can deviate from this due to delays or other cost increasing factors. Nevertheless managers are able to determine what levels of capital costs are to be made, indicating that the variable can be seen as discretionary.

Outputs

Unloading capacity is measured in *tonnes* of LNG per annum. Unloading capacity measures the amount of tonnes LNG an import terminal is able to unload from LNG carriers in a year. The capacity is determined by factors like the amount of *jetty heads*, the diameter of the piping and the size of the ships receivable. Larger unloading capacities can result in higher regasification capacities, as long as the storage and regasification equipment is sufficient. This measure is included as unloading is, together with storage and regasification, one of the three main functions of LNG import terminals. The capacity of a terminal to unload LNG carriers indicates the scale at which it operates. Unloading capacity, regasification capacity and storage capacity are closely related and interdependent. Eventually the main function of import terminals is to regasify LNG. As mentioned before, this is determined by, among others, the unloading capacity. Within what is economically and physically possible, a terminal shall always try to maximise their unloading capacity. For this reason this variable is included as an output. In attempts to maximise the unloading capacity of LNG terminals management can decide to alter unloading processes or equipment. The capacity can be changed according to the needs and can be seen as discretionary.

Regasification capacity is measured in *billion cubic meters* (BCM) of gas per annum. Regasification capacity measures the amount of LNG an import terminal is able to regasify into gas per year. It is dependent on the levels of LNG present, which in its turn is dependent on unloading and storage capacity, and the possibility to regasify this LNG. New technologies increase regasification capacities and make the process more efficient. Eventually regasification is the main function of an LNG import terminal, it, therefore, strives to maximise its regasification capacity. Although demand for gas and supplies of LNG influence the need and possibility to regas LNG the terminal wants to maximise its capacity in case of full utilisation. Regasification capacity is, therefore, chosen as output. Choices with respect to regasification equipment, the levels of LNG imported and the sales of gas supplies determine the level of regasification at a terminal. Management is able to influence these factors in trying to maximise regasification capacity, and, therefore, the variable is determined as a discretionary variable.

Maximum sendout capacity is measured in *cubic meters* (or m3) of gas per hour. Maximum sendout capacity, or *peak capacity*, indicates how much gas a LNG import terminals is able to sendout (into the gas network for example) when operating at its maximum capacity. The maximum sendout capacity is called upon in times of sudden demand and is mostly only used for a short period of time. The maximum sendout capacity is, therefore, higher than the average sendout capacity of the terminal. This variable is included as it indicates the performance of a terminal. An up-to-date, high-tech and large terminal is able to sendout more gas and therefore higher sendout levels give an indication of the terminal scale. The maximum sendout capacity of a terminal should be maximised, as this makes it possible to supply as much of the peak demand as quickly as possible. Although the sendout is dependent on the available levels of LNG and the capacity to regasify, higher maximum levels are advantageous. For this reason the variable is believed to be an output. Despite the possibilities of sending out the maximum levels of gas, a terminal may not always choose to do so. Management has the possibility to determine the levels of gas it sends out, according to their preferences. The variable is, thus, seen as a discretionary variable.

Storage capacity is measured in cubic meters of LNG. Storage capacity measures the amount of LNG a regasification terminal is able to store. The storage capacity is fully dependent on the size of the storage tanks. The type and size of tank(s) depends on the average demands for gas and the amounts and size of LNG loads delivered. As storage tanks are the largest cost factor of these terminals, decisions about the most efficient level of storage capacity is of utmost importance. Higher levels of storage capacity make it possible to store more LNG as buffer for any peak demands or high gas prices. However, the high costs of the tanks have to be compensated by sales, thus idle or empty storage tanks are not profitable. Despite the financial considerations, it is assumed that terminals want to increase their storage capacity as this makes the provision of LNG during high demands possible and simultaneously makes it possible for large supplies to be delivered. Storage capacity provides flexibility for terminals and should be maximised. It is assumed that storage capacity is an output variable. And although storage capacities are fixed to the size of the tanks, managers are able to determine how much LNG should be stored in a terminal. According to what is economically and operationally most efficient, the maximum capacity can be appointed by management, thereby making the variable discrete.

For this DEA the variables are thus: unloading capacity, regasification capacity, maximum sendout capacity, storage capacity, surface area and capital costs. It is assumed that the last two are inputs whilst the rest are outputs. Also no non-discretionary or non-controllable variables are included in this model.

3.7.2 Orientation

In measuring the efficiency of LNG import terminals it has to be determined whether DMUs can decrease their inefficiencies by decreasing their inputs, increasing their outputs or changing the mix between these two. In this case the inputs are capital costs and surface area, whilst the outputs are unloading-, regasification-, maximum sendout- and storage capacity. Terminals, capital costs and surface area are variables that have a fixed character. Capital costs are *sunk costs* that have been made to construct or renovate the terminal towards its current state. Decision makers cannot reverse these sunk costs (Brealey, Myers, & Allen, 2011). Surface area has similar characteristics. Land acquisitions are also regarded sunk costs, in order to facilitate the terminal towards its current state. It is not possible to decrease this area, unless there was underutilised space. As decreasing input thus seems impossible, the remaining option is to increase outputs. All four outputs are capacities, indicating the terminal's constraints of unloading, regasification, maximum sendout and storage. If a terminal wants to improve its efficiency it should try to increase these capacities. Increasing these capacities can be done by investing in more advanced or larger elements in the LNG receiving structure. Often the original designs have taken such future investments into account (Habibullah, Lardi, & Passmore, 2009).

Thus, as capital costs have already been made there is no possibility to decrease this input and the same counts for surface area. The four outputs in this case have the possibility of being increased, thereby increasing the handling capacity of the LNG terminal. Higher capacities at the fixed input levels will result in efficiency gains. The situation described indicates the DEA shall be output oriented, trying to increase outputs with a fixed set of inputs.

3.7.3 Efficiency

When deciding on which efficiency to measure, there are only two choices. Technical efficiency, which is the goal of most DEA models (Khai & Yabe, 2011), and mixed efficiency. Mixed efficiency originates from the slack based model (Tone, 2001) and allows changes in the proportional relationship between inputs and outputs. As it is decided to implement an output oriented model the simultaneous movements of variables, which is only possible in non-oriented models, is restricted. For this reason the model chosen here will focus on technical efficiency.

3.7.4 Returns to scale

In determining which returns to scale the LNG (import) terminal industry is subject to, it is important to note that the often discussed economies of scale and the returns to scale are not entirely the same (Bell, 1988). Economies of scale focus on a company's cost, whilst returns to scale refer to the production function. There is, however, a situation in which they coincide (Gelles & Mitchell, 1996). As long as using more inputs, like labour or capital expenditure, does not influence their price a situation exists where economies of scale and RTS are linked (Truett & Truett, 1990). Increasing returns to scale are then present if there are economies of scale, whilst decreasing returns to scale are present if *diseconomies of scale* (unit costs increase if size increases) occur. If using more inputs does affect their price then the opposite could apply (Truett & Truett, 1995). In the LNG terminal industry an increase in inputs has the potential to increase the price of these inputs, depending on the size of the project and the context in which it finds itself. For example, a large *greenfield* terminal built in a country like Brazil, can result in the labour prices increasing in that (scarcely populated) area. The LNG terminals in Europe, however, shall have a less drastic effect on the price of inputs, necessary to construct the terminal, as the labour market (for example) is more competitive. It is, for this reason, assumed that an increase in inputs will not influence their price, and thus that increasing returns to scale are present if there are economies of scale.

As the amount of literature on the economics of LNG import terminals is limited, appointing relevant economies of scale should be based on the economics of (LNG) terminals in a broader sense. Historically, economies of scale have been a driving factor in the LNG industry as it is known to be very capital intensive (Grabau, 2013). The industry, both shipping and terminals, are known to have high fixed costs and show economies of scale (Danish Maritime Authority, 2012). These high costs can largely be attributed to infrastructural costs, like storage tanks, jetties, quays and land preparation or dredging. Economies of scale are shown in storage tanks for example, as the costs per unit stored decreases with an increase in tank size (Scarr & Jackson, 2007). As capital costs can vary between 500 million and 1.5 billion dollars per terminal, economies of scale have to be realised in order to achieve realistic costs per unit (Galway Energy Advisors, 2012).

Assuming the industry is competitive and an increase of inputs by a terminal does not result in the price of these inputs becoming higher, IRS are present if the sector shows economies of scale. And although literature does not clearly indicate if LNG import terminals have economies of scale, the LNG industry and terminals in general do present these economics. Keeping this in mind it is assumed that LNG import terminals operate under increasing returns to scale.

3.7.5 Over specification

Having chosen a model, simulations can be run to test the outcomes. The choices (output oriented, increasing returns to scale, technical efficiency and the variables) are indicated in the OSDEA software and after uploading the relevant data the simulation can be implemented. As a result of these test runs it became apparent that the amount of variables, in relation to the amount of DMUs, was too high resulting in more terminals being identified as efficient than inefficient (Appendix 11). This is caused by an over-specified model, as the dataset is not large enough to create a relevant efficiency frontier (Tongzon, 2001). As data availability is already constrained, it is, therefore, decided to remove a variable from the analysis. Removing an input would mean that efficiency is based on only one input, being capital costs or surface area. As this is highly unlikely, it is decided to remove an output. Only when removing maximum sendout capacity as output the problem of over specification (more than seven efficient DMUs) is resolved (Appendix 12). Fortunately regasification capacity and sendout capacity are closely related, both being part of the third (after unloading and storage) performance indicator of regasification terminals (Andrieu, 2013), thus removing one of these is (partially) compensated by the other. Despite the added value of including this variable, the limited dataset forces a removal.

To summarise, from all data collected and discussed during the data collection section, the variables included in the model are chosen to be unloading-, regasification- and storage capacity (as inputs), and surface area and capital costs (as outputs). Maximum sendout capacity was excluded as output since there were too many variables for the amount of DMUs. None of these variables are non-controllable or non-discretionary. The fixed character of the inputs indicates that efficiency can only be improved by increasing outputs, indicating the output orientation of this situation. As only outputs, and not inputs simultaneously, are changed this also implicates the model is measuring technical efficiency. The LNG industry in general shows economies of scale, not much is known about import terminals specifically. However, it is assumed that these also show increasing returns to scale. In conclusion, the model to be chosen in this case is the output oriented variable (increasing) returns to scale model, measuring technical efficiency by using unloading, regasification and storage as inputs, and surface area and capital costs as outputs.

3.8 Limitations

The research question is set up to measure efficiency differences among LNG import terminals. If the methodology and the implementation of this do not contribute to finding these efficiency differences, then the validity of the study can be questioned. Very basically, validity indicates whether a concept is really measured by the measurement of that concept (Bryman, 2008). Incapability to do so indicates limitations of the study. The following limitations were encountered in constructing the study.

In measuring the efficiency of European LNG import terminals the DEA is limited in the sense that it does not calculate absolute efficiency scores, but only indicates the relative efficiency scores. For this research question this is not particularly a problem, but the efficiency scores are dependent on the population of DMUs included. This links to the real first limitation, which is the exclusion of certain LNG import terminals from the population. The small-scale terminals and the terminals with missing data were excluded from the study. By excluding these terminals the measurement does not actually measure the efficiency differences of all European terminals, it actually measures the differences among large-scale terminals with sufficient data. The concept is thus not completely measured, which affects the *content validity*.

As a result of this exclusion, only 15 DMUs remain. The empirical rule, discussed earlier, in order to prevent over-specification of the model, advises to adjust the amount of variables to this number. As a result only a limited amount of variables can be included. Would the amount of DMUs have been bigger, then more variables could have contributed to indicating efficiency differences. *Criterion-related validity* is influenced, as possibly not all of the relevant aspects of the concept are captured.

A third limitation is the OSDEA software used to calculate the efficiency scores. The software is especially time saving, but a negative side effect is that it lacks transparency. Data is uploaded, choices regarding orientation, efficiency and returns to scale are made and the problem is solved accordingly. The process, or mathematics, of this problem is not presented, merely the outcome. The *replicability* is decreased, which affects the *reliability* negatively.

The outcome of the DEA provides insight in efficient and inefficient terminals. Slacks indicate where inefficient terminals are inefficiently using their inputs or outputs. This information can be used in providing an explanation for the (possible) efficiency differences. However, as these slacks are based on the variables included, they only present a limited range of explanations for possible differences. Focussing merely on these slacks would be over-simplifying, therefore, additional research has to be conducted in explaining inefficiencies. This decreases the earlier discussed criterion-related validity.

In conclusion, limitations encountered in sampling, data collection, measurements and the analysis techniques have harmed the validity of this study to a certain extent. As the DEA model only measures relative efficiency, the exclusion of certain terminals, affects the outcome of the analysis. A further effect of this exclusion is that the amount of variables that can be included in the analysis is restricted. Therefore, possibly relevant variables are excluded. As slacks can be used to indicate why certain inefficiencies exist, the exclusion of these variables also limits the degree to which these efficiency differences can be explained. Finally, the software used to conduct the DEA is also limiting in the sense that the mathematical calculations that lie at the basis of this model are not visible. This prevents the researcher from elaborating on this, and makes it possible for others to replicate the calculation.

3.9 Establishing credibility

As already briefly mentioned, there are certain evaluation criteria that a study can be judged upon (Blumberg et al., 2011). The best known criteria are validity and reliability. Reliability can be divided into three criteria: *stability*, *internal reliability* and *inter-observer consistency*. Validity can be divided into *measurement*, *internal*, *external* and *ecological validity*. Measurement validity is deemed most relevant for quantitative research (Bryman, 2008). Apart from these replicability and practicality are also mentioned as evaluation criteria.

In this case the study, despite some limitations mentioned above, can be regarded as valid. The research question is looking for efficiency differences in LNG import terminals and the DEA is a suitable methodology to do so. It indicates relative efficiency scores and through the use of slacks, explanation for inefficiencies can be obtained. Despite the lack in transparency the OSDEA software has the advantage of being extremely consistent in its calculation. As long as the researcher sets it up in the correct manner, there is little room for inconsistencies. This consistency increases reliability and, therefore, contributes to the validity of the study.

In order to secure replicability, the degree to which research is replicable, this methodological chapter has tried to describe all procedures and choices in great detail. Reliability is also increased, if it is clear what choices are made and which procedures are followed. Although there have been some limitations, indicating where these were encountered and how they were dealt with can provide useful information for readers and possibly future researchers.

Whilst the abovementioned mentioned criteria ensure the scientific standards of the study, the practicality of a study must also be ensured (Blumberg et al., 2011). In order for the study to be operationally feasible economics, convenience and interpretability should be kept in mind. Although more data was available, the costs of these databases outweighed the importance of this extra data. One of these paid databases was addressed for the ease of data collection. At that point time was under stress and this was the only way to obtain such data under this constraint. Regarding convenience the DEA, which is quite complex, was simplified by the OSDEA software. This software does the calculations as long as the data is included and a model choice is made. The interpretability of the outcomes provided by this software might be more troublesome, however. For people with little knowledge about this analysis method the outcomes will not provide much information. This stresses the need for a clear presentation and explanation of the results in the chapter that follows.

Despite the limitations presented in the preceding section, this study is relatively valid. The analysis presents outcomes that fit the need of the research question. In addition the OSDEA software, although not so transparent, is consistent and, therefore, reliable. Finally, the chapter has tried to increase the replicability of the study. Regarding the operational requirements, a limit was set to data collection due to economic choices. The convenience of the DEA was improved by the (free) software, which provides results that might be difficult for the average reader to understand. The next chapter, therefore, needs to be clear in what the findings are.

3.10 Ethical considerations

In research there are certain ethics that have to be accounted for. Ethical considerations take place during every decision made. The considerations depend on the type of research implied. Due to the nature of this study, for example, ethical considerations like the rights of participants and sponsors, design standards and safety measurements (Blumberg et al., 2011) are of no concern. In this study the ethics that have to be respected are namely the ethics that are subject to the research community. These ethical considerations can be categorised in various ways, for example into: *carefulness*, *openness*, *objectivity*, *honesty* and *respect towards intellectual property* (Shamoo & Resnik, 2009).

This methodological chapter has already presented some of these considerations. Discussing the sampling methods was one of them. It was discussed how the method of convenience was chosen in order to match the researchers possibilities. Although this decision presents subjectivity, acknowledging this subjectivity safeguards objectivity to certain extent. Furthermore, the chapter contains the discussion of the choice for certain variables and the modifications and assumptions implied. A higher level of openness is created through argumenting these choices, modifications and assumptions. In addition, criticism or remarks by outsiders like Prof. Dr. Acciaro and Mr. Paul Fitton are openly received and incorporated.

It is also important for research to be honest. Data, results and methods have to be complete and true. In this study, for example, the data included originates from well-known sources and is cited accordingly. When this raw data is modified this will be indicated and discussed. The final results and data are treated in a similar fashion. No false data will be produced and the outcome will be free of misrepresentation. Furthermore, insignificant results will not be ignored as this is regarded as significant information nevertheless.

Finally, the study presents carefulness and respect for intellectual property. Plagiarism and the exclusion of quotations and citations is probably the most common and well known unethical handling, especially in academic research. In the case of this research every quotation, citation or inspiration from another source is, therefore, correctly mentioned. By using the reference manager *Mendeley* the study carefully records sources and implements them in the correct fashion. In this case it is chosen to use the *American Psychological Association* (sixth edition) method for citations.

Thus, each research contains various ethical considerations to deal with. This study mainly deals with scientific ethical considerations due to the research design and methodology chosen. So far it is shown how the study, despite some subjective choices, tries to maintain a certain level of objectivity. Also being open about the choice of variables and the measurements and assumptions implied, shows effort of maintaining ethical standards. Furthermore, the outcome of the analysis will be honest and clear of falsification and misrepresentation. Finally, plagiarism will be prevented through a careful way of managing citations.

3.11 Summary methodology

The design of this study will be formal, collecting data from archival sources. The researcher is not able to influence the variables and the measurements represent a snapshot in time. The study, being a mix of descriptive and causal elements, will start with a statistical part, using mathematical simulations (DEA) to test the hypothesis. In determining the explanatory factors behind possible efficiency differences a (simple) case study will be applied.

Data will be collected from secondary sources, mainly from the GLE and Zeus Intelligence datasets and they will be merged into one database by the researcher. This merging poses some quality risk, however. Further, the variables included are subject to the researcher's interpretation of what is deemed important. A set of assumptions is also made, like excluding small-scale terminals and terminals with missing data. Capital costs and surface area data was incomplete and, therefore, needed quite some external information.

With this information a DEA can be run in order to determine what the relative efficiency of LNG import terminals in Europe is. The chosen model is the output oriented variable (increasing) returns to scale model, measuring technical efficiency by using unloading, regasification and storage as outputs and surface area and capital costs as inputs. Maximum sendout capacity was excluded as output since there were too many variables for the amount of DMUs. By uploading the gathered data into OSDEA software, and setting the model to the one described, a solution (the outcome) is provided.

Limitations were the amount of variables that could be included, due to the relatively low amount of DMUs and the resulting exclusion of possibly relevant variables. As slacks can be used to determine what would lead to inefficiencies, excluding these variables might prevent this possibility from being utilized. The OSDEA software, though very reliable, is also not very transparent. However, as the DEA fits the research question the validity of the methodology is believed to be up to standards. By explaining the methodological procedures in this chapter an attempt was made to increase the replicability of this study. Nevertheless the following chapter has the task of clearly explaining the outcome of the DEA, as the results are difficult to interpret for the average reader.

4 Results

4.1 Introduction

The methodological chapter introduced the methods used for data collection and analysis. The selected method of analysis should contribute to determining if there are efficiency differences between European LNG import terminals. If so, it should be determined what could have led to these differences. Data is analysed, predominantly originating from GLE and Zeus Intelligence, through a DEA. The chosen model is the output oriented, variable (increasing) returns to scale model, measuring technical efficiency by using unloading, regasification and storage as outputs and surface area and capital costs as inputs. In addition, this is run in OSDEA software. As mentioned before the software is capable of presenting solutions, as long as the correct data has been uploaded and the accompanying model choice has been made.

The following chapter will start with the findings. After familiarising with the aspects included in the solution of OSDEA, the actual outcome of this analysis will be discussed. Relevant findings, towards the research question, are presented without elaborating on the effects towards this research question. This elaboration will be done in the discussion, where the significance of the findings towards the research question and existing literature are discussed. The chapter finalises by a conclusion, summarising the findings and how these contribute to the research question.

4.2 Findings

4.2.1 Solutions provided

After uploading the relevant data and selecting the appropriate model, OSDEA software calculates and presents the solutions. When creating a DEA problem mathematics are able to provide the researcher with more information than just the efficiency scores. For each problem presented, OSDEA is able to provide the researcher with six explanatory datasheets. Apart from restating the model details, raw data and variables chosen, OSDEA provides the researcher with the objectives, projections, lambdas, peer group, slacks and weights. Depending on the software preferred by the researcher, these outputs can be exported to *Microsoft Office* (Excel) or *Libre Office*. An explanation of the solution objectives, projections, lambdas, peer group (*reference set*), slacks and weights will be provided, after which the solutions of this study will be presented.

The objective values are the first aspect presented by OSDEA. As the objectives are related to the efficiency scores of the DMUs this is also the most informational sheet towards answering the research question. The datasheet presents the DMUs with their matching values $(\varphi/1)$ and indicates if these represent efficiency $((\varphi/1) = 1)$ or not $(0 < (\varphi/1) < 1)$. However, in maximising the outputs the researcher is interested in the efficiency score (φ), which is calculated by $1/\varphi$. Subsequently $\varphi - 1$ gives the proportional increase in outputs that can be achieved by this DMU, at the current input levels (Coelli, 2008). For example, an output oriented objective value $(\varphi/1)$ of 0.8 would result in an efficiency score (φ) of 1.25 $(1/0.8)$. This means that the outputs of this DMU, considering the current inputs, could increase by 25 percent $(1.25 - 1 = 0.25)$. The proportional increase of inefficient DMUs can thus be $1 \leq \varphi < \infty$.

The second aspect presented by OSDEA are the projections. Projections indicate, for inefficient units, the values of the variables if they were efficient. In other words, the maximum outputs, given these inputs. In explaining how these projections can be calculated it is important to know what a peer group or *efficiency reference set* (ERS) is and what their accompanying weights or lambdas (λ) mean. An ERS is the group of efficient DMUs against which an inefficient DMU is found to be most directly inefficient (Sherman & Zhu, 2006). The weights of these DMUs in calculating this inefficiency is indicated by their lambda (λ). The projections of the inefficient DMUs are actually simulated (and efficient) versions of themselves. Their variables (and the matching levels) are composed by aggregating the variables of the reference DMUs. In doing so, the lambdas determine the weight of each reference DMU's variables towards this aggregate. The projections are thus calculated as the sum of the reference DMU's variables multiplied by their respective lambda. An example is provided in Appendix 13 (Table 26). There is an alternative way of calculating projections. In this case the inputs are the original inputs minus the input slacks. The outputs are calculated by multiplying the original outputs by φ (phi) and adding the output slacks.

OSDEA also presents these slacks. Slacks, as already discussed, basically indicate excess inputs or shortage in outputs (more relevant with output orientation) in inefficient DMUs. Slacks are valuable data as they indicate sources of inefficiency. Efficient DMUs don't have slacks, as it is believed that they use all their inputs to produce as much outputs as is possible. Output slacks indicate that even when output is increased by the efficiency score (φ), bringing the DMU on the efficient frontier, it is not completely efficient as best practice shows it is possible to increase outputs even further, given these levels of input. The slacks indicate the missed outputs, given these input levels. If the calculations in the previous paragraph are turned around input slacks are calculated as the difference between the actual input levels and the projected values, thus calculated as (Ozcan, 2008):

$$original\ input\ levels - projected\ input\ levels$$

Output slacks are the difference between the projected values and the original values (multiplied by φ), thus calculated as:

$$projected\ outputs - (original\ outputs * \varphi)$$

Slacks are a valuable part of DEAs as they indicate what leads to inefficiencies and thus what needs to improve, to overcome these inefficiencies.

Finally, the OSDEA presents weights. These weights are not to be mistaken with the lambdas. Weights were incorporated by Charnes, Cooper and Rhodes (Charnes et al., 1978) to allow DMUs to value their inputs and outputs in such a way that they presented these in the best way, compared to other DMUs. Despite these weights maximising a DMU's efficiency, it is possible that other DMUs have higher efficiency levels, resulting in an inefficient score for the lower DMU.

4.2.2 LNG import terminal findings

After reassuring the data and methodological choices are represented in the DEA, OSDEA is requested to perform the calculations and present the solutions. These solutions can be exported to Excel and analysed there. The first three datasheets this document contains are model details, raw data and variables. These have already been discussed in the methodology, but are included in Appendix 14 for reassurance and ease of reading. Before the findings are presented, it must be noted that all following findings have been rounded to four decimals, for ease of reading.

The fourth datasheet, and the first relevant findings, contain information on objective values. Table 1 illustrates these findings. The objective values ($\varphi/1$) are given by OSDEA. The efficiency scores are calculated ($1/\varphi$) and added to these values. Efficiency scores of one indicate efficient terminals, whereas efficiency scores above one indicate inefficient terminals. This is summarised in the last column.

Table 1, Objectives and efficiency scores LNG import terminals Europe (Author).

DMU Name	Objective Value (φ/1)	Efficiency Score (φ)	Efficient
Zeebrugge LNG	0.8207	1.2185	
Fos-Cavaou	0.6930	1.4430	
Adriatic LNG	1	1	Yes
Livorno FSRU	0.8557	1.1686	
Gate LNG	1	1	Yes
Sines LNG	1	1	Yes
Bahia de Bizkaia LNG	0.7625	1.3115	
Sagunto	1	1	Yes
Galician Terminal	0.8877	1.1265	
Marmara Ereglisi	0.7887	1.2679	
Aliaga LNG	0.9302	1.0751	
Grain LNG	1	1	Yes
South Hook LNG	1	1	Yes
Dragon LNG	0.9475	1.0555	
Teesside LNG	1	1	Yes

The table illustrates how seven terminals are efficient, whilst eight are inefficient. The most inefficient LNG import terminal in Europe is Fos-Cavaou, which has an efficiency score of 1.443. As described earlier this indicates that the terminal could produce 43.30 percent more outputs with their current level of inputs. Dragon LNG, however, is only barely inefficient. With an efficiency score of 1.0555 they are only able to increase outputs with 5.55 percent under their current input constraints.

The next datasheet provided by OSDEA contains the projections. These projections are (only) relevant for inefficient terminals as they indicate what values their variables would have had if the terminal had been efficient. Projections of efficient terminals depict their current variable levels and, therefore, need no further explanation. Table 2 presents these projections. The projected output levels of the inefficient terminals all increase according to the efficiency scores of Table 1 and the slacks which will be discussed in Table 4. Logically the most inefficient terminals, like Fos-Cavaou, show the most potential to increase their outputs. The inputs only decrease if there are input slacks present. This is the case for Dragon LNG, where increasing outputs can be accompanied by a decrease in surface area. As discussed in the methodology, questions can be asked whether this is possible. The projections have been explained trough calculations with original output levels, slacks and efficiency scores. But it must not be forgotten that the projections are derived from their peer group and their accompanying lambdas.

Table 2, Projections LNG import terminals Europe (Author).

DMU Name	Unloading Capacity (LNG, tonnes)	Regasification Capacity (Gas, bm3/y)	Storage Capacity (LNG, m3)	Surface Area (Hectare)	Capital Costs (€M)
Zeebrugge LNG	8164010.138	11.3516	543328.6398	32	755
Fos-Cavaou	8379341.435	11.9045	507794.9824	80	430
Adriatic LNG	6500000	7.56	250000	1.5	800
Livorno FSRU	3617647.059	4.7929	157764.7059	1.5	240
Gate LNG	8500000	12	540000	35	800
Sines LNG	5200000	7.9	390000	23	208
Bahia de B.	6517975.998	9.1802	413527.1279	23	510
Sagunto	6800000	8.8	600000	22	535
Galician Terminal	4837733.142	6.3590	337948.924	10	343
Marmara Ereglisi	5466781.842	7.8610	364398.3587	19	323.85
Aliaga LNG	4807244.075	6.4505	301024.097	10	337
Grain LNG	15000000	19.5	1000000	385	1351
South Hook LNG	15600000	21	775000	210	930
Dragon LNG	5804986.15	8.6620	412396.1219	33.8781	250
Teesside LNG	3000000	4.2	138000	1.5	120

The lambdas and peer groups are presented on two separate datasheets, which can easily be shown in one. Table 3 illustrates this unified datasheet. The peer group is the group of efficient DMUs against which an inefficient DMU is found to be most directly inefficient. This amount can vary, Dragon LNG, for example, has two reference DMUs, whilst Aliaga LNG has four. For each of these reference DMUs the lambda is indicated. These lambdas indicate what weight is given to their inputs and outputs before they are combined to form the projected DMUs shown in Table 2. An example of Dragon LNG is given in Appendix 13 (Table 27).

Table 3, Peer groups (and lambdas) of LNG import terminals Europe (Author).

DMU Name	Adriatic	Gate	Sines	Sagunto	Grain	South Hook	Teesside
Zeebrugge	0.0237	0.8065	0	0.1698	0	0	0
Fos-Cavaou	0	0.0035	0.6919	0	0	0.3046	0
Adriatic LNG	1	0	0	0	0	0	0
Livorno FSRU	0.1765	0	0	0	0	0	0.8235
Gate LNG	0	1	0	0	0	0	0
Sines LNG	0	0	1	0	0	0	0
Bahia de B.	0.1827	0.3274	0.4899	0	0	0	0
Sagunto	0	0	0	1	0	0	0
Galician Term.	0.0749	0	0	0.4146	0	0	0.5105
Marmara E.	0.1895	0.0062	0.8043	0	0	0	0
Aliaga LNG	0.1707	0	0.2049	0.1997	0	0	0.4246
Grain LNG	0	0	0	0	1	0	0
South Hook	0	0	0	0	0	1	0
Dragon LNG	0	0	0.9418	0	0	0.0582	0
Teesside LNG	0	0	0	0	0	0	1

Related to the datasheets discussed before, but more informative towards answering the research question, is the datasheet containing the slacks. This datasheet is shown in Table 4. Slacks indicate where DMUs are missing output or using too much inputs. Efficient DMUs therefore do not show any slacks.

Table 4, Slacks among LNG import terminals Europe (Author).

DMU Name	Unloading	Regasification	Storage	Area	Costs
Zeebrugge LNG	0	0.3850	80295.2290	0	0
Fos-Cavaou	154381.526	0	31613.0929	0	0
Adriatic LNG	0	0	0	0	0
Livorno FSRU	403921.5686	0.4106	0	0	0
Gate LNG	0	0	0	0	0
Sines LNG	0	0	0	0	0
Bahia de B. LNG	1272141.272	0	20089.5234	0	0
Sagunto	0	0	0	0	0
Galician Terminal	1796192.826	2.3036	0	0	0
Marmara Ereglisi	141621.1711	0	41085.0322	0	0
Aliaga LNG	399391.2266	0	0	0	0
Grain LNG	0	0	0	0	0
South Hook LNG	0	0	0	0	0
Dragon LNG	0	0.6406	74651.4732	121.1219	0
Teesside LNG	0	0	0	0	0

Table 5, Weights per variable of LNG import terminals Europe (Author).

DMU Name	Unloading	Regasification	Storage	Area	Costs
Zeebrugge LNG	1.49254E-07	0	0	0.0089	0.0005
Fos-Cavaou	0	0.1212	0	0.0057	0.0007
Adriatic LNG	1.53846E-07	0	0	0.0125	0.0008
Livorno FSRU	0	0	7.40741E-06	0.1422	0.0012
Gate LNG	0	0.0602	5.14992E-07	0.0124	0
Sines LNG	0	0	2.5641E-06	0.0230	0.0017
Bahia de B. LNG	0	0.1429	0	0.0189	0.0006
Sagunto	0	0	1.66667E-06	0.0320	0.0003
Galician Terminal	0	0	3.33333E-06	0.0640	0.0005
Marmara Ereglisi	0	0.1613	0	0.0214	0.0007
Aliaga LNG	0	0.1440	4.85691E-07	0.0272	0.0008
Grain LNG	6.38702E-09	0	9.04195E-07	0.0011	0
South Hook LNG	6.41026E-08	0	0	0.0026	0
Dragon LNG	1.81818E-07	0	0	0	0.0026
Teesside LNG	0	0.2381	0	0.0362	0.0012

It was already mentioned that Dragon LNG has input slacks, meaning it excessively uses its surface area. All other inefficient DMUs have output slacks. Most terminals have two slacking outputs, only Aliaga LNG has one. In order to determine which slacks are substantial, their size must be put in context with their original value. A table indicating the slacks over their original levels has been created (Appendix 15) to illustrate this. This table indicates that especially the slacks of Galician Terminal are substantial. The slacks represent over 60 percent of their original level. Other mentionable slacks are the storage capacity of Zeebrugge LNG, Dragon LNG and Marmara Ereglisi and the unloading capacity of Bahia de Bizkaia LNG.

Finally, the last datasheet presented by OSDEA, indicates the weights of each DMU's inputs and outputs so that it scores the highest efficiency possible. These weights are shown in Table 5. All weights are small positive figures to prevent other inputs or outputs from being outweighed (Emrouznejad, 2012*b*). The table shows that even though DMUs are able to appoint weights to their variables, they can still score relatively inefficient.

In conclusion, this section has discussed the findings of the data collection and analysis. The chosen methodology, DEA, has been implemented using OSDEA software. The outcome of this analysis is presented in a document containing multiple datasheets. The first three sheets contain the model details, raw data and variables chosen. The following, and more relevant datasheets are the objectives, projections, lambdas, peer group, slacks and weights. In order to understand these datasheets a short explanation was provided. The first sheet contains objective values which can be adapted to indicate the efficiency scores. The findings show how seven terminals are efficient, whilst eight are inefficient. The most inefficient LNG import terminal in Europe is Fos-Cavaou, which has an efficiency score of 1.4430, indicating the terminal could produce 44.30 percent more outputs with their current level of inputs. The next sheet contains the projections. Projections indicate, for inefficient units, the values of the variables if the DMU was efficient. These projections are calculated by forging the variables, after weighing them according to the given lambda, of reference DMUs. These projections can also be calculated according to the DMU´s slacks and efficiency score. The projected output levels of the inefficient terminals all increase according to their efficiency scores and slacks. The most inefficient terminals, like Fos-Cavaou, show the most potential to increase their outputs. Inputs only decrease if there are input slacks present. This is only the case for Dragon LNG. OSDEA also presents output slacks. Slacks are valuable data as they indicate sources of inefficiency. All inefficient DMUs have output slacks, most have two slacking outputs, only Aliaga LNG has one. By putting these slacks in context with their original values, the size can be determined. This indicates that especially the slacks of Galician Terminal are substantial. The slacks represent over 60 percent of their original level. Other mentionable slacks are the storage capacity of Zeebrugge LNG, Dragon LNG and Marmara Ereglisi and the unloading capacity of Bahia de Bizkaia LNG. Finally, the last datasheet presented by OSDEA, indicates the weights of each DMU's inputs and outputs so that it scores the highest efficiency possible. All weights are small positive figures and despite these weights, terminals can still score relatively inefficiently.

4.3 Discussion

Having presented the outcome of the data analysis, it can be determined how these findings relate to the research question. This section will, therefore, restate the research question and discuss how the findings agree, extend, refine or conflict with it (Schafer, 2014). The research question developed in the introduction stated:

Are there substantial efficiency differences among LNG import terminals in Europe, and if so, how can they be explained?

The first question to answer is, therefore, if there are any substantial efficiency differences among LNG import terminals in Europe. Subsequently any possible differences will be explained.

4.3.1 Efficiency differences

Objectives

According to the DEA findings eight of the 15 DMUs are regarded to be relatively inefficient (Table 1), the remaining seven terminals are thus relatively efficient. The efficient terminals all score one, and can therefore not be distinguished from each other. However, it is not said that these do not present any inefficiencies, but compared to the other terminals these inefficiencies are not clear enough (Sherman & Zhu, 2006). Among the inefficient terminals these inefficiencies can be distinguished. Here it is apparent that seven of the eight terminals present the possibility to increase outputs between 5.5 and 31.1 percent, but that one (Fos-Cavaou) could increase this by as much as 44.3 percent. According to these figures clear efficiency differences exist among European LNG import terminals.

Table 6, Relationship country and efficiency (Author).

DMU Name	Country	Objective Value	Efficiency Score
Adriatic LNG	Italy	1	1
Grain LNG	United Kingdom	1	1
South Hook LNG	United Kingdom	1	1
Sines LNG	Portugal	1	1
Sagunto	Spain	1	1
Teesside LNG	United Kingdom	1	1
Gate LNG	Netherlands	1	1
Dragon LNG	United Kingdom	0.9475	1.0555
Aliaga LNG	Turkey	0.9302	1.0751
Galician Terminal	Spain	0.8877	1.1265
Livorno FSRU	Italy	0.8557	1.1686
Zeebrugge LNG	Belgium	0.8207	1.2185
Marmara Ereglisi	Turkey	0.7887	1.2679
Bahia de Bizkaia LNG	Spain	0.7625	1.3115
Fos-Cavaou	France	0.6930	1.4430

It is difficult to appoint the efficiency differences to certain countries as some countries only have one terminal whilst others have more (Table 6). From the countries that only have one terminal (in this dataset) the Netherlands and Portugal have efficient terminals, whereas France has an inefficient terminal. Among the countries with multiple terminals only Turkey merely has inefficient terminals, all other countries have at least one efficient and one inefficient terminal. Therefore, when looking at efficiency differences among countries, the only distinguishable fact is that Turkey only has inefficient terminals.

A more clear relation lies between annual unloading capacity and efficiency. The four largest LNG import terminals, when looking at annual unloading capacity (Table 7), all score efficient. This indicates that terminals with large unloading capacities are more likely to be efficient. This is even more eminent when looking at storage capacity (Table 8). In this case the five largest terminals, regarding storage capacity, are all efficient. Apart from two offshore terminals, which have relatively low storage capacity but score efficient nevertheless, all smaller terminals score inefficient. It would be logical if the last output, regasification capacity, would show similar trends. And the three largest regasifying terminals do indeed score efficient (Table 9), but the remaining four efficient terminals are equally distributed over the rest of the regasification capacities (sizes). Thus this output is less convincing in this fashion. Nevertheless, when relating efficiency scores to outputs, there is a trend that higher outputs result in more efficient terminals.

Table 7, Relationship unloading capacity and efficiency (Author).

DMU Name	Unloading	Objective Value	Efficiency Score
South Hook LNG	15600000	1	1
Grain LNG	15000000	1	1
Gate LNG	8500000	1	1
Sagunto	6800000	1	1
Zeebrugge LNG	6700000	0.8207	1.2185
Adriatic LNG	6500000	1	1
Fos-Cavaou	5700000	0.6930	1.4430
Dragon LNG	5500000	0.9475	1.0555
Sines LNG	5200000	1	1
Marmara Ereglisi	4200000	0.7887	1.2679
Aliaga LNG	4100000	0.9302	1.0751
Bahia de Bizkaia LNG	4000000	0.7625	1.3115
Teesside LNG	3000000	1	1
Livorno FSRU	2750000	0.8557	1.1686
Galician Terminal	2700000	0.8877	1.1265

Table 8, Relationship storage capacity and efficiency (Author).

DMU Name	Storage	Objective Value	Efficiency Score
Grain LNG	1000000	1	1
South Hook LNG	775000	1	1
Sagunto	600000	1	1
Gate LNG	540000	1	1
Sines LNG	390000	1	1
Zeebrugge LNG	380000	0.8207	1.2185
Fos-Cavaou	330000	0.6930	1.4430
Dragon LNG	320000	0.9475	1.0555
Bahia de Bizkaia LNG	300000	0.7625	1.3115
Galician Terminal	300000	0.8877	1.1265
Aliaga LNG	280000	0.9302	1.0751
Marmara Ereglisi	255000	0.7887	1.2679
Adriatic LNG	250000	1	1
Teesside LNG	138000	1	1
Livorno FSRU	135000	0.8557	1.1686

Table 9, Relationship regasification capacity and efficiency (Author).

DMU Name	Regasification	Objective Value	Efficiency Score
South Hook LNG	21	1	1
Grain LNG	19.5	1	1
Gate LNG	12	1	1
Zeebrugge LNG	9	0.8207	1.2185
Sagunto	8.8	1	1
Fos-Cavaou	8.25	0.6930	1.4430
Sines LNG	7.9	1	1
Dragon LNG	7.6	0.9475	1.0555
Adriatic LNG	7.56	1	1
Bahia de Bizkaia LNG	7	0.7625	1.3115
Marmara Ereglisi	6.2	0.7887	1.2679
Aliaga LNG	6	0.9302	1.0751
Teesside LNG	4.2	1	1
Livorno FSRU	3.75	0.8557	1.1686
Galician Terminal	3.6	0.8877	1.1265

It must be noted that although higher outputs contribute to efficiency, it is the question whether this is always desirable. From the perspective of terminals, fully utilising their capacity means reaping economies of scale and thus efficiency, but this differs for the customers. If unloading capacity, for example, is at its full capacity then additional demand will result in capacity shortage. Capacity shortage has proven, in other transportation terminals, to lead to multiple negative consequences (Islam & Olsen, 2013). From the customer point of view capacity shortage, therefore, decreases the attractiveness of certain terminals, which in their turn lose customers to terminals with spare capacity. This debate indicates how the efficiency analysis is limited to indicating relative efficiency scores, thereby not taking into account factors like customer requirements.

Continuing the logic of efficiency one would expect terminals that use lower amounts of inputs, to have higher efficiency scores. When looking at inputs, however, it is more challenging to distinguish any clear trends (Table 10). Especially the relationship between surface area and efficiency is one that is difficult to explain. The three offshore terminals are all assumed to be 1.5 hectares, the smallest size among European terminals. Two of these three terminals do score efficient, which is in line with the abovementioned efficiency logic. However, the remaining efficient terminals are quite evenly distributed among the different sizes of terminals. No clear relation can thus be distinguished. The relation between capital costs and efficiency, which is more pronounced, is contradictory to the efficiency theory (Table 11). The two ‘cheapest’ terminals are indeed efficient, but five out of seven efficient terminals are distributed among the top six most expensive terminals. One might, therefore, think that investing sizeable amounts into terminals would increase efficiency.

In terms of efficiency theory more expensive terminals being efficient does not make sense, but if one steps outside the boundaries of the efficiency analysis explanations can be found. In this case the analysis excludes the technology dimension of LNG import terminals. Terminals can improve their efficiency by implementing modern technology, like *submerged combustion vaporisers* (Tusiani &

Shearer, 2007). But the costs of these technological improvements are high, resulting in high capital costs. Nevertheless, their increased efficiency prevents the terminal, despite higher capital costs, from scoring inefficiently. As was the case with capacity utilisation, and overseeing capacity shortages, this is a limitation of the efficiency analysis that needs further attention.

Table 10, Relationship surface area and efficiency (Author).

DMU Name	Area	Objective Value	Efficiency Score
Adriatic LNG	1.5	1	1
Livorno FSRU	1.5	0.8557	1.1686
Teesside LNG	1.5	1	1
Galician Terminal	10	0.8877	1.1265
Aliaga LNG	10	0.9302	1.0751
Marmara Ereglisi	19	0.7887	1.2679
Sagunto	22	1	1
Sines LNG	23	1	1
Bahia de Bizkaia LNG	23	0.7625	1.3115
Zeebrugge LNG	32	0.8207	1.2185
Gate LNG	35	1	1
Fos-Cavaou	80	0.6930	1.4430
Dragon LNG	155	0.9475	1.0555
South Hook LNG	210	1	1
Grain LNG	385	1	1

Table 11, Relationship capital costs and efficiency (Author).

DMU Name	Costs	Objective Value	Efficiency Score
Teesside LNG	120	1	1
Sines LNG	208	1	1
Livorno FSRU	240	0.8557	1.1686
Dragon LNG	250	0.9475	1.0555
Marmara Ereglisi	323.85	0.7887	1.2679
Aliaga LNG	337	0.9302	1.0751
Galician Terminal	343	0.8877	1.1265
Fos-Cavaou	430	0.6930	1.4430
Bahia de Bizkaia LNG	510	0.7625	1.3115
Sagunto	535	1	1
Zeebrugge LNG	755	0.8207	1.2185
Adriatic LNG	800	1	1
Gate LNG	800	1	1
South Hook LNG	930	1	1
Grain LNG	1351	1	1

Projections

In determining what causes the inefficient terminals to score low, the projections and slacks can be used. Projections indicate what levels of outputs terminals would produce if they were to be efficient. Differences between the current levels and these projection thus indicate where a terminal can improve. In order to make these differences comparable among terminals, they should be indicated as a percentage (difference) of the original output (or input) levels. Having done this (Table 12), the projections clearly indicate where terminals' outputs would increase would they have been efficient. Taking an average of these percentage differences, indicates that especially unloading capacity would increase (36 percent), followed by regasification (31 percent) and storage (30 percent). Especially Galician Terminal, Fos-Cavaou and Bahia de Bizkaia show large possible improvements. An efficient Galician Terminal, would increase its unloading capacity by 79 percent, its regasification capacity by 76 percent and its storage capacity by 12 percent. Fos-Cavaou would improve its unloading with 47 percent, its regasification capacity with 44 percent and its storage with 53. These figures for Bahia de Bizkaia are 62, 32 and 37 respectively. There are also terminals, although inefficient, that would only slightly increase their outputs. Examples are Aliaga LNG and Dragon LNG. Aliaga LNG could improve its unloading capacity with 17 percent and both its regasification and storage capacity by 7.5 percent. Dragon LNG, although showing slightly higher levels of possible improvement (6, 14 and 29 percent respectively), could theoretically even lower its surface area simultaneously.

Table 12, Projections as a percentage of original input/output levels (Author).

DMU Name	Unloading	Regasification	Storage	Area	Costs
Zeebrugge LNG	21.8509	26.1286	42.9812	0	0
Fos-Cavaou	47.0060	44.2975	53.8773	0	0
Livorno FSRU	31.5508	27.8118	16.8627	0	0
Bahia de Bizkaia LNG	62.9494	31.1459	37.8424	0	0
Galician Terminal	79.1753	76.6377	12.6496	0	0
Marmara Ereglisi	30.1615	26.7895	42.9013	0	0
Aliaga LNG	17.2499	7.5086	7.5086	0	0
Dragon LNG	5.5452	13.9743	28.8738	-78.1432	0
Average change	36.9361	31.7867	30.4371	-9.7679	0

Table 13, Slacks as a percentage of original input/output levels (Author).

DMU Name	Unloading	Regasification	Storage	Area	Costs
Zeebrugge LNG	0	4.2777	21.1303	0	0
Fos-Cavaou	2.7084	0	9.5797	0	0
Livorno FSRU	14.6881	10.9490	0	0	0
Bahia de Bizkaia LNG	31.8035	0	6.6965	0	0
Galician Terminal	66.5257	63.9880	0	0	0
Marmara Ereglisi	3.3719	0	16.11177735	0	0
Aliaga LNG	9.7412	0	0	0	0
Dragon LNG	0	8.4291	23.3286	78.1432	0
Average slacks	16.1049	10.9555	9.6059	9.7679	0

Slacks

Where projections take into account the efficiency scores, and thus how terminals could improve if they were to increase their efficiency, slacks do not. Slacks indicate where terminals are currently missing output or using excess inputs, which lead to their inefficiency. If terminals need to improve efficiency these areas of slack should be dealt with. In order to make the slacks comparable they are indicated as a percentage of the current output (or input) level (Table 13). This results in a clear view of slacks, and how large these are compared to the actual output levels. On average unloading capacity slacks are 16 percent of the current capacity levels. For regasification this is 10 percent and for storage 9 percent. When looking at individual terminals especially the slacks of Galician Terminal are remarkable. With an unloading slack of 1,7 million tonnes of LNG, 66 percent of its actual 2.7 million tonnes of LNG unloading capacity, it is clearly missing output. On top of this a slack of 63 percent over its current regasification capacity further adds to the inefficiency of the terminal. Further, the unloading slacks of Bahia de Bizkaia LNG (31 percent) and Livorno FSRU (14 percent) are significant, whilst the storage slacks of Dragon LNG (23 percent) and Zeebrugge (21 percent) are worth mentioning.

It has become apparent that there are sizeable efficiency differences, varying from 5.5 percent possible improvement up to 44.3 percent. Knowing this, the question arises where these differences can be appointed to. A first analysis proved it difficult to distinguish any trends in the efficiency scores related to the country in which the terminals are located. A clearer trend was the increasing efficiency scores that paired with higher output levels. The relation between input levels and efficiency scores indicated some remarkable trends. Surface area and efficiency levels are difficult to relate, as the efficient terminals are quite equally distributed among the surface levels. Regarding capital costs it was clearly distinguishable that more costly terminals were also more efficient. Looking at terminals in general, both projections and current slacks indicated that most improvement could be made in unloading capacity. Regasification capacity and storage capacity followed closely. Galician terminal showed the most room for improvement, followed closely by Fos-Cavaou and Bahia de Bizkaia LNG. Galician Terminal also showed the most output slacks. These abovementioned trends will sought to be explained in the next section.

4.3.2 Explanations

Uncertainties

The first trend that will be discussed is the increasing efficiency that is paired with higher output levels. Efficiency or performance in this output oriented study, indicate the terminal's ability to unload, store and regasify LNG. The goal towards efficiency is, therefore, to maximise these outputs. However, uncertainty can present a threat to this maximisation. LNG import terminals experience uncertainty in both the incoming LNG shipments (supply) and the demand for regasified LNG. Regarding *supply uncertainties*, factors like the weather (Grin, de Wilde, & van Doorn, 2005) or fluctuations on the spot market (Rogers & Stern, 2014) might result in shipments being delayed or diverted altogether. The uneven spread of these supplies presents a problem for import terminals, as the simultaneous arrival of shipments can result in queues (van Asperen, Dekker, Polman, & de Swaan Arons, 2003). Queues are a result of import constraints and develop when terminals have (too) low unloading capacities or shortages in storage capacity. There are also uncertainties regarding the level of demand. Especially peak demands form a threat to import terminals. The unexpected high demand for gas, as a result of colder weather or the unavailability of other energy sources (Miyamoto, Ishiguro, & Nakamura, 2012), might present the terminals with a problem. If the capacity to regasify LNG is too low, or the storage capacities (or stocks) are not high enough, then this will result in unmet demand (Goel, Furman, Song, & El-Bakry, 2012). Unmet demand and queues indicate how uncertainties endanger the performance of LNG import terminals. To prevent these issues from arising, terminals could increase their unloading, storage and regasification capacity. Higher levels of these outputs will reduce the chance of uncertainties influencing the performance of terminals. The trend that high output levels are paired with increasing efficiency might, therefore, be explained by these terminals' capability to deal with uncertainties.

Technology

The second clearly visible trend is the relation between efficiency and capital costs. The larger part of the efficient terminals are also the most capital (input) intensive, which according to efficiency theory should be the opposite. However, as mentioned before, capital costs include costs for efficiency enhancing equipment. In the process of unloading, storing and regasifying LNG, terminals can configure these elements according to their needs. A trade-off is made between costs and efficiency, as the most efficient equipment is often costly.

The elements of an LNG import terminal can roughly be divided into marine facilities, storage tanks, *recondensers*, *LNG pumps* and *vaporisers* (Tarlowski & Sheffield, 2002). Regarding marine facilities, terminal efficiency can be improved by excluding *vapour return blowers*, for example. As long as there is enough pressure in the *vapour return lines* these blowers are not needed and save energy as a result. Sufficient pressure levels are realised in case of *full containment storage tanks*. These tanks are more costly than other alternatives, however. The vaporisers used to regasify the stored LNG are large determinants of the terminals costs and efficiency levels. Although the larger part of the LNG import terminals use *open rack vaporisers*, other terminals also use submerged combustion vaporisers, *shell & tube vaporisers* and *ambient air vaporisation systems* (CH-IV International, 2007). The foremost difference between these vaporisers is their heat source, which is constantly changing to improve their efficiency levels. One example of an efficient heat source is the *boil-off gas* created by terminals or LNG vessels. As LNG is subject to certain levels of heat during operations it releases boil-off gas. Apart from functioning as heat source for certain vaporisers these gasses can also, when compressed to pipeline pressure, be distributed along with the regasified LNG. A further efficiency improving technology is a recondenser, which can mix these boil-off gasses with LNG before it gets regasified.

These mentioned technologies are only an indication of the wide array of possibilities to improve terminal efficiency. Each of these elements, however, also contribute to the capital costs of the terminal. Storage tanks account for the largest part of capital costs (Energy Information Administration, 2003). It is most efficient to have a small amount of larger tanks (Peiris, Cushing, Lubkowski, & Scarr, 2006). This can be distinguished when looking at storage tank data (Appendix 16). Nearly all onshore terminals have full containment storage tanks, only Marmara Ereglisi has *double containment tanks*. The size of these tanks is higher among the efficient terminals. These large full containment tanks, however, also contribute to the high capital costs of these terminals. Looking solely at storage tanks it, therefore, seems as if large and advanced storage tanks do indeed contribute to efficiency and capital costs simultaneously.

The reason for the high capital costs of efficient terminals can, thus, be found in the technology used on site. Terminals strive to improve efficiency through the implementation of technologically advanced elements. These improvements often come at high costs, however. A trade-off between efficiency and capital costs underlies these technological decisions. For this reason terminals that favour high efficiency levels will tend to have higher capital costs. This explanation is supported by looking at storage tanks, which are a large cost determinant, as the efficient tanks and terminals are paired with high capital costs.

Individual terminals

When looking at individual terminals, it became apparent that Galician Terminal, Fos-Cavaou and Bahia de Bizkaia LNG were not performing optimally. Galician Terminal and Bahia de Bizkaia LNG showed (in the projections) large possibilities for output improvements whilst Fos-Cavaou had the lowest efficiency rating. The projections and slacks of these individual terminals might shed some light as to why they are underperforming.

Starting with Galician Terminal, an efficiency score of 1.1265 indicates that it should be able to produce 12.65 percent more outputs with its current level of inputs. This is no shocking figure, as there are other terminals with significantly higher scores. However, the relative slacks (based on original output values) on unloading capacity and regasification capacity are alarmingly high. With the terminal's level of inputs these capacities should be able to increase with more than 65 percent. One could question where these slacks originate. One explanation could be the relatively limited space the terminal has. Although less space is positive towards efficiency there seem to be boundaries to this assumption. Especially Andreas Hambuecker, senior process engineer at Tractebel Gas Engineering GMbH, has highlighted this space restriction (Hambuecker & Isalski, n.d.; Kaspar & Hambuecker, 2007). Apart from the offshore terminals this surface area is the smallest in the dataset. These space restrictions, together with European safety codes, posed the design of the terminal with some significant challenges. Eventually certain compromises have to be made with regards to performance, in able to assure safety. According to Hambuecker the costs of dealing with limited surface area outweigh the cost savings of a smaller plot and less piping. For this reason it may seem that the terminal should be able to produce more outputs with this level of inputs (especially capital costs), but in reality the expanding these capacities will be paired with even higher capital investments.

The second terminal, Bahia de Bizkaia LNG should be able to increase its outputs with 31.15 percent according to its efficiency score. This is the second largest efficiency score, indicating substantial room for improvement. Especially the unloading capacity of the terminal is slacking. With four million tonnes of LNG per year the terminal is only higher than Galician Terminal and two small offshore terminals (Livorno FSRU & Teesside LNG). In addition, other terminals with similar unloading capacities (Aliaga LNG and Marmara Ereglisi) are substantially (66 and 63 percent respectively) cheaper. It can be questioned why this unloading capacity is falling behind. No literature so far has discussed this issue, making it difficult to indicate why the capacity of this terminal is not in line with its inputs.

The final terminal which presented high levels of inefficiency was Fos-Cavaou. This terminal is assumed to be the most inefficient terminal in Europe, with the possibility to increase its outputs with 44.3 percent according to its current input levels. It is difficult to pinpoint this inefficiency, however. The slacks in unloading and storage capacity are not as high as one would expect with this efficiency score. Looking at the projections, however, it is indicated that the output capacities of the terminal would increase substantially had the terminal been efficient. The difference, which can be appointed to the inefficient score, indicates that outputs are too low or inputs are too high. In this case evidence exists for the latter. Compared to terminals with similar outputs Fos-Cavaou exhibits high costs and a vast surface area. Only Dragon LNG requires more surface area for similar outputs, but it requires only 58 percent of Fos-Cavaou's costs. There are even four terminals that require less surface area for the higher levels of output. Also the costs of Fos-Cavaou are not competitive. With 430 million capital costs it is around twice as expensive as Dragon LNG (€250 million) and Sines LNG (€208 million), terminals with similar output levels. When questioning these levels of inputs, multiple issues experienced during the construction of the terminal might provide an answer. In 2005, one year into construction, it was determined by the French government that the seismic requirements of the project needed to be increased (Hydrocarbons Technology, 2014). As a result construction was suspended and the schedule extended by eight months. In 2008, despite predictions to be finished by 2007, construction was still not completed. In the beginning of that year the start-up had to be further postponed because of damage to the piping infrastructure during testing of the project (Leblond, 2008). And on top of this, the completion was postponed one last time due to delays in the delivery of certain cooling equipment necessary for operations. Eventually the terminal was completed in April 2010, nearly three years later than planned. These delays and additional requirements have most likely added to the capital costs of the terminal. It is, therefore, possible that the capital costs are higher than would have been necessary to realise a terminal of this capacity. For that reason the projections suggest higher levels of output than are currently realised.

Summarising the discussion, findings indicated sizeable efficiency differences among LNG import terminals in Europe. Where higher output levels clearly led to improved efficiency, the relation between input levels and efficiency was less clear. Remarkably, the capital intensive terminals scored higher efficiency levels. Unloading capacity, followed closely by regasification and storage capacity, showed the most room for improvement among European LNG import terminals in general. Galician terminal, Fos-Cavaou and Bahia de Bizkaia LNG were leading in this. Larger terminals, with higher output levels, tend to have better efficiencies. The capability to cope with uncertainties through high capacities prevents underperformance during unexpected supply or demands. Furthermore, the terminals with the highest capital costs proved to be the most efficient terminals. The implementation of costly technology, in order to improve terminal efficiency, can explain this trend. When looking at the most inefficient terminals, certain terminal specific explanation could be provided for their inefficiencies. Galician Terminal, which has very high output slacks, is under serious space constraints. This results in performance compromises in favour of safety and high costs for special equipment and designs. As a result the input (costs) are relatively high compared to the levels of outputs, indicating slacks there. Bahia de Bizkaia LNG has remarkably low unloading capacities, especially when looking at the costs of the terminal. It is difficult to pinpoint an explanation for this, however. This is less so for Fos-Cavaou, the least efficient terminal in the dataset. Although the terminal does not have any remarkably high slacks, the projections (as a result of the efficiency score) indicate large possible improvements. With its level of inputs, higher outputs should be realised. However, this is most likely due to the high capital costs, which are higher than necessary due to multiple delays during the construction of the terminal. Would these issues not have occurred, then costs and outputs would probably have been more in line.

4.4 *Summary results*

This section has discussed the findings of the data analysis, after which these are discussed. The findings indicated that seven terminals are efficient, whilst eight are inefficient. Efficiencies scores vary between 1.055 for Dragon LNG and 1.443 for Fos-Cavaou, meaning the terminal could produce 44.30 percent more outputs with their current level of inputs. The OSDEA software, used to analyse the data, also provides projections. These projections, calculated according to reference DMUs and their weights (also calculated by OSDEA), indicate the output levels of inefficient terminals would they have been efficient. Logically the most inefficient terminals show the largest potential for improvement. Furthermore slacks are calculated. These indicate sources of inefficiency and are therefore valuable towards answering the research question. Most slacks occur in unloading capacity, indicating this is an area of concern for LNG import terminals. Galician Terminal has the largest slacks, being around 65 percent of its current outputs.

These findings have clearly illustrated sizeable efficiency differences among LNG import terminals in Europe. Where higher output levels clearly led to improved efficiency, the relation between input levels and efficiency was more challenging to distinguish. Remarkably the capital intensive terminals scored higher levels of efficiency. When looking at the projections and slacks it was clear that unloading capacity, followed closely by regasification and storage capacity, showed the most room for improvement. The terminals with the highest level of inefficiency, slacks or room for improvement were Galician terminal, Fos-Cavaou and Bahia de Bizkaia LNG.

Reasons for the efficiency differences were also explored. Terminals with larger outputs (unloading, storage and regasification capacity) benefit from the ability to cope with uncertainties, thereby ensuring their performance. The high efficiency scores of the capital intensive terminals are the result of investments in technologically advanced terminal elements. Regarding the inefficient terminals mentioned above, the Galician Terminal proved to be under serious space constraints. For this reason costs were exceptionally high, suggesting outputs could have been higher. For Bahia de Bizkaia LNG no such relationship could be found, the question why it has such low levels of unloading capacity still stands. Of all analysed terminals Fos-Cavaou proved to be the most inefficient. Similarly to Galician Terminal its costs were high, due to multiple delays in construction, which indicated the projections could have achieved higher levels of outputs.

The following chapter will consider these findings and indicate how they answer the research question. Furthermore, it will discuss the study’s contribution to practice and literature. Before finalising the thesis, the limitations and recommendations for further research will also be addressed.

5 Conclusions & recommendations

5.1 Introduction

Global energy demands are continuing to increase. To meet these demands new fuel sources are being addressed. Natural gas is becoming one of the largest fuel sources, due to its beneficial characteristics. Where transporting gas posed a problem in the past, the introduction of LNG has removed these barriers. The first signs of a global gas market are becoming imminent and demand is further increasing due to the introduction of LNG as maritime bunker fuel.

As a result competition around this fuel has increased and countries are focussing on securing their supply. Especially in Europe, which is dependent on Russian and Middle Eastern gas, new ways of securing their supplies are being sought. LNG plays a major role in this, as it breaks down pipeline dependence and allows a diversification of suppliers. The Ukraine crisis has boosted the development of the European LNG infrastructure, especially in Central and Eastern Europe. A growing amount of countries is importing LNG and the amount of LNG import terminals, necessary for these imports, is growing along.

However, as LNG terminals are capital intensive there are financial risks tied to the expansion of the LNG import infrastructure. The terminals are capital intensive and demand fluctuations can jeopardise the required investments. Economies of scale have provided a way to cope with these high costs, through lowering the capital intensity of the terminals. High levels of terminal efficiency can stimulate economies of scale, thereby covering a part of the financial risk and making the further introduction of an LNG infrastructural network in Europe possible.

For these reasons, gaining insight in the efficiency of LNG import terminals in Europe is of utmost importance. Efficiency and inefficiencies can be identified and provide useful information for the further development of LNG in Europe. Currently no such attention has been dedicated to this topic, however. Efficiency benchmarking has been implemented in similar industries and can extended towards LNG import terminals.

This thesis provides a start towards measuring LNG import terminal efficiency and creating a European benchmark. With a benchmark as such, LNG import terminals can compare their performance levels and identify sources of inefficiency. For this reason the research question was introduced:

Are there substantial efficiency differences among LNG import terminals in Europe, and if so, how can they be explained?

The question structures the research towards measuring relative efficiency levels among European LNG import terminals. The question also stimulates research to seek explanations for any possible inefficiencies. If the question can be answered, this will make it possible for terminals to benchmark their performance and learn from each others' mistakes.

The question has been answered by collecting data on the performance, or efficiency, of European LNG import terminals. The data, mainly originating from secondary sources, have been analysed using DEA methodology. This methodology measures relative efficiency among, in this case, terminals and indicates where inefficient terminals are falling behind. The information that this analysis has produced can be used towards answering the research question posed.

5.2 Answer to research question

The DEA of LNG import terminals in Europe, run in OSDEA software, has provided answers to the research question stated above. Outcomes of the analysis provide information on efficiency scores, projections, lambdas, reference sets, slacks and weights. Especially the efficiency scores, projections and slacks provide useful information. The efficiency scores indicate that eight of the 15 terminals are deemed inefficient, varying from 5.5 percent possible output increases to 44.3 percent. The projections logically indicate that the most inefficient terminals show the most potential for improvement. Slack figures show that most slacks occur in unloading capacity, which projections also indicate, indicating that this is an area of attention for LNG import terminals.

Findings thus indicate that there are indeed clear efficiency differences among LNG import terminals in Europe. Terminals with higher levels of output tend to score higher efficiency levels. This, however, is from an efficiency point of view. From a customer point of view one could question if high outputs and possible capacity shortages are desirable. The relation between inputs and efficiency is more difficult to distinguish, especially regarding surface area. Higher levels of capital costs tend to result in more efficient terminals. Seeing capital costs as an input, this is in conflict with efficiency theory, however, an explanation probably lies outside the scope of this analysis. Higher investments may originate from expensive technological equipment, but this is overseen in the efficiency measurements. The limitations of the analysis must, therefore, be kept in mind. Projections and slacks indicate that especially unloading capacity shows room for improvement, followed by regasification and storage capacity. Among the current terminals in Europe especially Fos-Cavaou, Galician Terminal and Bahia de Bizkaia LNG score inefficient and show room for improvement.

The reason for terminals with higher levels of output scoring high efficiency levels is, explained by their capability to cope with uncertainties. The uneven distribution of the arrival of LNG shipments and unexpected peak demands, pose a threat to the performance of LNG import terminals. If the unloading, storage and regasification capacities of these terminals are not high enough uncertainties can, therefore, lead to queues or unmet demand. Terminals with higher capacities are less likely to experience such issues and will, therefore, score higher efficiency levels. An explanation for the high capital costs of efficient terminals is found in their equipment. LNG import terminals consist of multiple elements, which can each be changed according to the terminal's needs. In striving for efficiency, technologically advanced equipment can be introduced, however, this comes at a cost. Full containment storage tanks, recondensers or boil-off gas compressors are examples of efficiency enhancing equipment terminals can implement. Doing so will result in improved efficiency at higher capital costs. Capital intensive terminals are, thus, likely to score higher efficiency levels. Finally, it is important to note that the relation between inputs and outputs can be distorted. Research into the reason of inefficiencies of Galician Terminal, Fos-Cavaou and Bahia de Bizkaia LNG indicated that some inefficiencies are the result of external factors. For example Galician Terminal, due to its space constraints, and Fos-Cavaou, due to multiple delays in construction, had costs that were out of proportion with their outputs. As a result the levels of output where too low compared to these costs, indicating inefficiency.

In conclusion, the research question can be answered by stating that there are indeed efficiency differences among European LNG import terminals, and that these differences are mainly explained by economies of scale, terminal design and external factors.

5.3 Contributions and implications

5.3.1 Academic literature

The role of LNG and, therefore, LNG import terminals, in the global gas market is increasingly important. And although terminals have been around for longer, research in this field is relatively new. Most findings in this study, therefore, contribute to this limited amount of scientific knowledge. The study contributes by expanding the implementation of DEA towards the LNG and especially import terminals, sector. DEA has been implemented in related sectors, and started discussions there. Possibly the implementation of DEA here can result in similar value adding discussions. One of the conclusions, that LNG import terminals present economies of scale, validates the general assumption that the LNG value chain is characterised by these scale economies. However, the DEA and the related efficiency theory have also proven to show some limitations in encompassing all relevant aspects related to terminal efficiency. Altogether this study, despite its limited scope, can provide a basis for future efficiency benchmarking in LNG import terminals.

5.3.2 Practice

LNG import terminals can profit from the benchmarking possibility described above. By comparing their relative efficiency with other terminals, performance levels can be assessed. There are possibilities to learn from inefficiencies of others, thereby underlining which areas need extra attention. As this study is limited by a number of reasons, the direct findings might be too restricted for commercial use. However, the methods provide a basis for further (private) studies, which are able to include more detailed information, to build upon. Not only LNG terminal operators, but also governments can profit from these opportunities. As LNG import terminals play a large role in securing energy supplies, governments have an interest in the performance of these terminals. Through benchmarking and the focussing of attention towards sources of inefficiency governments can point support directly at the terminals, or parts of them, that need attention. Government support can therefore be efficiently directed to where it is needed.

5.4 Further research

5.4.1 Future studies

Despite the findings of this study, certain limitations indicate room for improvement. One of these is finding a way to include the external factors, like construction delays, in efficiency measurements. By overcoming these limitations a more complete analysis of LNG import terminal efficiency can be conducted, leading to more grounded outcomes. In addition, the dataset of this study can also be expanded. Where certain terminals were left out due to data availability issues, further studies might focus on gaining insight in these figures, and so they might expand the dataset used in the DEA. This study is limited to data collection from secondary sources, future studies might contribute to these figures by means of primary data collection. Regarding the scores and inefficiencies, more complete case studies for terminals could provide insights in the reasons behind these efficiency measurements. Similarly, interviews with experts from the LNG importing industry could provide depth to, and perform triangulation with, the results of the study. The commercial sensitivity of this information, however, will continue to pose a limitation. Furthermore, the DEA used in this study indicates relative efficiency figures among LNG import terminals. The efficiency of terminals will, therefore, be dependent on other terminals included. In order to gain insight in actual efficiency figures of these terminals future studies should focus on measuring absolute efficiency figures. Terminals are likely to measure these figures individually and confidentially, nevertheless these figures could further strengthen efficiency benchmarking among LNG import terminals. Finally, the analysis conducted in this study is limited to import terminals. No further attention is paid to the remaining LNG supply chain and how inefficiencies can effect profitable LNG trades. The first recommendation would be to expand DEA towards export terminals. Although inputs and outputs differ between these types of terminals, the DEA is capable of handling these altered variables and can, therefore, provide efficiency figures for export terminals as well. Studies as such could contribute to gaining insight in the overall efficiency of the LNG value chain. Altogether, research can expand upon the relatively narrowly scoped methods implemented in this study. By doing so efficiency measurements all through the value chain can contribute to knowledge and possible optimisation of LNG movements.

5.4.2 Future trends

The findings from this study and the methods implemented in any possible future studies, should, however, recognise future patterns, variations and trends. As discussed throughout this study, the demand for LNG, as a result of higher gas demands and the possibility of using LNG as maritime bunker fuel, is likely to increase. In order for this to develop in this fashion, investments in the LNG infrastructure, and thus terminals, should be further stimulated. The benchmark set here can provide some indication how and where this should happen. However, the future also holds certain uncertainties. One of these lies in the fact that LNG is increasingly traded under short-term contracts at spot prices. As is currently the case with LNG demanded by Europe being diverted to Japan, shipments are eventually directed to the markets offering the highest netbacks. This, therefore, poses a risk that demanding regions like Europe will be bypassed and if major investments in terminal capacity have been realised, this will result in underutilisation. In the same line, the demand knows certain uncertainties. In the US for example, the shale gas revolution has turned the country from a demander towards a supplier. As a result the developed import terminals have become underutilised. Large investments are lost and new ones being made, as these terminals have to be adapted towards enabling exports. Similar developments in Europe would, therefore, also lead to underutilisation and loss of the investments currently made. Another development that influences LNG import terminal efficiency, is the continuous improvement of technology used in these terminals. Modern terminals will include these new technologies, making existing terminals relatively less efficient. Should existing terminals decide to adapt to these technologies, then sizeable investments will have to be made. This, in its turn, alters the relative position of the terminals. Finally, the importance of LNG is dependent on the role of natural gas in the global energy market. As natural gas is believed to be a transition fuel it is questionable how long it will take before a new dominant energy source will appear. However, as projection indicates that natural gas and, therefore, LNG are likely to increase in demand over the next couple of decades, investments in an LNG infrastructure are not under direct risk of becoming unnecessary.

5.5 Wrap-up

Having read this study, it should have become clear that LNG import terminals in Europe indeed show efficiency differences. There are multiple reasons for these differences, all of which can contribute to the understanding of terminal efficiencies and inefficiencies. Insight into terminal efficiency can contribute to knowledge, supporting the expansion of the infrastructure needed to allow the shift towards natural gas as global energy source. Although energy movements are subject to relatively swift contextual changes, creating a solid infrastructure is the bare minimum required to lubricate the movement away from the currently dominant fossil fuels.

Bibliography

Acciaro, M. (2014). A real option application to investment in low-sulphur maritime transport. *International Journal of Shipping and Transport Logistics*, *6*(22), 189–212.

Acciaro, M., & Gritsenko, D. (2014). Energy innovation in ports: the role of local contexts in LNG bunkering terminal development. In *IAME 2014 Conference Norfolk*. Norfolk: IAME.

Adamchak, F., & Adede, A. (2013). LNG As Marine Fuel. In *LNG-17 Conference*. Houston: Poten & Partners.

Agrell, P., & Bogetoft, P. (2005). Economic and environmental efficiency of district heating plants. *Energy Policy*, *33*(10), 1351–1362.

Andrieu, C. (2013). Small scale LNG import terminal: Not as simple as a reduced one. In *LNG-17 Conference*. Houston: GDF Suez.

Bagdadioglu, N., Waddams Price, C., & Weyman-Jones, T. (1996). Efficiency and ownership in electricity distribution: A non-parametric model of the Turkish experience. *Energy Economics*, *18*(1), 1–23.

Baldwin, J. (2008). *World's first LNG onboard regasification port* (No. 34). London: Port Technology International.

Banker, R., Charnes, A., & Cooper, W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, *30*(9), 1078–1092.

Banker, R., Charnes, A., Cooper, W., Swarts, J., & Thomas, D. (1989). An Introduction to Data Envelopment Analysis with some of its Models and their Uses. *Research in Government and Nonprofit Accounting*, *5*(1), 125–163.

Banker, R., & Morey, R. (1986a). Efficiency analysis for exogenously fixed inputs and outputs. *Operations Research*, *34*(4), 513–521.

Banker, R., & Morey, R. (1986b). The use of categorical variables in data envelopment analysis. *Management Science*, *32*(12), 1613–1627.

Banker, R., & Natarajan, R. (2008). Evaluating Contextual Variables Affecting Productivity Using Data Envelopment Analysis. *Operations Research*, *56*(1), 48–58.

Barros, C. (2003). The Measurements of Efficiency of Portugese Sea Port Authorities with DEA. *International Journal of Transport Economics*, *30*(3), 335–354.

Barros, C. (2006). A Benchmark Analysis of Italian Seaports Using Data Envelopment Analysis. *Maritime Economics & Logistics*, *8*(4), 347–365.

Barros, C., & Athanassiou, M. (2004). Efficiency in European Seaports with DEA: Evidence from Greece and Portugal. *Maritime Economics & Logistics*, *6*(2), 122–140.

Bell, C. (1988). Economies of, versus returns to, scale: A clarification. *Journal of Economic Education*, *19*(4), 331–335.

Bhagavath, V. (2006). Technical efficiency measurement by data envelopment analysis: an application in transportation. *Alliance Journal of Business Research*, *2*(1), 60–72.

Bilgin, M. (2009). Geopolitics of European natural gas demand: Supplies from Russia, Caspian and the Middle East. *Energy Policy*, *37*(11), 4482–4492.

Blumberg, B., Cooper, D., & Schindler, P. (2011). *Business Research Methods* (3rd ed.). Berkshire: McGraw-Hill.

BP. (2014). *BP Statistical Review of World Energy June 2014*. London.

Brealey, R., Myers, S., & Allen, F. (2011). *Principles of Corporate Finance* (10th ed.). New York: McGraw-Hill.

Bryman, A. (2008). *Social Research Methods* (3rd ed.). New York: Oxford University Press.

Byrnes, P., Färe, R., & Grosskopf, S. (1984). Measuring productive efficiency: an application to Illinois strip mines. *Management Science*, *30*(6), 671–681.

Byrnes, P., Färe, R., Grosskopf, S., & Lovell, C. (1988). The effect of unions on productivity: US surface mining of coal. *Management Science*, *34*(9), 1037–1053.

Chambers, R., & Mitchell, T. (2001). Homotheticity and non-radial changes. *Journal of Productivity Analysis*, *15*(1), 31–39.

Charnes, A., Cooper, W., Golany, B., Seiford, L., & Stutz, J. (1985). Foundations of data envelopment analysis for Pareto-Koopmans efficient empirical production functions. *Journal of Econometrics*, *30*(1), 91–107.

Charnes, A., Cooper, W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, *2*(6), 429–444.

Chazan, G. (2014, April 27). Europe seeks alternative gas supplies. *The Financial Times*.

CH-IV International. (2007). *Oregon LNG Import Terminal - Vaporizer Alternatives Study*. Houston: CH-IV International.

Cobb, C., & Douglas, P. (1928). A Theory of Production. *The American Economic Review*, *18*(1), 139–165.

Coelli, T. (2008). *A Guide to DEAP Version 2.1: A Data Envelopment Analysis (Computer) Program* (No. 96). Armidale: Centre for Efficiency and Productivity Analysis.

Coelli, T., & Perelman, S. (1999). A comparison of parametric and non-parametric distance functions: With application to European railways. *European Journal of Operational Research*, *117*(2), 326–339.

Cook, J. (2006). Gulf Gateway Energy Bridge - The First Year of Operations and the Commercial and Operational Advantages of the Energy Bridge Technology. In *Offshore Technology Conference*. Houston: Offshore Technology Conference.

Cook, W., Kress, M., & Seiford, L. (2014). On the Use of Ordinal Data in Data Envelopment Analysis. *The Journal of the Operational Research Society*, *44*(2), 133–140.

Cook, W., & Seiford, L. (2009). Data envelopment analysis (DEA) – Thirty years on. *European Journal of Operational Research*, *192*(1), 1–17.

Cook, W., Tone, K., & Zhu, J. (2014). Data envelopment analysis: Prior to choosing a model. *Omega*, *44*(1), 1–4.

Cooper, W., Seiford, L., & Tone, K. (2007). *Data Envelopment Analysis - A Comprehensive Text with Models, Applications References and DEA-Solver Software* (2nd ed.). New York: Springer Science & Business Media.

Cooper, W., Seiford, L., & Zhu, J. (2011). Data envelopment analysis: history, models, and interpretations. In W. Cooper, L. Seiford, & J. Zhu (Eds.), *Handbook on data envelopment analysis* (2nd ed., pp. 1–40). New York: Springer Science & Business Media.

Correljé, A., & van der Linde, C. (2006). Energy supply security and geopolitics: A European perspective. *Energy Policy*, *34*(5), 532–543.

Costantini, V., Gracceva, F., Markandya, A., & Vicini, G. (2007). Security of energy supply: Comparing scenarios from a European perspective. *Energy Policy*, *35*(1), 210–226.

Cullen, T. (2004). Three teams hunt £115m gas job. *Construction news*. Retrieved August 20, 2014, from http://www.cnplus.co.uk/news/three-teams-hunt-115m-gas-job/401378.article#

Cullinane, K., Ji, P., & Wang, T. (2005). The relationship between privatization and DEA estimates of efficiency in the container port industry. *Journal of Economics and Business*, *57*(5), 433–462.

Cullinane, K., Song, D., Ji, P., & Wang, T. (2004). An Application of DEA Windows Analysis to Container Port Production Efficiency. *Review of Network Economics*, *3*(2), 184–206.

Cullinane, K., Wang, T., Song, D., & Ji, P. (2006). The technical efficiency of container ports: Comparing data envelopment analysis and stochastic frontier analysis. *Transportation Research Part A: Policy and Practice*, *40*(4), 354–374.

Cunningham, N. (2013). *The Geopolitical Implications of U.S. Natural Gas Exports*. Washington DC: American Security Project.

Danish Maritime Authority. (2012). *North European LNG Infrastructure Project: A feasibility study for an LNG filling station infrastructure and test of recommendations*. Copenhagen: Danish Maritime Authority.

De Oliveira, G., & Cariou, P. (2011). A DEA study of the efficiency of 122 iron ore and coal ports and of 15/17 countries in 2005. *Maritime Policy & Management*, *38*(7), 727–743.

Debreu, G. (1951). The coefficient of resource utilization. *Econometrica: Journal of the Econometric Society*, *19*(3), 273–292.

Edirisinghe, N., & Zhang, X. (2007). Generalized DEA model of fundamental analysis and its application to portfolio optimization. *Journal of Banking & Finance*, *31*(11), 3311–3335.

Emrouznejad, A. (2012a). Scale efficiency. *DEA Zone*. Retrieved August 03, 2014, from http://deazone.com/en/scale-efficiency

Emrouznejad, A. (2012b). Weights to determine relative efficiency. *DEA Zone*. Retrieved August 12, 2014, from http://deazone.com/en/resources/tutorial/weights-to-determine-relative-efficiency

Enerdata. (2014). World LNG Database. *Enerdata*. Retrieved August 09, 2014, from http://www.enerdata.net/enerdatauk/knowledge/subscriptions/database/lng-trade-terminals-and-plants-database.php

Energy Information Administration. (2003). *Liquefied Natural Gas Market: Status & Outlook*. Washington DC: Energy Information Administration.

Energy Information Administration. (2013). *Annual Energy Outlook 2013*. Washington DC: Energy Information Administration.

European Commission. (2009). Directive 2009/73/EC Of The European Parliament And Of The Council. *Official Journal of the European Union*, *14*(1), 94–136.

European Commission. (2011). *The Internal Energy Market - Time To Switch Into Higher Gear*. Brussels: European Commission.

European Investment Bank. (2013). Bahia de Bizkaia LNG Termina-II-TEN. *European Investment Bank*. Retrieved August 20, 2014, from http://www.eib.org/projects/pipeline/2006/20060390.htm

European Shortsea Network. (2013). *ESN – Way Forward SECA report*. Cyprus.

Evans, R. (2004). US firm wins LNG deal. *Wales Online*. Retrieved August 20, 2014, from http://www.walesonline.co.uk/business/business-news/us-firm-wins-lng-deal-2415051

Exxon Mobil. (2014). *The Outlook for Energy: A View to 2040*. Irving: Exxon Mobil Corporation.

Färe, R., Grosskopf, S., & Logan, J. (1983). The relative efficiency of Illinois electric utilities. *Resources and Energy*, *5*(4), 349–367.

Färe, R., Grosskopf, S., & Logan, J. (1985). The relative performance of publicly-owned and privately-owned electric utilities. *Journal of Public Economics*, *26*(1), 89–106.

Fare, R., Grosskopf, S., & Lovell, C. (1994). *Production frontiers* (1st ed.). Cambridge: Cambridge University Press.

Färe, R., Grosskopf, S., & Yaisawarng, S. (1990). Productivity growth in Illinois electric utilities. *Resources and Energy*, *12*(4), 383–398.

Farey, B. (2010). U.K. Isle of Grain LNG Terminal's Expansion Delayed, Grid Says. *Bloomberg*. Retrieved August 20, 2014, from http://www.bloomberg.com/news/2010-11-29/u-k-isle-of-grain-lng-terminal-s-expansion-delayed-grid-says.html

Farrell, M. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society*, *120*(3), 253–290.

Fisher, J. (2009). Liquified natural gas gains currency. *Alberta Oil Magazine*. Retrieved August 11, 2014, from http://www.albertaoilmagazine.com/2009/10/lng%E2%80%99s-ship-comes-in/2/

Fluxys. (2013). Fluxys: De geschiedenis van de LNG-terminal in Zeebrugge. *Vimeo*. Retrieved August 20, 2014, from http://vimeo.com/61533086

Førsund, F., & Kittelsen, S. (1998). Productivity development of Norwegian electricity distribution utilities. *Resource and Energy Economics*, *20*(3), 207–224.

Galagedera, D., & Silvapulle, P. (2003). Experimental evidence on robustness of data envelopment analysis. *The Journal of the Operational Research Society*, *54*(6), 654–660.

Galway Energy Advisors. (2012). *LNG Imports to Hawaii: Commercial & Economic Viability Study*. Houston: Galway Energy Advisors.

Gas LNG Europe. (2013). *GLE Small Scale LNG STUDY: Map of the small scale LNG infrastructure in Europe*. Brussels: Gas LNG Europe.

Gas LNG Europe. (2014). LNG MAP. *Gas Infrastructure Europe*. Retrieved August 09, 2014, from http://www.gie.eu/index.php/maps-data/lng-map

Gate Terminal. (2014). Gate terminal: Een op- en overslagbedrijf. *Gate Terminal*. Retrieved August 20, 2014, from http://www.gate.nl/gate-terminal/profiel.html

Gately, D., & Huntington, H. (2002). The asymmetric effects of changes in price and income on energy and oil demand. *The Energy Journal*, *23*(1), 19–55.

GDF Suez. (2008). *GDF Suez European Leader in Liquefied Natural Gas (LNG)*. Paris: GDF Suez.

Gelles, G., & Mitchell, D. (1996). Returns to scale and economies of scale: Further observations. *Journal of Economic Education*, *27*(3), 259–261.

Giannakis, D., Jamasb, T., & Pollitt, M. (2005). Benchmarking and incentive regulation of quality of service: an application to the UK electricity distribution networks. *Energy Policy*, *33*(17), 2256–2271.

Gillen, D., & Lall, A. (1997). Developing measures of airport productivity and performance: an application of data envelopment analysis. *Transportation Research Part E: Logistics and Transportation Review*, *33*(4), 261–273.

Global Energy Observatory. (2012). Bahia de Bizkaia (BBE) CCGT Power Plant Spain. *Global Energy Observatory*. Retrieved August 20, 2014, from http://globalenergyobservatory.org/geoid/43768

Goel, V., Furman, K., Song, J., & El-Bakry, A. (2012). Large neighborhood search for LNG inventory routing. *Journal of Heuristics*, *18*(6), 821–848.

Golany, B., & Roll, Y. (1989). An application procedure for DEA. *Omega*, *17*(3), 237–250.

Grabau, D. (2013). Use integrally geared compressors for small-scale LNG. *Gas Processing News*. Retrieved August 05, 2014, from http://www.gasprocessingnews.com/features/201310/use-integrally-geared-compressors-for-small-scale-lng.aspx

Grin, R., de Wilde, J., & van Doorn, J. (2005). *Assessment of LNG Transport Chains Using Weather-Based Voyage Simulations* (No. 3). Alexandria: Society of Naval Architects and Marine Engineers.

Habibullah, A., Lardi, P., & Passmore, M. (2009). LNG conceptual design strategies. In *The 88th GPA Annual Convention*. San Antonio: WorleyParsons.

Hambuecker, A., & Isalski, H. (n.d.). Mitigating LNG plant risks in compact spaces. *Oil & Gas Technology China*. Retrieved August 14, 2014, from http://www.tge-gas.com/sites/cms/tge/WebFiles/08 summer - Oil and Gas Technology China - Article.pdf

Haralambides, H., & Gujar, G. (2012). On balancing supply chain efficiency and environmental impacts: An eco-DEA model applied to the dry port sector of India. *Maritime Economics & Logistics*, *14*(1), 122–137.

Harperscheidt, J. (2011). Bunkering, infrastructure, storage, and processing of LNG. *Ship & Offshore*, *1*(1), 12–15.

Hawdon, D. (2003). Efficiency, performance and regulation of the international gas industry - a bootstrap DEA approach. *Energy Policy*, *31*(11), 1167–1178.

Hjalmarsson, L., & Veiderpass, A. (1992). Productivity in Swedish electricity retail distribution. *The Scandinavian Journal of Economics*, *94*(1), 193–205.

Honeywell Building Solutions. (2007). *Honeywell protects new Transgás LNG terminal and alternative energy supply to Iberian Peninsula*. Bracknell.

Huang, Y. (2011). *The Drivers of Rising Global Energy Demand: New Evidence* (No. 52). Cambridge: University of Cambridge.

Hulbert, M. (2010). *Unconventional gas: Producer pickle or consumer curse* (No. 76). Zurich: Center for Security Studies.

Hydrocarbons Technology. (2014). Fos Cavaou LNG Terminal: Fos-sur-Mer. *Hydrocarbons Technology*. Retrieved August 14, 2014, from http://www.hydrocarbons-technology.com/projects/fos-cavaou-lng-terminal-fos-sur-mer/

International Energy Agency. (2013). *World Energy Outlook 2013*. Paris: International Energy Agency.

International Gas Union. (2013). *World LNG Report - 2013 Edition*. Fornebu: International Gas Union.

Islam, S., & Olsen, T. (2013). Factors affecting seaport capacity: Managerial implications for a simulation framework. In *22nd National Conference of the Australian Society for Operations Research*. Adelaide: ASOR.

Jamasb, T., & Pollitt, M. (2003). International benchmarking and regulation: an application to European electricity distribution utilities. *Energy Policy*, *31*(15), 1609–1622.

Jarvie, D., Hill, R., Ruble, T., & Pollastro, R. (2007). Unconventional shale-gas systems: The Mississippian Barnett Shale of north-central Texas as one model for thermogenic shale-gas assessment. *AAPG Bulletin*, *91*(4), 475–499.

Jenkins, L., & Anderson, M. (2003). A multivariate statistical approach to reducing the number of variables in data envelopment analysis. *European Journal of Operational Research*, *147*(1), 51–61.

Jensen, J. (2004). *The Development of a Global LNG Market* (No. 5). Oxford: Oxford Institute for Energy Studies.

Kaare, K., Koppel, O., & Leppiman, A. (2013). The Eastern Baltic LNG terminal as a prospect to improve security of regional gas supply. In *Proceedings of the 2013 International Conference on Environment, Energy, Ecosystems and Development*. Tallinn: Tallinn University of Technology.

Kashani, H. (2005a). Regulation and efficiency: an empirical analysis of the United Kingdom continental shelf petroleum industry. *Energy Policy*, *33*(7), 915–925.

Kashani, H. (2005b). State intervention causing inefficiency: an empirical analysis of the Norwegian Continental Shelf. *Energy Policy*, *33*(15), 1998–2009.

Kaspar, J., & Hambuecker, A. (2007). Reganosa LNG Terminal - La Coruna - Spain. In *LNG-15 Conference*. Barcelona: Tractebel Gas Engineering.

Khai, H., & Yabe, M. (2011). Technical efficiency analysis of rice production in Vietnam. *Journal of ISSAAS*, *17*(1), 135–146.

King & Spalding. (2008). *LNG in Europe: An Overview of European Import Terminals*. Houston: King & Spalding.

Kingma, D., Lijesen, M., & Mulder, M. (2002). Gas-to-gas competition versus oil price linkage. In *25th Annual International Conference of the IAEE*. The Hague: CPB.

Koopmans, T. (1951). Activity Analysis of Production and Allocation. In *Activity Analysis of Production and Allocation Conference*. New York: John Wiley & Sons.

Kulshreshtha, M., & Parikh, J. (2002). Study of efficiency and productivity growth in opencast and underground coal mining in India: a DEA analysis. *Energy Economics*, *24*(5), 439–453.

Kumar, S., Kwon, H., Choi, K., Hyun Cho, J., Lim, W., & Moon, I. (2011). Current status and future projections of LNG demand and supplies: A global prospective. *Energy Policy*, *39*(7), 4097–4104.

Kumbhakar, S., & Lovell, C. (2000). *Stochastic Frontier Analysis* (1st ed.). Cambridge: Cambridge University Press.

Le Coq, C., & Paltseva, E. (2009). Measuring the security of external energy supply in the European Union. *Energy Policy*, *37*(11), 4474–4481.

Leblond, D. (2008). Pipe damage delays Fos Cavaou LNG regas start-up. *Oil & Gas Journal*. Retrieved August 14, 2014, from http://www.ogj.com/articles/2008/02/pipe-damage-delays-fos-cavaou-lng-regas-start-up.html

Lightfoot, H. (2007). Understand the three different scales for measuring primary energy and avoid errors. *Energy*, *32*(8), 1478–1483.

Lin, W., Liu, C., & Chu, C. (2005). Performance efficiency evaluation of the Taiwan's shipping industry: an application of data envelopment analysis. In *Proceedings of the Eastern Asia Society for Transportation Studies*. Poznan: Poznan University of Economics.

LNG market. (2013a). Montoir de Bretagne LNG Terminal. *LNG market*. Retrieved August 11, 2014, from http://www.lngmarket.com/installation/Montoir-de-Bretagne-LNG-Terminal-21

LNG market. (2013b). Sines LNG Terminal (Sines). *LNG market*. Retrieved August 20, 2014, from http://www.lngmarket.com/installation/Sines-LNG-Terminal-70

Lotfi, F., & Jahanshahloo, G. (2007). Non-Discretionary Factors and Imprecise Data in DEA. *International Journal of Mathematical Analysis*, *1*(5), 237–246.

Madhanagopal, R., & Chandrasekaran, R. (2014). Selecting Appropriate Variables for DEA Using Genetic Algorithm (GA) Search Procedure, *1*(2), 28–33.

Marine Traffic. (2014). FSRU Toscana. *Marine Traffic*. Retrieved August 11, 2014, from http://www.marinetraffic.com/en/ais/details/ships/247323700

Martinez-Budria, E., Diaz-Armas, R., Navarro-Ibanez, M., & Ravelo-Mesa, T. (1999). A study of the efficiency of Spanish port authorities using data envelopment analysis. *International Journal of Transport Economics*, *26*(2), 237–253.

Maxwell, D., & Zhu, Z. (2011). Natural gas prices, LNG transport costs, and the dynamics of LNG imports. *Energy Economics*, *33*(2), 217–226.

Meagher, J. (2010). LNG's unexpected,unconventional shift. *Petroleum Economist*. Retrieved July 29, 2014, from http://www.petroleum-economist.com/Article/2731201/LNGs-unexpected-unconventional-shift.html

Medina-Borja, N. (2002). *A non-parametric approach to evaluate the performance of social service organizations*. Virginia State University.

Miyamoto, A., Ishiguro, C., & Nakamura, M. (2012). *A Realistic Perspective on Japan's LNG Demand after Fukushima* (No. 62). Oxford: Oxford Institute for Energy Studies.

Morita, H., & Avkiran, N. (2009). Selecting inputs and outputs in data envelopment analysis by designing statistical experiments, *52*(2), 163–173.

Morita, H., & Haba, Y. (2005). Variable Selection in Data Envelopment Analysis Based on External Information. In *8th Czech-Japan Seminar on Data Analysis and Decision Making Under Uncertainty*. Trest: UTIA.

Muñiz, M. (2002). Separating managerial inefficiency and external conditions in data envelopment analysis. *European Journal of Operational Research*, *143*(3), 625–643.

Muñiz, M., Paradi, J., Ruggiero, J., & Yang, Z. (2006). Evaluating alternative DEA models used to control for non-discretionary inputs. *Computers & Operations Research*, *33*(5), 1173–1183.

Munksgaard, J., Pade, L., & Fristrup, P. (2005). Efficiency gains in Danish district heating. Is there anything to learn from benchmarking? *Energy Policy*, *33*(15), 1986–1997.

Neumann, A. (2008). *Linking natural gas markets: Is LNG doing its job?* (No. 822). Berlin: German Institute for Economic Research.

Newbery, D. (2000). *Privatization, Restructuring and Regulation of Network Utilities*. Cambridge: MIT Press.

Open Source DEA. (2014). Open Source DEA. *Open Source DEA*. Retrieved August 10, 2014, from http://www.opensourcedea.org/index.php?title=Open_Source_DEA

Ozcan, Y. (2008). *Health Care Benchmarking and Performance Evaluation* (Hardcover.). New York: Springer Science & Business Media.

Panayides, P., Maxoulis, C., Wang, T., & Ng, K. (2009). A Critical Analysis of DEA Applications to Seaport Economic Efficiency Measurement. *Transport Reviews*, *29*(2), 183–206.

Park, R., & De, P. (2004). An alternative approach to efficiency measurement of seaports. *Maritime Economics & Logistics*, *6*(1), 53–69.

Pascoe, S., Kirkley, J., Greboval, D., & Morrison-Paul, C. (2003). *Measuring and assessing capacity in fisheries*. Rome: Food and Agriculture Organization of the United Nations.

Pastor, J., Ruiz, J., & Sirvent, I. (2002). A statistical test for nested radial DEA models. *Operations Research*, *50*(4), 728–735.

Peiris, N., Cushing, A., Lubkowski, Z., & Scarr, D. (2006). Dynamic Analysis and Design of Large-Diameter LNG Tanks to Resist Seismic Events. In *1st European Conference on Earthquake Engineering and Seismology*. Geneva: ECEE.

Pfeifer, S. (2012, October 29). Europe plans more import terminal. *The Financial Times*.

Poitras, G., Tongzon, J., & Li, H. (1996). *Measuring Port Efficiency: An Application of Data Envelopment Analysis*. Singapore: National University of Singapore.

Pollitt, M. (1996). Ownership and Efficiency in Nuclear Power Production. *Oxford Economic Papers*, *48*(2), 342–360.

Portela, M., Borges, P., & Thanassoulis, E. (2003). Finding closest targets in non-oriented DEA models: the case of convex and non-convex technologies. *Journal of Productivity Analysis*, *19*(2), 251–269.

Rączka, J. (2001). Explaining the performance of heat plants in Poland. *Energy Economics*, *23*(4), 355–370.

Ratner, M., Belkin, P., Nichol, J., & Woehrel, S. (2013). *Europe 's Energy Security: Options and Challenges to Natural Gas Supply Diversification*. Washington DC: Congressional Research Service.

Ray, S. (1991). Resource-use efficiency in public schools: a study of Connecticut data. *Management Science*, *37*(12), 1620–1628.

Rogers, H., & Stern, J. (2014). *Challenges to JCC Pricing in Asian LNG Markets* (No. 81). Oxford: Oxford Institute for Energy Studies.

Roll, Y., & Hayuth, Y. (1993). Port performance comparison applying data envelopment analysis (DEA). *Maritime Policy & Management*, *20*(2), 153–161.

Royal Haskoning DHV. (n.d.). *LNG as a Bunker Fuel: Future Demand Prospects & Port Design Options*. Nijmegen: Royal Haskoning DHV.

Ruester, S., & Neumann, A. (2006). Economics of the LNG Value Chain and Corporate Strategies An Empirical Analysis of the Determinants of Vertical Integration. In *10th Annual ISNIE conference*. Boulder: ISNIE.

Ruggiero, J. (1996). On the measurement of technical efficiency in the public sector. *European Journal of Operational Research*, *90*(3), 553–565.

Ruggiero, J. (1998). Non-discretionary inputs in data envelopment analysis. *European Journal of Operational Research*, *111*(3), 461–469.

Ruggiero, J. (2004). Performance evaluation when non-discretionary factors correlate with technical efficiency. *European Journal of Operational Research*, *159*(1), 250–257.

Ruggiero, J. (2005). Impact Assessment of Input Omission on DEA. *International Journal of Information Technology and Decision Making*, *4*(3), 359–368.

Ruggiero, J. (2007). Non-Discretionary Inputs. In J. Zhu & W. Cook (Eds.), *Modeling Data Irregularities and Structural Complexities in Data Envelopment Analysis* (1st ed., pp. 85–102). Boston: Springer US.

Ruggiero, J. (2011). Data Envelopment Analysis. In J. Ruggiero (Ed.), *Frontiers in Major League Baseball* (1st ed., pp. 7–20). New York: Springer New York.

Scarr, D., & Jackson, G. (2007). Achieving Economies of Scale with Very Large LNG Storage Tanks. In *LNG-15 Conference*. Des Plaines: GTI.

Schafer, M. (2014). Science Thesis Writing Discussion. *University of Florida*. Retrieved June 22, 2014, from http://web.clas.ufl.edu/users/msscha/ThesisCSS/thesis_disc.html

SGS Belgium. (2013). *Niet-technische samenvatting mer voor uitbreiding van de nv Fluxys lng te Zeebrugge*. Antwerpen.

Shamoo, A., & Resnik, D. (2009). *Responsible Conduct of Research* (2nd ed.). New York: Oxford University Press.

Shell. (2014). What is LNG? *Shell Global*. Retrieved July 29, 2014, from http://www.shell.com/global/future-energy/natural-gas/liquefied-natural-gas/what-is-lng.html

Shephard, R. (1953). Cost and production functions, *82*(327), 1059–1061.

Sherman, H., & Zhu, J. (2006). *Service Productivity Management: Improving Service Performance using Data Envelopment Analysis (DEA)* (Hardcover.). New York: Springer Science & Business Media.

Siliverstovs, B., Hégaret, L., Neumann, A., & Von Hirschhausen, C. (2005). International Market Integration for Natural Gas ? A Cointegration Analysis of Prices in Europe , North America and Japan, *27*(194), 603–615.

Société du Terminal Méthanier de Fos Cavaou. (2010). *Information Memorandum: Sale of Access Capacity at the Fos Cavaou Terminal*. Fos-sur-Mer: Société du Terminal Méthanier de Fos Cavaou.

Songhurst, B. (2014). *LNG Plant Cost Escalation* (No. 83). Oxford: Oxford Institute for Energy Studies.

Stern, J. (2002). *Security of European natural gas supplies*. *London, the Royal Institute of International Affairs*. London: Royal Institute of International Affairs.

Stern, J. (2007). Is there a rationale for the continuing link to oil product prices in continental european long-term gas contracts? *International Journal of Energy Sector Management*, *1*(3), 221–239.

Stern, J. (2009). *Continental European Long-Term Gas Contracts: is a transition away from oil product-linked pricing inevitable and imminent?* (No. 34). Oxford: Oxford Institute for Energy Studies.

Stern, J., & Rogers, H. (2011). *The Transition to Hub-Based Gas Pricing in Continental Europe* (No. 49). Oxford: Oxford Institute for Energy Studies.

Stevens, P. (2010). *The “Shale Gas Revolution”: Hype and Reality*. London: Catham House.

Syrjänen, M. (2004). Non-discretionary and discretionary factors and scale in data envelopment analysis. *European Journal of Operational Research*, *158*(1), 20–33.

Tarlowski, J., & Sheffield, J. (2002). *LNG Import Terminals - Recent Developments*. Houston: KBR.

The Economist. (2014, April 5). European energy security: Conscious uncoupling. *The Economist*.

Thompson, R., Dharmapala, P., Rothenberg, L., & Thrall, R. (1996). DEA/AR efficiency and profitability of 14 major oil companies in US exploration and production. *Computers & Operations Research*, *23*(4), 357–373.

Thompson, R., Dharmapala, P., & Thrall, R. (1995). Linked-cone DEA profit ratios and technical efficiency with application to Illinois coal mines. *International Journal of Production Economics*, *39*(1), 99–115.

Thompson, R., Lee, E., & Thrall, R. (1992). DEA/AR-efficiency of US independent oil/gas producers over time. *Computers & Operations Research*, *19*(5), 377–391.

Tone, K. (2001). A slacks-based measure of efficiency in data envelopment analysis. *European Journal of Operational Research*, *130*(3), 498–509.

Tongzon, J. (2001). Efficiency measurement of selected Australian and other international ports using data envelopment analysis. *Transportation Research Part A: Policy and Practice*, *35*(2), 107–122.

TRADE. (1995). *How to Measure Performance: A Handbook of Techniques and Tools*. Oak Ridge: Oak Ridge Associated Universities.

Truett, L., & Truett, D. (1990). Regions of the production function, returns, and economies of scale: Further considerations. *Journal of Economic Education*, *21*(4), 411–419.

Truett, L., & Truett, D. (1995). Exploring the relation between returns to scale and pecuniary economies/diseconomies. *Journal of Economic Education*, *26*(2), 140–149.

Tugnoli, A., Paltrinieri, N., Landucci, G., & Cozzani, V. (2010). LNG regasification terminals: comparing the inherent safety performance of innovative technologies. *Chemical Engineering Transactions*, *19*(39), 391–396.

Tusiani, M., & Shearer, G. (2007). *LNG: A Nontechnical Guide* (Hardcover.). Oklahoma: PennWell Books.

Valentine, V., & Gray, R. (2001). The measurement of port efficiency using Data Envelopment Analysis. In *9th World Conference on Transport Research*. Seoul: WCTR Society.

Van Asperen, E., Dekker, R., Polman, M., & de Swaan Arons, H. (2003). Arrival processes in port modeling: insights from a case study. In *35th Conference on Winter Simulation: Driving Innovation*. New Orleans: WSC.

Von Hirschhausen, C., & Neumann, A. (2008). Long-Term Contracts and Asset Specificity Revisited: An Empirical Analysis of Producer–Importer Relations in the Natural Gas Industry. *Review of Industrial Organization*, *32*(2), 131–143.

Waddams Price, C., & Weyman-Jones, T. (1996). Malmquist indices of productivity change in the UK gas industry before and after privatization. *Applied Economics*, *28*(1), 29–39.

Waters, L., Mueller, C., Hellen, P., & Hurst, G. (2007). *Design and Construction of Gravity Based Structure and Modularized LNG Tanks for the Adriatic LNG Terminal*. Houston: Exxon Mobil Corporation.

Weisser, H. (2007). The security of gas supply—a critical issue for Europe? *Energy Policy*, *35*(1), 1–5.

Weyman-Jones, T. (1991). Productive efficiency in a regulated industry. *Energy Economics*, *13*(2), 116–122.

Wijngaarden, W. (2004). Offshore LNG terminal: sunk or floating. In *Offshore Technology Conference*. Houston: Offshore Technology Conference.

World Port Source. (2014). Port of La Spezia. *World Port Source*. Retrieved August 20, 2014, from http://www.worldportsource.com/ports/commerce/ITA_Port_of_La_Spezia_1069.php

X-Rates. (2014). Historic Exchange Rates. *X-Rates*. Retrieved August 11, 2014, from http://www.x-rates.com/historical/

Yang, H., & Pollitt, M. (2009). Incorporating both undesirable outputs and uncontrollable variables into DEA: The performance of Chinese coal-fired power plants. *European Journal of Operational Research*, *197*(3), 1096–1105.

Yang, Z., & Paradi, J. (2006). Cross firm bank branch benchmarking using“ Handicapped” data envelopment analysis to adjust for corporate strategic effects. In *39th Hawaii International Conference on System Sciences*. Kauai: IEEE.

Yun, Y., Nakayama, H., & Tanino, T. (2002). Dual Approach to Generalized Data Envelopment Analysis based on Production Possibility. In T. Trzaskalik & J. Michnik (Eds.), *Multiple Objective and Goal Programming: Recent*

Developments (1st ed., pp. 196–205). Heidelberg: Springer-Verlag Berlin Heidelberg.

Yun, Y., Nakayama, H., Tanino, T., & Arakawa, M. (1999). A Multi-Objective Optimization Method Combining Generalized Data Envelopment Analysis and Genetic Algorithms. In *1999 IEEE, Man, and Cybernetics*. Tokyo: IEEE.

Yun, Y., Nakayama, H., Tanino, T., & Arakawa, M. (2001). Generation of Efficient Frontiers in Multi-Objective Optimization Problems by Generalized Data Envelopment Analysis. *European Journal of Operational Research*, *129*(3), 586–595.

Zeus Intelligence. (2014). World LNG Trade Database. *Zeus Intelligence*. Houston. Retrieved August 09, 2014, from http://member.zeusintel.com/lng/export/index.aspx

Zhou, P., Ang, B., & Poh, K. (2008). A survey of data envelopment analysis in energy and environmental studies. *European Journal of Operational Research*, *189*(1), 1–18.

Appendices

Appendix 1, Explanation of geographical groupings (BP, 2014, p. 44).
North America: US (excluding Puerto Rico), Canada, Mexico.

South & Central America: Caribbean (including Puerto Rico), Central and South America.

Europe: European members of the OECD plus Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Cyprus, Former Yugoslav Republic of Macedonia, Gibraltar, Malta, Romania, Serbia and Montenegro.

Former Soviet Union: Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan.

Europe & Eurasia: All countries listed above under the headings Europe and Former Soviet Union.

Middle East: Arabian Peninsula, Iran, Iraq, Israel, Jordan, Lebanon, Syria.

North Africa: Territories on the north coast of Africa from Egypt to western Sahara.

West Africa: Territories on the west coast of Africa from Mauritania to Angola, including Cape Verde, Chad.

East and Southern Africa: Territories on the east coast of Africa from Sudan to Republic of South Africa. Also Botswana, Madagascar, Malawi, Namibia, Uganda, Zambia, Zimbabwe.

Asia Pacific: Brunei, Cambodia, China, China Hong Kong SAR*, Indonesia, Japan, Laos, Macau, Malaysia, Mongolia, North Korea, Philippines, Singapore, South Asia (Afghanistan, Bangladesh, India, Myanmar, Nepal, Pakistan, Sri Lanka), South Korea, Taiwan, Thailand, Vietnam, Australia, New Zealand, Papua New Guinea, Oceania. *Special Administrative Region.

Australasia: Australia, New Zealand.

OECD members:
Europe: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Republic of Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, UK.
Other member countries: Australia, Canada, Chile, Israel, Japan, Mexico, New Zealand, South Korea, US.

OPEC members:
Middle East: Iran, Iraq, Kuwait, Qatar, Saudi Arabia, United Arab Emirates.
North Africa: Algeria, Libya. West Africa: Angola, Nigeria.
South America: Ecuador, Venezuela.

European Union members: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Republic of Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, UK.

Non-OECD: All countries that are not members of the OECD.

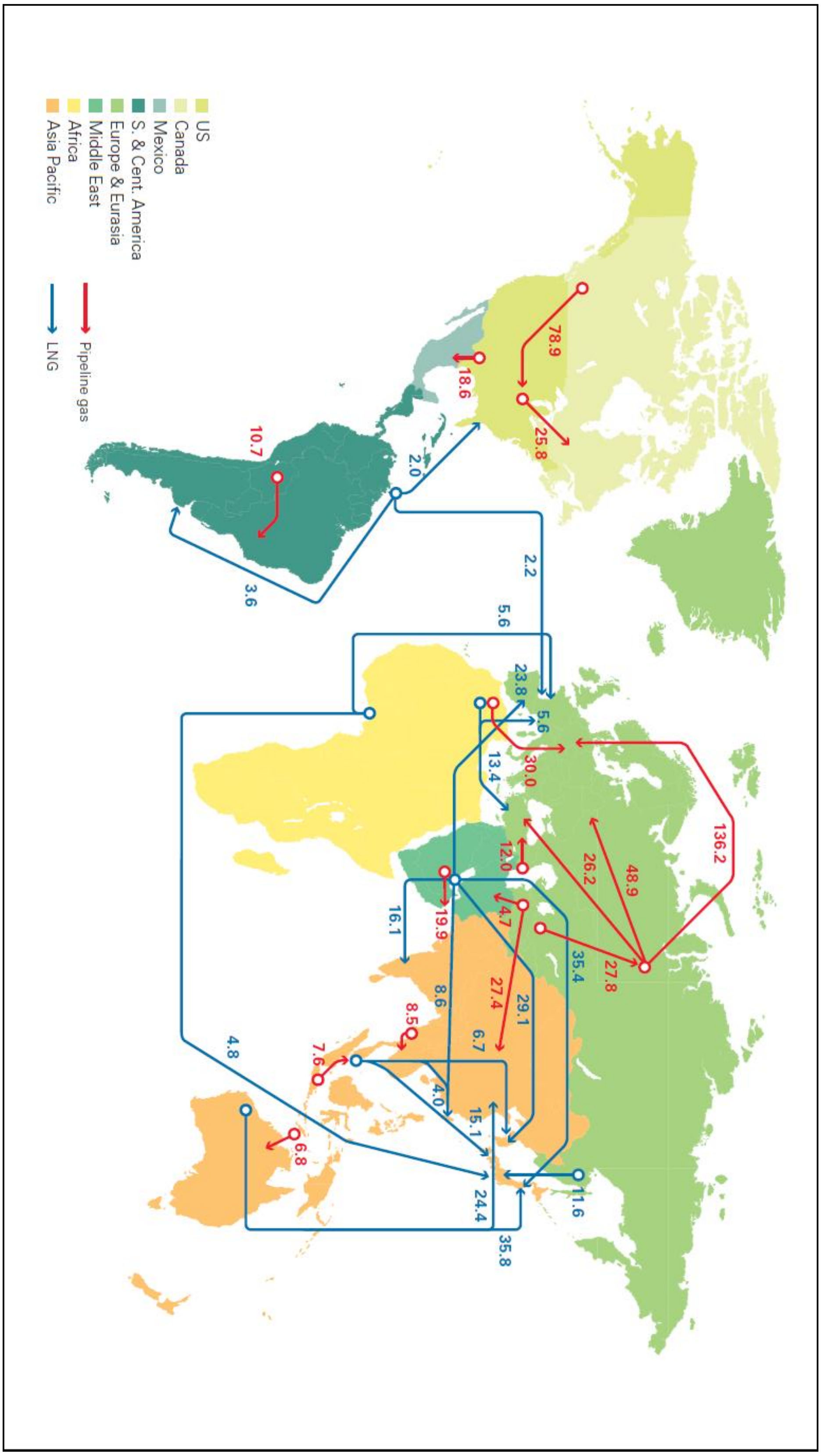
Appendix 2, Gas trade in 2012 and 2013 (BP, 2014).

Table 14, Gas trade in 2012 and 2013 (BP, 2014).

	2012				2013			
(BCM)	**Pipeline imports**	**LNG imports**	**Pipeline exports**	**LNG exports**	**Pipeline imports**	**LNG imports**	**Pipeline exports**	**LNG exports**
US	83.8	4.9	45.1	0.9	78.9	2.7	44.4	0.1
Canada	27.5	1.8	83.8	-	25.8	1.1	78.9	-
Mexico	17.6	4.8	-	-	18.6	7.8	-	-
Trinidad and T.	-	-	-	18.9	-	-	-	19.8
Other America	15.8	15.2	15.8	5.5	18.6	19.6	18.6	5.7
France	32.3	10.3	1.2	0.2	30.5	8.7	1.1	0.6
Germany	83.5	-	12.5	-	95.8	-	15.1	-
Italy	55.4	7.1	0.1	-	51.6	5.5	0.2	-
Netherlands	20.9	0.8	48.6	-	21.5	0.8	53.2	0.2
Norway	-	-	107.6	4.8	0.0	-	102.4	3.8
Spain	13.3	20.4	0.7	1.2	15.3	14.9	0.9	2.6
Turkey	37.4	7.7	0.6	-	38.2	6.1	0.6	-
UK	37.7	13.7	12.0	-	41.9	9.3	8.9	-
Other Europe	101.9	8.2	10.5	1.6	102.2	6.1	11.9	1.6
Russian Fed.	29.8	-	194.2	14.8	27.8	-	211.3	14.2
Ukraine	29.4	-	-	-	26.9	-	-	-
Other F.S.U.	29.3	-	63.3	-	29.5	-	68.5	-
Qatar	-	-	19.2	103.1	-	-	19.9	105.6
Other Middle E.	24.4	4.6	8.8	25.7	25.1	4.5	9.4	28.5
Algeria	-	-	34.2	15.3	-	-	28.0	14.9
Other Africa	6.3	-	9.7	38.5	6.4	-	8.6	31.6
China	21.4	20.0	2.8	-	27.4	24.5	2.8	-
Japan	-	118.8	-	-	-	119.0	-	-
Indonesia	-	-	10.2	24.8	-	-	8.9	22.4
South Korea	-	49.1	-	-	-	54.2	-	-
Other Asia P.	28.8	36.7	15.8	68.9	28.5	40.4	16.9	73.5
Total World	696.6	324.2	696.6	324.2	710.6	325.3	710.6	325.3

Appendix 3, Major trade movements natural gas 2013 (BP, 2014).

Figure 4, Major trade movements natural gas 2013 (BP, 2014).



Appendix 4, Scale distinctions LNG import terminals (Danish Maritime Authority, 2012).

Table 15, Scale distinctions LNG import terminals (Danish Maritime Authority, 2012).

	Large-scale	Medium-scale	Small-scale
Storage capacity	≥ 100000 m3	10000-100000 m3	< 10000 m3
Ship capacity	≥ 100000 m3	10000-100000 m3	< 10000 m3

Appendix 5, European LNG import terminals (Zeus Intelligence, 2014).

Table 16, European LNG import terminals (Zeus Intelligence, 2014).

	Storage capacity	Ship capacity
Grain LNG	1000000 m3	266000 m3
South Hook LNG	775000 m3	265000 m3
Barcelona Terminal	760000 m3	266000 m3
Huelva Terminal	619500 m3	173400 m3
Sagunto	600000 m3	266000 m3
Gartagena Terminal	587000 m3	266000 m3
Gate LNG	540000 m3	266000 m3
Sines LNG	390000 m3	216000 m3
Zeebrugge LNG	380000 m3	266000 m3
Montoir-de-Bretage LNG	360000 m3	265000 m3
Fos-Cavaou	330000 m3	270000 m3
Dragon LNG	320000 m3	217000 m3
Bahia de Bizkaia LNG	300000 m3	270000 m3
Galician Terminal	300000 m3	266000 m3
Aliaga LNG	280000 m3	265000 m3
Marmara Ereglisi	255000 m3	130000 m3
Adriatic LNG	250000 m3	152000 m3
Fos-Tonkin LNG	150000 m3	75000 m3
Teesside LNG	138000 m3	150900 m3
Livorno FSRU	135000 m3	155000 m3
Revithoussa LNG	130000 m3	135000 m3
Panigaglia-Portovenere	100000 m3	70000 m3
Brunnsvikholme LNG	20000 m3	15000 m3
Øra LNG (Fredrikstad)	6500 m3	15000 m3
Mosjøen LNG	3500 m3	1100 m3

Appendix 6, Variables after first data search (Author).

Table 17, Variables after first data search (Author).

Variable	**Description**
Type	Type of LNG terminal
Age	Amount of years in operation
Annual unloading capacity	LNG unloading capacity
Annual regasification capacity	Capacity to regasify LNG
Maximum sendout capacity	Peak sendout capacity
Storage capacity	Capacity to store LNG
Tanks	Amount of LNG storage tanks
Surface area	Area covered by LNG terminal
Jetties	Amount of jetties available for vessels
Vessel capacity	The maximum receivable vessel size
Capital costs	Total investments (including expansions)

Appendix 7,Sources used for data collection (Author).

Table 18, Sources used for data collection (Author).

Variable	**Source**
Type	Zeus Intelligence
Age	GLE
Annual unloading capacity	Zeus Intelligence & additional
Annual regasification capacity	GLE
Maximum sendout capacity	GLE
Storage capacity	GLE
Tanks	GLE
Surface area	Zeus Intelligence, Google Earth Pro & additional
Jetties	GLE, Zeus Intelligence
Vessel capacity	GLE
Capital costs	Zeus Intelligence & additional

The table above indicates the sources used to collect data on the variables mentioned. The sources shall be shortly discussed:

Zeus Intelligence (Zeus Intelligence, 2014).

This data originates from the World LNG Trade Database developed by Zeus Intelligence.

GLE (Gas LNG Europe, 2014).

This data originates from the LNG Map (& Database) developed by Gas LNG Europe (GLE).

Google Earth Pro.

Google Earth Pro is a software program developed by Google that (among others) makes it possible to measure distances and surface areas.

Additional

Any other source, than the ones mentioned before, used for data collection are presented in Appendix 8.

Appendix 8, Variables with multiple sources (Author).

Table 19, Variables with multiple sources (Author).

Terminal	Unloading	Surface area	Jetties	Capital costs
Zeebrugge LNG	(Zeus Intelligence, 2014)	(SGS Belgium, 2013)	(Gas LNG Europe, 2014)	(Fluxys, 2013; King & Spalding, 2008)
Montoir-de-Bretagne	(LNG market, 2013*a*)	(Zeus Intelligence, 2014)	(Gas LNG Europe, 2014)	-
Fos-Tonkin	(Zeus Intelligence, 2014)	(GDF Suez, 2008)	(Gas LNG Europe, 2014)	-
Fos-Cavaou	(Zeus Intelligence, 2014)	(Société du Terminal Méthanier de Fos Cavaou, 2010)	(Gas LNG Europe, 2014)	(King & Spalding, 2008)
Revithoussa	(Zeus Intelligence, 2014)	Google Earth Pro	(Gas LNG Europe, 2014)	-
Panigaglia-Portovenere	(Zeus Intelligence, 2014)	(World Port Source, 2014)	(Gas LNG Europe, 2014)	-
Adriatic LNG	(Zeus Intelligence, 2014)	(Waters et al., 2007)	(Gas LNG Europe, 2014)	(King & Spalding, 2008)
Livorno FSRU	(Zeus Intelligence, 2014)	(Marine Traffic, 2014)	(Gas LNG Europe, 2014)	(Zeus Intelligence, 2014)
Gate Terminal	(Zeus Intelligence, 2014)	(Gate Terminal, 2014)	(Gas LNG Europe, 2014)	(Gate Terminal, 2014)
Sines	(Zeus Intelligence, 2014)	(Honeywell Building Solutions, 2007)	(Gas LNG Europe, 2014)	(LNG market, 2013*b*)
Barcelona	(Zeus Intelligence, 2014)	Google Earth Pro	(Gas LNG Europe, 2014)	-
Huelva	(Zeus Intelligence, 2014)	Google Earth Pro	(Gas LNG Europe, 2014)	-
Cartagena	(Zeus Intelligence, 2014)	Google Earth Pro	(Gas LNG Europe, 2014)	-
Bahia de Bizkaia LNG	(Zeus Intelligence, 2014)	(Global Energy Observatory, 2012)	(Gas LNG Europe, 2014)	(European Investment Bank, 2013; King & Spalding, 2008)

Table 19, continued.

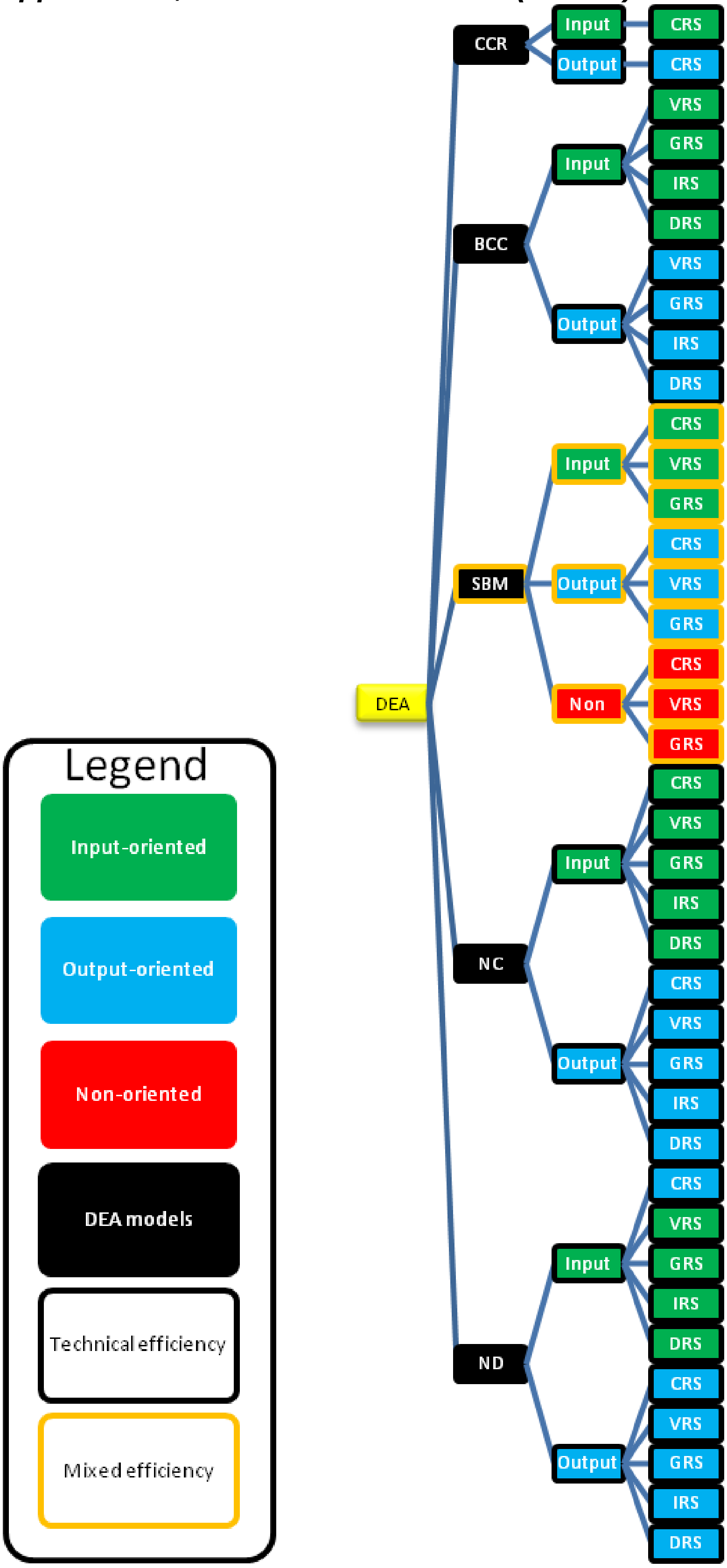
Terminal	Unloading	Surface area	Jetties	Capital costs
Sagunto	(Zeus Intelligence, 2014)	(Zeus Intelligence, 2014)	(Gas LNG Europe, 2014)	(Zeus Intelligence, 2014)
Galician Terminal	(Zeus Intelligence, 2014)	(Hambuecker & Isalski, n.d.)	(Gas LNG Europe, 2014)	(King & Spalding, 2008)
Marmara Ereglisi	(Zeus Intelligence, 2014)	Google Earth Pro	(Gas LNG Europe, 2014)	(King & Spalding, 2008)
Aliaga LNG	(Zeus Intelligence, 2014)	Google Earth Pro	(Gas LNG Europe, 2014)	(Zeus Intelligence, 2014)
Grain LNG	(Zeus Intelligence, 2014)	(Cullen, 2004)	(Gas LNG Europe, 2014)	(Farey, 2010)
South Hook LNG	(Zeus Intelligence, 2014)	(Evans, 2004)	(Gas LNG Europe, 2014)	(Enerdata, 2014)
Dragon LNG	(Zeus Intelligence, 2014)	Google Earth Pro	(Zeus Intelligence, 2014)	(King & Spalding, 2008)
Teesside LNG	(Fisher, 2009)	Google Earth Pro	(Gas LNG Europe, 2014)	(Baldwin, 2008)

Appendix 9, Missing data and excluded terminals (Author).

Table 20, Missing data and excluded terminals (Author).

Terminal	Reason for exclusion
Zeebrugge LNG	-
Montoir-de-Bretagne	Missing data on capital costs
Fos-Tonkin	Missing data on capital costs
Fos-Cavaou	-
Revithoussa	Missing data on capital costs
Panigaglia-Portovenere	Missing data on capital costs
Adriatic LNG	-
Livorno FSRU	-
Gate Terninal	-
Sines LNG	-
Barcelona	Missing data on capital costs
Huelva	Missing data on capital costs
Cartagena	Missing data on capital costs
Bahia de Bizkaia LNG	-
Sagunto	-
Galician	-
Marmara Ereglisi	-
Aliaga LNG	-
Grain LNG	-
South Hook LNG	-
Dragon LNG	-
Teesside LNG	-
Mosjøen	Small-scale terminal
Øra LNG (Fredrikstad)	Small-scale terminal
Brunnsviksholme LNG	Small-scale terminal

Appendix 10, Available DEA models (Author).



Appendix 11, Efficiency scores of test run (Author).

Table 21, Efficiency scores of test run (Author).

DMU Name	Objective Value (φ/1)	Efficient
Zeebrugge LNG	1	Yes
Fos-Cavaou	0.693012497	
Adriatic LNG	1	Yes
Livorno FSRU	0.855704698	
Gate LNG	1	Yes
Sines LNG	1	Yes
Bahia de Bizkaia LNG	0.762509726	
Sagunto	1	Yes
Galician Terminal	0.887708108	
Marmara Ereglisi	0.788708597	
Aliaga LNG	0.930158093	
Grain LNG	1	Yes
South Hook LNG	1	Yes
Dragon LNG	0.947461348	
Teesside LNG	1	Yes
Efficient DMU's	8	

Appendix 12, Efficiency scores excluding certain variables (Author).

Table 22, Excluding unloading capacity (Author).

DMU Name	Objective Value (φ/1)	Efficient
Zeebrugge LNG	1	Yes
Fos-Cavaou	0.693012497	
Adriatic LNG	1	Yes
Livorno FSRU	0.855704698	
Gate LNG	1	Yes
Sines LNG	1	Yes
Bahia de Bizkaia LNG	0.762509726	
Sagunto	1	Yes
Galician Terminal	0.887708108	
Marmara Ereglisi	0.788708597	
Aliaga LNG	0.930158093	
Grain LNG	1	Yes
South Hook LNG	1	Yes
Dragon LNG	0.87739047	
Teesside LNG	1	Yes
Efficient DMU's	8	

Table 23, Excluding regasification capacity (Author).

DMU Name	Objective Value (φ/1)	Efficient
Zeebrugge LNG	1	Yes
Fos-Cavaou	0.689096276	
Adriatic LNG	1	Yes
Livorno FSRU	0.855704698	
Gate LNG	1	Yes
Sines LNG	1	Yes
Bahia de Bizkaia LNG	0.628300783	
Sagunto	1	Yes
Galician Terminal	0.887708108	
Marmara Ereglisi	0.76765361	
Aliaga LNG	0.852932438	
Grain LNG	1	Yes
South Hook LNG	1	Yes
Dragon LNG	0.947461348	
Teesside LNG	1	Yes
Efficient DMU's	8	

Table 24, Excluding storage capacity (Author).

DMU Name	Objective Value (φ/1)	Efficient
Zeebrugge LNG	1	Yes
Fos-Cavaou	0.693012497	
Adriatic LNG	1	Yes
Livorno FSRU	0.794314274	
Gate LNG	1	Yes
Sines LNG	1	Yes
Bahia de Bizkaia LNG	0.762509726	
Sagunto	1	Yes
Galician Terminal	0.558025128	
Marmara Ereglisi	0.788708597	
Aliaga LNG	0.914199481	
Grain LNG	1	Yes
South Hook LNG	1	Yes
Dragon LNG	0.947461348	
Teesside LNG	1	Yes
Efficient DMU's	8	

Table 25, Excluding maximum sendout capacity (Author).

DMU Name	Objective Value (φ/1)	Efficient
Zeebrugge LNG	0.82067512	
Fos-Cavaou	0.693012497	
Adriatic LNG	1	Yes
Livorno FSRU	0.855704698	
Gate LNG	1	Yes
Sines LNG	1	Yes
Bahia de Bizkaia LNG	0.762509726	
Sagunto	1	Yes
Galician Terminal	0.887708108	
Marmara Ereglisi	0.788708597	
Aliaga LNG	0.930158093	
Grain LNG	1	Yes
South Hook LNG	1	Yes
Dragon LNG	0.947461348	
Teesside LNG	1	Yes
Efficient DMU's	7	

Appendix 13, Examples of projection calculation (Sherman & Zhu, 2006).

Table 26, Example Sherman & Zhu (2006).

Output	λ 1	Efficient DMU 1	λ 2	Efficient DMU 2	Projection
X	0.2857	1000	0.7143	1000	
* λ		285.7		714.3	1000
Input	**λ 1**	**Efficient DMU 1**	**λ 2**	**Efficient DMU 2**	**Projection**
Y	0.2857	40	0.7143	20	
* λ		11.428		14.286	25.714
Z	0.2857	100	0.7143	200	
* λ		28.57		142.86	171.43

Table 27, Example Dragon LNG (Author).

Output	λ Sines	Sines	λ South Hook	South Hook	Projection
Unload	0.9418	5200000	0.0582	15600000	
* λ		4897360		907920	5805280
Regasification	0.9418	7.9000	0.0582	21	
* λ		7.4402		1.2222	8.6624
Storage	0.9418	390000	0.0582	775000	
* λ		367302		45105	412407
Input	**λ Sines**	**Sines**	**λ South Hook**	**South Hook**	**Projection**
Area	0.9418	23	0.0582	210	
* λ		21.6614		12.222	33.8834
Costs	0.9418	208	0.0582	930	
* λ		195.894		54.126	250.0204

Appendix 14, Methodological choices OSDEA (Author).

Table 28, Model details (Author).

Model Name	BCC IRS Output Oriented Excluding Sendout
Model Type	IRS_O
Model Orientation	OUTPUT_ORIENTED
Model Efficiency Type	TECH
Model RTS	INCREASING
Model Description	An extension of the Banker Charnes and Cooper Model (BCC) where the convexity constraint only allow INCREASING Returns to Scale. The only difference with the BCCO model is the fact e*Lambdas are as follows: 1 <= e*Lambdas
Return To Scale Lower Bound	1.0
Return To Scale Upper Bound	1.0

Table 29, Raw data (Author).

DMU Name	Unloading	Regasification	Storage	Area	Costs
Zeebrugge LNG	6700000	9	380000	32	755
Fos-Cavaou	5700000	8.25	330000	80	430
Adriatic LNG	6500000	7.56	250000	1.5	800
Livorno FSRU	2750000	3.75	135000	1.5	240
Gate LNG	8500000	12	540000	35	800
Sines LNG	5200000	7.9	390000	23	208
Bahia de Bizkaia LNG	4000000	7	300000	23	510
Sagunto	6800000	8.8	600000	22	535
Galician Terminal	2700000	3.6	300000	10	343
Marmara Ereglisi	4200000	6.2	255000	19	323.85
Aliaga LNG	4100000	6	280000	10	337
Grain LNG	15000000	19.5	1000000	385	1351
South Hook LNG	15600000	21	775000	210	930
Dragon LNG	5500000	7.6	320000	155	250
Teesside LNG	3000000	4.2	138000	1.5	120

Table 30, Variables (Author).

Variable Name	Variable Orientation	Variable Type
Unloading	OUTPUT	STANDARD
Regasification	OUTPUT	STANDARD
Storage	OUTPUT	STANDARD
Area	INPUT	STANDARD
Costs	INPUT	STANDARD

Appendix 15, Ratio of slacks over original input/output levels (Author).

Table 31, Ratio of slacks over original input/output levels (Author).

DMU Name	Unloading	Regasification	Storage	Area	Costs
Zeebrugge LNG	0	0.0428	0.2113	0	0
Fos-Cavaou	0.0271	0	0.0958	0	0
Adriatic LNG	0	0	0	0	0
Livorno FSRU	0.1469	0.1095	0	0	0
Gate LNG	0	0	0	0	0
Sines LNG	0	0	0	0	0
Bahia de Bizkaia LNG	0.3180	0	0.0670	0	0
Sagunto	0	0	0	0	0
Galician Terminal	0.6653	0.6399	0	0	0
Marmara Ereglisi	0.0337	0	0.1611	0	0
Aliaga LNG	0.0974	0	0	0	0
Grain LNG	0	0	0	0	0
South Hook LNG	0	0	0	0	0
Dragon LNG	0	0.0843	0.2333	0.7814	0
Teesside LNG	0	0	0	0	0

Appendix 16, LNG storage tanks (Author).

Table 32, LNG storage tanks (Author).

DMU Name	**Costs**	**Storage**	**Tanks**	**Size Tanks**	**Tank type**	**(φ/1)**
Grain LNG	1351	1000000	8	190000	FC	1
South Hook LNG	930	775000	5	155000	FC	1
Gate LNG	800	540000	3	188000	FC	1
Adriatic LNG	800	250000	2	-	-	1
Zeebrugge LNG	755	380000	4	119000	FC (in-ground)	0.8207
Sagunto	535	600000	4	150000	FC	1
Bahia de B. LNG	510	300000	2	150000	FC	0.7625
Fos-Cavaou	430	330000	3	110000	FC	0.6930
Galician Terminal	343	300000	2	150000	FC	0.8877
Aliaga LNG	337	280000	2	140000	FC	0.9302
Marmara Ereglisi	323.85	255000	3	85000	DC	0.7887
Dragon LNG	250	320000	2	165000	FC (in-ground)	0.9475
Livorno FSRU	240	135000	4	-	-	0.8557
Sines LNG	208	390000	3	120000	FC	1
Teesside LNG	120	138000	1	-	-	1