An Approaching Spot Market for LNG?

“The Drivers, Likelihood and Implications”

Combining a Social-Technical System Perspective with the Bottom-Up Agent-Based Modeling Paradigm to Assess the Drivers, Likelihood and Implications of a Transitioning International LNG Trade

Keywords: LNG Market, Spot Trade, Market Drivers, Agent-Based Modeling
Information about the Cover Page

Pictured on the cover page are the first LNG tanker that shipped a cargo of LNG, the Methane Pioneer and the world’s largest LNG tanker, the Mozah. In 1959 the Methane Pioneer, a converted World War II liberty freighter (i.e. the Normati) with a capacity of 5,000 cubic-meter, shipped a cargo of LNG from Lake Charles, Louisiana, to Canvey Island in the United Kingdom (Tusiani 2007). The Mozah, named after the wife of the Emir of Qatar Her Highness Sheikha Mozah Bint Nasser Al-Missned, holds a capacity of 266,000 cubic-meter and has made its maiden voyage to the South Hook LNG Terminal in Milford Haven, Wales (Qatargas 2008; 2009).
"The whole edifice of modern life is built upon it. Although energy can be bought and sold like any other commodity, it is not 'just another commodity,' but the precondition of all commodities, a basic factor equally with air, water and earth"

William Stanley Jevons (1835-1882)

"There are no facts only interpretations”

Friedrich Wilhelm Nietzsche (1844-1900)
Preface

This document represents the account of the Master Thesis project that was conducted by Robert Praet within the Energy & Industry Research Section of the Systems Engineering, Policy Analysis and Management Faculty at Delft University of Technology.

First of all, I wish to take this opportunity to thank my highly knowledgeable examination committee consisting of my graduation supervisor Dr. ir. G.P.J. Dijkema, secondary supervisor Dr. A.F. Correljé, external supervisor ir. E.J.L Chappin, and the head of the research section of E&I Prof. dr. ir. M.P.C. Weijenen for their continuous support, constructive criticism, and professional guidance. My thanks are also due to the other members of the Energy & Industry Section for providing me with an inspiring and hospitable working atmosphere during my graduation.

Finally I wish to thank my friends and family who made my years of study an interesting, shaping, and enjoyable experience in more ways than one can imagine. I owe much gratitude to my parents, sister and Eva for their continuous support, humor, freedom, patience, and love.
Executive Summary

This report represents the account of a Master Thesis Project that aimed to fulfill the following two research objectives:

- To understand the impact of imminent key market drivers and inhibitors on the development of the spot market for LNG by relating these with the trade decisions of its participants.

- To execute an explorative investigation that supplements the existing base of literature on the development of a spot market for LNG with a more quantitative analysis that makes use of agent-based modeling to assess the perceived transition of the LNG market that emanates from the decisions of the market participants.

These objectives follow the observation that the LNG market is subject to considerable changes that include but are not limited to: the expansion of the LNG trade, liberalization of natural gas and electricity markets, and the expansion of the global LNG infrastructure. It seems that the traditional LNG market with its long-term, high volume and low-risk project arrangements is giving way to the more flexible and short-term oriented spot market for LNG. Although the majority of the global LNG trade is currently governed by the Sales and Purchase Agreements with durations of up to 25 or 30 years, there seems to be a general consensus that the spot market for LNG will eventually amount to 15-30 percent of the global LNG trade. Although the current base of literature discusses the imminent key market drivers and inhibitors of the spot market for LNG and describes the future role of the LNG spot market, it remains unclear how this perceived market transition materializes. The following overall thesis question was therefore formulated:

- To what degree and under which conditions will a spot market for Liquefied Natural Gas materialize?

Providing this question with an effective answer required a rigorous investigation of the LNG market that involved two research steps, a LNG case study and the development of an agent-based simulation model. While the global LNG infrastructure is expanding rapidly the cost structure of the LNG value-chain is expected to widen the gap between the global regasification, shipping, and liquefaction capacities. Technological innovations include offshore liquefaction and regasification and the creation of LNG storage and trading hubs. As a matter of course, economics will determine the speed and way in which the global LNG infrastructure develops. From a social perspective it proved that the existing roles of the LNG Sellers (typically a joint venture between the NOC, IOC, and possibly upstream integrated customers) and LNG Buyers (integrated utilities, merchant gas transportation companies) are changing, while new ones are being created. While LNG Sellers are seeking to expand their LNG activities and gain customer preference, LNG Buyers are seeking to balance the benefits of secure long-term contracts with the flexibility of the short-term spot market.

With the LNG market fundamentals in place it was time to look at the process of market evolution, which showed that long-term bilateral trading in an expanding market is gradually being replaced by spot market trading. The subsequent identification of the existing traded models through the criteria of a ‘perfect’ commodity market made it clear that the contract arrangement that governs the majority of the LNG trade is the Sale and Purchase Agreement. The risk sharing logic of a SPA is perhaps best captured in the phrase ‘the buyer takes the volume risk and the seller takes the price risk’ (Jensen 2003) which are enforced by Take or Pay obligations, Destination clauses, and Price Sharing mechanisms. Market changes however require the market to move away from the traditional, highly structured, risk adverse LNG trade towards more flexible short-term trade arrangements. The market criteria of a ‘perfect’ spot market were subsequently used to assess the current LNG spot market and to identify its imminent key market drivers and inhibitors. This investigation classifies short-term contracts, spot cargoes, and cargo swaps with a maximum duration of 1 year as part of the LNG spot trade. For the market drivers it was found that these could be divided in three categories: economic, technical, and institutional. These include, but are not limited to, economies of scale, market liberalization, market expansion, innovative technologies, standardized contracts, and security of supply.

With the trading models and their drivers in place, the centre of attention turned to assessing their impact on the LNG market development though a mathematical Polynomial and Verhulst extrapolation of existing market data. The extrapolation results of the most reliable and complete data sets with the best data fit indicated that approximately 42 percent the LNG business will be traded on the spot market by 2030. Although this extrapolation shows that the LNG spot trade will continue to grow it does not show the
conditions under which this is the case and hence, is unable to satisfy the research objectives. As such, a different research approach was deemed necessary.

Consequently, this investigation proposed to use the agent-based modeling paradigm to capture the transition of the LNG market. The agent-based modeling paradigm proposes to model the autonomous parts of a complex system and look at their interactions and emergent behavior to unravel the systems complexities. In a way agent-based modeling can be said to model the forest through its individual components: the trees. The conceptual LNG-model that was subsequently constructed used the smallest autonomous part of the LNG market, its market participants, to assess the market transition. As such it envisioned LNG Agents (companies engaging in the LNG trade) that invest in LNG Projects (containing the components of the LNG value-chain), negotiate about LNG Contracts (containing the details of a partnership), and in a given LNG Scenario (containing possible futures trends of the LNG market) as a way to model the LNG market. More specifically it recognized that the strategic and managerial decisions of the LNG Agent and the impact of the imminent key market drivers and inhibitors on these decisions are essential in meeting the research objectives.

This investigation acknowledges that a transition of the LNG market is hard to realize through changes in the exogenous market drivers alone and argues that expectations about the future development influence the strategic and managerial decision making. Brito and Hartley (2007) argue that "while exogenous changes in costs or demand are critical to promoting a change in market structure, there is also a substantial endogenous component. Expectations about the evolution of the market influence investments and trading decisions and can make the change in market structure much faster and more abrupt". In order to enable the LNG Agent to make reasoned strategic and managerial decisions and model the impact of imminent key market drivers on these decisions, this research decided to use a adjusted stylized model of contracting that is based on the ideas of Diamond (1984), Diamond and Maskin (1979; 1980), and their adoption by Brito and Hartley (2007). The conceptual Agent-Based LNG-model was built on the existing Agent-based modeling knowledge base of the Energy & Industry Group at the Technology, Policy and Management faculty of Delft University of Technology and expanded with the adjusted model of contracting.

The LNG-model thus created views a shift in the LNG Agents timing of investment during the initiation of new LNG Projects as the most important indicator for a transition in the LNG market. While the traditional LNG market required firms to have a long-term SPA in place before investing in LNG infrastructure, the alternate or global LNG market envisions firms to invest in LNG infrastructure before such an agreement is formed. This implies that investments are made without having a complete coverage of the anticipated output in place, and hence that a substantial part of the LNG trade needs to be conducted on a short-term spot basis. The LNG-model also looked at the contract negotiation process on the managerial level of the LNG Agent as these are related to the investment decision. When LNG Agents decide to breach existing contracts in favor of a new partnership the breached LNG Project becomes available on the short-term spot market and hence, increases the liquidity of the spot market for LNG.

The averaged simulation results (i.e. of the complete scenario space) indicated that the initial superiority of searching for a partner before investing in a LNG infrastructure is diminishing in favor of its alternative investing before searching. The simulation also indicated that it is more beneficial for owners of LNG infrastructure that is poorly matched to keep on searching and pay the costs of searching than it is to stop searching and receive the ROI of a poor match. This implies that the simulation has not yet reached its market equilibrium, and more importantly that the LNG infrastructure that becomes available on the short-term spot market will increase. The impact of this development will transpire to the strategic decisions of the LNG Agent and favor the investment in LNG infrastructure prior to the partnership search process, and hence make the market more susceptible to a possible transition. The exploration of the scenario extremes in which a comparison between the parameter settings of a 'SPA-favored' and 'MSA-favored' LNG market is made indicates that the LNG Agents are sensitive to the market drivers and inhibitors of the LNG-model. A general trend of the individually assessed market drivers is that the value of searching before investing in LNG infrastructure declines, and converges with a steadily increasing value of investing in LNG infrastructure before searching for a partner.

The overall assessment of this investigation must therefore be that the research objectives are acceptably satisfied, and that in doing so it has created the possibility to explore the impact of the imminent key market drivers and inhibitors on the trade decisions from the LNG Agent through a quantitatively based agent-based model. The actual quantitative analysis however, is expected to benefit from adjusted parameter settings and identified modeling expansions.
# Glossary of Technical Terms and Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AB</td>
<td>Agent-Based</td>
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<tr>
<td>ABM</td>
<td>Agent-Based Model</td>
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<tr>
<td>ACQ</td>
<td>Annual Contract Quantity</td>
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<tr>
<td>BCM</td>
<td>Billion Cubic Meters, 1 BCM of natural gas equals 6.29 Million barrels of oil equivalent (Mmboe) and 0.7246377 Mt of LNG</td>
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<tr>
<td>CIF</td>
<td>Cost Insurance Freight</td>
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<tr>
<td>CRS</td>
<td>Congressional Research Service</td>
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<tr>
<td>DE</td>
<td>Discrete Events</td>
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<tr>
<td>DS</td>
<td>Dynamic Systems</td>
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<tr>
<td>EPC</td>
<td>Engineering Procurement Construction</td>
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<tr>
<td>FOB</td>
<td>Free on Board</td>
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<tr>
<td>FSRU</td>
<td>Floating Storage and Regasification Unit</td>
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<tr>
<td>HPC</td>
<td>High Performance Cluster</td>
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<tr>
<td>IOC</td>
<td>International Oil Company</td>
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<tr>
<td>LNG</td>
<td>Liquefied Natural Gas</td>
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<tr>
<td>LOI</td>
<td>Letter of Intention</td>
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<tr>
<td>Mmboe</td>
<td>Million barrels of oil equivalent, is a standard unit in the energy industry to express the calorific value of different energy sources in terms of one ton of oil</td>
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<tr>
<td>MTPA</td>
<td>Million Tons per Annum</td>
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<tr>
<td>MOU</td>
<td>Memorandum of Understanding</td>
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<tr>
<td>MSE</td>
<td>Mean Squared Error</td>
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<tr>
<td>MSA</td>
<td>Master Sales Agreement</td>
</tr>
<tr>
<td>Mt</td>
<td>Metric Ton, 1 Mt of LNG equals 1.38 BCM of natural gas</td>
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<tr>
<td>NBP</td>
<td>National Balancing Point</td>
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<tr>
<td>NCE</td>
<td>Neoclassical Economics</td>
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<tr>
<td>NOC</td>
<td>National Oil Company</td>
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<tr>
<td>ROI</td>
<td>Return on Investment</td>
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<tr>
<td>SD</td>
<td>System Dynamics</td>
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<tr>
<td>SPA</td>
<td>Sales and Purchase Agreement</td>
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<tr>
<td>SRV</td>
<td>Shuttle and Regasification Vessel</td>
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<tr>
<td>TCE</td>
<td>Transaction Costs Economics</td>
</tr>
<tr>
<td>TCM</td>
<td>Trillion Cubic Meters</td>
</tr>
<tr>
<td>TOP</td>
<td>Take or Pay</td>
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1. Introduction

This Thesis will commence with an introductory segment that starts off with the formulation of the preliminary research objective (§1.1). Some general information about natural gas in a global context (§1.2) and a brief introduction to Liquefied Natural Gas (§1.3) follows. After this general introduction, the motivation for this research is explained (§1.4). The thesis questions are stated next (§1.5), along with the main research objective (§1.6). To avoid any indistinctness about the used terminology a definition of the spot market for LNG is provided for in §1.7. Finally, the used research methods (§1.8) are discussed and an outline for this investigation is given (§1.9).

1.1 Preliminary Objective

This document contains the account of a Master Thesis Project and constitutes an explorative research that aims to assess the development of the approaching spot market for Liquefied Natural Gas (LNG). Unlike the existing base of literature on this topic that for the most part combines a rather top-down perspective with a qualitative research approach to assess the future spot market for LNG, this research will combine a bottom-up perspective with a quantitative research approach to make the same assessment. Thus instead of anticipating what the LNG spot market will look like through a discussion of several general trends (while failing to quantify their impact on the LNG trade), this research will look at the social and technical base elements that constitute the LNG market and assess the potential transition towards a LNG spot market quantitatively by looking at the socio-technical interactions of the market.

1.2 Natural Gas in a Global Context

Energy is a prerequisite for all forms of human endeavor and as such it is hard to overestimate the importance of a reliable, affordable and abundant energy source. In today’s world an ever increasing population, technological progress, and economic expansion are coupled with both limited and unevenly distributed reserves of the most prominent energy resource: fossil fuels. In 2006, natural gas accounted for almost 24 percent of the global energy consumption, behind oil and coal with 35 and 28 percent respectively (BP 2007). The worldwide natural gas consumption amounted to 2.831 Billion Cubic Meters (BCM) in 2004 and is expected to reach 4.615 BCM in 2030 (EIA 2007). By energy source, this increase of 1.9 percent per year over the period is second only to coal in relative terms. In fact this tremendous increase of the natural gas sector has lead scenario planners at Royal Dutch Shell believe that natural gas could overtake oil as the world’s preferred fuel between 2020 and 2030 (Figure 1). Important drivers for this increased natural gas consumption are its intrinsic properties (clean combustion, high efficiency, lower carbon emissions than crude oil, its derivatives & coal) and its abundant reserves (180 TCM of global proven reserves as of 1 January 2005, representing a reserves-to-production ratio of 65 years).

![Figure 1: Developing Energy Use (Brinded 2003).](image-url)
One common characteristic of fossil fuels is that the main consumption regions are not the ones with the largest reserves and related production. Natural gas forms no exception as in 2006, the Organization of Economic Co-operation and Development (OECD) countries accounted for 50 percent of the global gas consumption and only 38 percent of the global gas production, making them dependent on imports from non-OECD sources for 25 percent. Due to limited OECD gas reserves and increased OECD gas consumption; this supply gap is set to increase. It is estimated that in 2030 the OECD accounts for only 31 percent of global gas production whereas the OECD gas consumption will reach 42 percent of the world total and the dependability on non-OECD sources 27 percent (EIA 2009). This scenario demonstrates the need to transport higher volumes of natural gas from the main producing regions (e.g. Middle East, Eurasia, and Africa) to the OECD countries. With respect to the natural gas reserves it is interesting to note that almost three quarters of the world’s natural gas reserves are located in the Middle East and Eurasia.

1.3 About Liquefied Natural Gas

Natural gas in general is transported in one of two ways to the main consumer markets: in a gaseous state through pipelines or liquefied as Liquefied Natural Gas. LNG provides a means of transporting natural gas if pipeline transport proves to be unfeasible or undesirable. Typically this involves the transport of natural gas over long distances (e.g. over 2,000 kilometers) or to avoid political unstable regions. The LNG value chain requires natural gas to be cooled to a temperature of minus 161 °C to convert it to a liquid form that takes approximately 1/600th of its original volume. As such the LNG value chain consists of five different stages: exploration & natural gas production, liquefaction, shipping, storage & regasification, and the final distribution to the end-users (Figure 2).

The first commercial shipment of LNG took place in 1964, delivering Algerian gas to the UK and France. One of the most important motivations for importing natural gas as LNG is that it offers the possibility of expanding natural gas imports in a diversified manner. As such, the LNG trade soon moved away from the specialized niche business it once was to a mainstream natural gas transporting option. In fact LNG accounted for about 6 percent of the world natural gas consumption and about 26 percent of internationally traded gas volumes in 2002 (EIA 2003). Currently there are two major LNG importing regions: the Atlantic Basin and the Pacific Basin. Japan is the world’s largest LNG importer and accounted for almost half the world imports in 2002. The dominance of the Pacific Basin is strengthened by major importers as South Korea and
Taiwan, resulting in a 66 percent share of world LNG imports in 2005 (EIA 2005). This leaves the Atlantic basin responsible for the remaining LNG imports of 34 percent (Figure 3).

1.4 Motivation for this Research

The motivation for this research proposal stems from the observation that the global market for LNG is rapidly changing. Declining natural gas reserves in the main consumer countries in combination with an increase in natural gas demand are the main ingredients for a rapid expansion of the LNG trade. In addition to this, LNG provides a means to utilize more remote and hospitable natural gas fields, more commonly referred to as ‘stranded gas reserves’, in producing regions that are running out of easily accessible natural gas. According to Cedigaz this results in an increase of LNG’s share of the total world gas market from 22.5 percent in 2006 to about 26 percent in 2020 (WEC 2007). Relatively speaking this increase seems rather modest, however in absolute terms this means more than a doubling of traded LNG volumes from 211 BCM to 510 BCM. In addition to the growing importance of LNG in the world natural gas market the market itself is also facing considerable changes. This section starts of with an introduction to traditional LNG marketing, after which it discusses some of the recent changes in the industry.

1.4.1 Traditional LNG Marketing

Traditionally the LNG market was characterized by huge investments and long lead times. Investments for a typical LNG project with an annual capacity of 6 Mt (or approximately 8.3 BCM) including liquefaction, shipment, and regasification were in the range of US$ 5 billion (IEA 2002). In addition to the large investments of a LNG project there are other project characteristics that add to the risk of a LNG project. The fact for instance, that the single largest investment of a LNG project is the liquefaction plant which is located in the producing country and thus outside the direct control of the consumer country (typically the largest contributor to the investment). Another characteristic of an LNG project is that it does not start to make money before the entire LNG value chain is fully operational. In order to cover the risks involved with such a risk intensive venture, rigid contractual agreements or Sales and Purchase Agreements between buyers and sellers were negotiated. “The key economic driver in an LNG project, and the agreement on which much of LNG project financing is made possible, is the Sales and Purchase Agreement” (BakerBotts). This is a contractual agreement between the buyer and seller of LNG for which the main features are high-volume, long-term, and low-risk trading conditions.
Initially there were only a small number of buyers and sellers active in the LNG market. Suppliers of LNG were state-owned national oil and gas companies and the five international majors, whereas the buyers of LNG were mostly government monopolies and large franchised utility companies. The rigidity that was imposed by the SPA, highlighted by the contractual terms of 20 to 25 years, and the inherent limited flexibility did not pose any insuperable problems in the traditional LNG market in which security of supply overruled market efficiency.

1.4.2 Recent Changes in the LNG Industry

Besides the strong increase in LNG trade and its growing importance in the global natural gas trade, there are a number of structural market changes that have the potential to change the traditional LNG marketing model. While the traditional LNG business model has functioned properly over the last four decades, it becomes ever more difficult to fully incorporate the demands of an increasingly dynamic market. Perhaps the most notable change is the liberalization of the power sector in many East Asian and European countries. In 2004, the power sector accounted for 31 percent of the world natural gas consumption and it is projected that, with the increased popularity of Combined Cycle Gas Turbines (CCGT) it will also account for the majority of incremental gas usage to 2030 (EIA 2007). Consequently there will be a rising number of potential customers (enhancing the market liquidity) with changing demands with regards to the flexibility of their LNG supply.

Another important change in the LNG market involves the significant lowering of costs throughout the LNG chain. Industries estimate believe that the costs throughout the LNG chain have halved (Nissen 2002), thereby strongly reducing the risks of initiating a new LNG project. The downward trend of the LNG construction costs of the early years of 2000 however has been dampened by the recent commodity boom and the shortage of skilled labor. Balancing this adverse effect on the LNG production costs is the rising oil related price of natural gas which shows a clear upward trend (Figure 4)

![Figure 4. Monthly Price of U.S. Natural Gas LNG Imports (EIA 2008).](image)

The success of the LNG market also acts as a promoter for change; as investments in the LNG market continue to rise and the global LNG infrastructure (e.g. liquefaction, shipping, and regasification) expands, new trading opportunities arise. As a result of the expanding LNG trade, which is driven by a surging and shifting LNG demand, new market drivers will surface that enable a relaxation of the rigid contractual terms of the SPA. These market drivers include, but are not limited to, spare liquefaction and regasification capacity and the appearance of an

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1 The five international majors refer to the principal international oil companies Exxon/Mobil, BP, Shell, Total, and Chevron/Texaco

2 In accordance with the International Energy Agency, this study defines flexibility as the ability to adapt supply to foreseeable volume variations in demand (mainly seasonal) and to adjust for erratic fluctuations in demand (mainly short-term temperature variations), or to adapt demand (i.e. reduce it) when supply is insufficient.
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The uncommitted tanker fleet. These ongoing developments already lead to a shortening of the contractual term and the launch of new LNG projects without the full coverage of its production volumes. It is the belief of this study that the current changes in the LNG market have the potential to facilitate a market transition away from long-term bilateral contracts towards a spot market for LNG.

1.4.3 The Approaching LNG Spot Market

The above-mentioned changes are reminders of the early development of the spot market for crude oil. While this market once served marginal markets and niche opportunities, it is today a major component of worldwide trading. Spot markets, unlike bilateral agreements on product delivery, are real-time (or within a few weeks) commodity markets for the sale and delivery of products. "An important feature of spot markets is that they enable marketers to instantly find other market parties to match deficits in the markets (i.e. immediately required products) with elsewhere existing surpluses, without entering into long-term agreements" (Jepma 2005). It seems that the LNG market is now not only willing, but also able to accommodate a more flexible LNG trade in which prices instead of contracts will do the work of matching supply and demand.

The spot trade of LNG originates from the 1990s and was created due to special circumstances (e.g. the Asia financial crisis) rather than through planning. Changes in the Asian LNG demand created supply surpluses in the Middle East that made the spot trade in this period possible. Subsequently, further growth was driven by other changes such as the liberalization of the electricity and gas market, which increased competition. According to economic literature, market development in energy markets takes place through several stages. While the demand and supply are initially matched through bilateral contracts to recover the high initial investments, the incentive for short-term trading increases as the market matures and market liberalization is pursued. "Short-term gas contracts are important in the deintegrated gas industry because of market participants' need to achieve physical balance between demand and supply in a short time frame (typically between one day and one month)" (Juris 1998). Or as a CRS Report for Congress puts it "The existence of a viable spot market is important because it allows consumers the flexibility to sell off excess supply to eliminate surpluses, and acquire additional supplies to ameliorate shortages as well as aiding in price discovery. These activities are central to the market process and the key to achieving lower prices and driving down costs. Market determined prices will also help determine future investment decisions in LNG capacity in a more efficient way" (Pirog 2004).

While in 1990, LNG spot trade was virtually non-existent, it accounted for 11.6 percent of the total LNG flows in 2005 (Figure 5). This strong growth becomes particularly interesting if one takes into consideration the growing importance of LNG in the global gas trade and the associated increase in traded volumes of LNG. Presumably long-term contracts will continue to play an important role in the LNG trade because of their risk sharing capabilities. The contractual terms of the once rigid SPA's however will be relaxed to incorporate more flexible market demands.
The similarities between the early days of the spot market for crude oil and those shown by the spot market for LNG are numerous. Proof of this can be found in the development of LNG pricing which seems to develop similar to the oil pricing in that strongly related regional prices (Henry Hub, Zeebrugge) will interact in the same way as benchmark crude oils (Tusiani 2007). Despite the similarities and the rapid growth of LNG spot trade, it seems unlikely that the LNG trade turns into a second oil market. Parfomak (2006) notes that “Unlike petroleum markets where all prices are essentially short-term, analysts believe LNG trade will stabilize with some mix of long and short-term contracts since infrastructure costs are so high”.

There seems to be general consensus among market analysts that the traditional LNG market will remain the backbone of the market, primarily due to its risk sharing capabilities and resulting security of supply and demand for both sellers and buyers. Nevertheless, the EIA predicts that the spot trade of LNG will amount to 15-30 percent of global LNG trade, and at least one major exporter, the chief executive of Petronas expects that about 30 percent of the LNG business will be traded on the spot market (Lloydslist 2004). It is important to put this figure into perspective and to realize the actual size and potential of the spot market (Figure 6). According to Cedigaz the world gas trade accounted for 30.2 percent of the world market production in 2006. LNG share of international gas flows (including intra-FSU trade) is 27.8 percent. As such, 7.2 percent of the total volume of gas produced was sold as LNG. The spot market for LNG represented around 12 percent of the total LNG market, or put differently 0.9 percent of the total natural gas market.
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1.4.4 Problem Statement

It seems that the traditional LNG market with its rigid long-term and high-volume contracts is giving way to a rising role for short-term trade and spot sales of LNG. According to the IEA long-term contracts will remain dominant in the foreseeable future with spot sales (which mean short-term deals or the sale of one cargo) expected to take a growing share. Although the exact estimates vary there seems to be an overall consensus that the spot market for LNG will eventually amount to 15-30 percent of the global LNG trade. Although the current base of literature discusses the drivers and inhibitors for increased LNG spot trade, including: the expansion of the global LNG infrastructure, deregulated consumer markets, new entrants, spare regasification capacity, and the capital intensity of LNG projects, it remains unclear how these drivers and inhibitors impact the trade decisions of market participants. In particular the trade-off between the realization of new opportunities that are provided by a more open and competitive market and the management of the risks that are involved with investing in LNG infrastructure.

In other words, insights about the actual interactions between the imminent key market drivers and inhibitors and the trade decisions that shape the development of the LNG market are currently missing. As such, it is not yet possible to assess the drivers, likelihood, and implications of the approaching LNG spot market in a quantitative manner, let alone to verify and validate claims about the future of the LNG spot trade.

1.5 Thesis Questions

The Overall Thesis Question of this investigation is stated as follows:

- To what degree and under which conditions will a spot market for Liquefied Natural Gas materialize?

Providing the following five sub-questions with effective answers should help to satisfy the Overall Thesis Question:

1. What are the main technical and social trends that shape the LNG market?

2. What are the key market drivers that contribute to or impede the development of a spot market for Liquefied Natural Gas and how will these develop?

3. Is it possible to predict demand trends for the LNG spot market with future extrapolations?
4. To what extent is it possible to use agent-based modelling to assess the transition towards a spot market for LNG?

5. Under which conditions does a spot market for LNG arise from the social and technical interactions of the market if agent-based modeling is used to assess the impact of its key market drivers?

1.6 Research Objectives

In answering the Overall Thesis Question, this research aims to fulfill the following two objectives:

- To understand the impact of imminent key market drivers and inhibitors on the development of the spot market for LNG by relating these with the trade decisions of its participants.

- To execute an explorative investigation that supplements the existing base of literature on the development of a spot market for LNG with a more quantitative analysis that makes use of agent-based modeling to assess the perceived transition of the LNG market that emanates from the decisions of the market participants.

As such, this research will not attempt to predict ‘the LNG market of the future’, but rather it seeks to understand to what degree and under which conditions a spot market for LNG could develop. Important in this respect is that it attempts to do so by looking at the impact of key market drivers on the trade decisions of its participants. As opposed to an approach where a general discussion of market changes ‘magically’ results in the relative importance of the future spot market for LNG. This paper will now proceed with the terminology that is used throughout this study.

1.7 Applied Terminology

Because the approaching spot market for LNG constitutes the central theme of this research it is important to provide it with a clear upfront definition that helps to avoid any misunderstandings that may otherwise arise from its use during this research. While markets in general can be described as “a meeting together of people for the purpose of trade by private purchase and sale” (Merriam-Webster 2008), this study requires a more specific definition. The UK Office of Fair Trading (OFT) has published guidelines to define a relevant market and assess the existence of market power in energy markets (OFT 2005). According to these guidelines a market definition contains three elements:

- a product,
- a geographical area, and
- a temporal dimension

Although an assessment of market power in the LNG market is not among the primary objectives of this research, the above-mentioned defining features of a market are believed to apply the spot market for LNG as well. Before proceeding with a definition of the spot market for LNG however, this research feels that it is necessary to define the market on which it operates first, namely the natural gas market. The UK Department of Trade and Industry applies the OFT guidelines to describe the European gas market and notes that on a superficial level, natural gas might be regarded as a homogeneous commodity (e.g. the product) that is traded in Europe (e.g. the geographical dimension), while the temporal dimension that is conventionally used in these market definitions is one year (INDUSTRY 2005). If the geographical dimension of this definition is changed to a global scale instead of Europe alone, it forms a good first draft for the
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Definition of the LNG spot market that is used in this study. Please note that there are various quality regimes in gas producing countries and varying quality requirements for major markets. Without going into detail at this point these differences arise from the composition of the natural gas and the corresponding heating values and it follows logically that these exist in LNG as well. Hence, making the homogenous commodity assumption explicit here avoids any problems that might otherwise arise during this study.

Liquefied Natural Gas is the product that is traded on the spot market for LNG, and since LNG is actually a means of transporting natural gas over large distances it is closely related to the natural gas market and as such works according to the same principles. Geographically speaking there are two different markets for LNG: the Pacific Basin LNG market (Pacific market) and the Atlantic Basin LNG market (Atlantic market) (Figure 7). At this point it suffices to say that the Atlantic market consists of all LNG producers and consumers that are physically located west of the Suez Canal, while the Pacific market consists of all the LNG producers and consumers east of the Suez Canal. It should be noted that both basins overlap where there is no price differential between transporting to either the Atlantic Basin or the Asia Pacific Basin.

Although spot markets are commonly defined as real-time commodity markets for the sale and delivery of products, this is not the case for the LNG market. Due to the lack of transparent pricing, and the limited number and scale of the assets in the industry, immediate delivery is rare. Consequently, spot LNG trades often refers to the delivery of multiple cargoes over an extended period (Tusiani 2007). Thus, in accordance with Cornot-Gandolphe (2005) and Boyoung (2006) this study will refer to LNG spot transactions if the temporal dimension is less than one year. Although this seems a rather long time for a spot market, it has to be remembered that the majority of the market for LNG still operates on long-term contractual agreements with durations of 20 to 25 years.

This introductionary segment will now proceed with the research methods that are used to satisfy the afore mentioned research objectives.
1.8 Research Method

The fact that the LNG market is created due to the interplay between, among other factors; specific social, technical, economic, institutional, legal, and cultural features makes it a complex area of study. This makes it important to specify the factors that are included and excluded from further analysis. It is the belief of this study that the social and technical trends of the LNG market and their impact on the trade decisions play a decisive role in the development of the LNG market and, since the LNG spot market is itself an extension of the LNG market, to that of the spot market for LNG as well.

1.8.1 The Socio-Technical System Research Approach

This study uses a socio-technical system perspective to assess the LNG market in a structured manner that acknowledges the complexities of the LNG trade. The socio-technical term was introduced by Eric Trist and Fred Emery (1951) and was first applied to systems thinking by Emery (1959). While socio-technical refers to the interrelatedness between people and society on the one hand and machines and technology on the others, systems thinking is characterized by the twin notions of ‘a complex whole’ formed from a ‘set of connected things or parts’ (Allen 1984; Walker 2007). The two main principles of socio-technical theory are thus that the interaction of social and technical factors create the conditions for (un) successful system performance, and two that the optimization of the socio or technical increases the unpredictability of the system and does not necessarily lead to a gain in performance (Walker 2007). As such, it is used in this research to gain insights in the interactions between the LNG market development and human behavior (e.g. trade decisions).

A socio-technical system is structurally composed of distinct subsystems: the social subsystem and the technical subsystem (Figure 8). The social subsystem comprises all human elements, which for the purpose of this study means the various market participants, their behaviour, and their interconnections. The technical subsystem is made up of human artefacts that support and interact with the social subsystem to fulfil the purpose of the system. While the socio-technical system transforms its input to its output it is influenced by various external factors. External factors are beyond the span of control of the socio-technical system itself, but nevertheless have a significant influence on the performance of the system.

Figure 8: Socio-Technical Framework.
If the LNG market is considered to be a socio-technical system, the approaching spot market for LNG is the result of the trade decisions from its market participants that are shaped by the social and technical trends. As the social and technical subsystems are interdependent in the LNG market, it seems appropriate to consider it as a socio-technical system. Further support for the use of the socio-technical system perspective to assess the LNG market development can be found in Palmer (2006) who notes “the relationship between technologies and society is judged to be particularly strong in sectors where the infrastructure is durable and capital and technology intensive”. According to (Hughes 1987) “The essential idea of the socio technical systems literature is that technical systems are both socially constructed and society happening”, and hence technology and society need to be analysed in conjunction to understand how the system transforms its input into the systems output. Put differently, understanding the rational behind the trade decisions from the market participants, the impact of imminent key market drivers on the decision outcome, and the resulting emergent market evolution can best be realized through a socio-technical research approach.

1.8.2 System Overview and Point of Departure

Based upon the socio-technical framework that is presented above, this section will provide an overview of both the social and technical subsystem of the LNG market.

The social subsystem that allocates the responsibility for the different parts of the LNG value chain has traditionally been the dominion of LNG sellers and LNG buyers. The LNG sellers carried the responsibility for the upstream segment of the LNG market in which the main processes are the production and liquefaction of LNG, while the LNG buyers carried the responsibility for the downstream segment of the LNG market in which LNG regasification and storage are the main processes. In the midstream segment, which involves the transport of LNG through LNG shipments, this responsibility was shared between both parties involved (Figure 9).

[Diagram of LNG value chain]

Figure 9: The Social Subsystem of Traditional LNG Projects.

The technical subsystem or LNG value-chain that supports and interacts with the social subsystem to constitute the market for LNG consists of strongly linked and related components. The upstream segment commences with the production of natural gas from a natural gas field, after which it is liquefied to LNG and stored before awaiting shipment. The midstream segment consists of LNG transport by purposely built and designed LNG tankers. When the LNG is unloaded from the LNG tanker it is temporarily stored until it passes through the regasification plant that transforms the LNG to regular natural gas. Finally the natural gas is distributed and consumed.
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Figure 10: The Technical Subsystem or LNG Value-Chain.

In order to acquaint the reader with the complexity of the LNG trade, a strongly simplified representation of the LNG market as a socio-technical system is provided for in Figure 11. The system input consists of the required investments, expertise, and natural gas. These are transformed by the LNG market to profits and natural gas at the point of consumption (e.g. the consumer market). Finally, the external factors that were depicted in the socio-technical framework (Figure 8) are not included in this overview for the sake of clarity, but might include factors such as the economic climate, technological progress, and political goodwill. Please note that this research reserves the right to change the system boundary and include or exclude system components at a later stage of this investigation, if it is in the best interest of this study to do so.

Figure 11: Simplified representation of the LNG market as a socio-technical system.

As part of the process of market evolution, the traditional allocation of responsibility for the LNG market is changing. This means that the existing market participants are reevaluating their positions and that new market participants are entering the LNG market. As such, the traditional division between upstream LNG sellers and downstream LNG buyers is fading. Major buyers of LNG (large utility companies) are actively involved in securing upstream supply whereas sellers are securing market access through downstream investments. Independent third parties are also emerging that undertake liquefaction and/or regasification on a tolling basis (based on (Griffin 2006)). LNG shipping is also increasingly undertaken by specialist independent shipping companies that are not directly connected to the LNG seller or buyer. Instead they expect to
make a profit from the transport of LNG under charter. The impact of this repositioning and reevaluation of traditional positions and strategies on the LNG trade remains to be seen, especially if new opportunities for spot trade are created through ongoing technical developments and social change.

1.9 Outline of the Investigation

The first step of this investigation will be to identify the LNG market fundamentals through an extensive literature study of relevant academic and non-academic information sources that focus on the transition of the LNG market. Accordingly, chapter 2 will discuss social and technical trends that shape the LNG market and answer the first sub-question: What are the main technical and social factors that shape the LNG market? Keeping a social-technical perspective during this assessment counters the natural tendency to view the technical and social trends as distinct entities and allows this research to map the LNG market with a minimum loss of explanatory power. With the LNG market fundamentals in place it is time to proceed with the identification of the existing trading models and the imminent key market drivers and inhibitors that shape their development.

This is exemplified by the research question of chapter 3: What are the key market drivers that contribute to or impede the development of a spot market for Liquefied Natural Gas and how will these develop? First the existing LNG trading models and their characteristics are identified and discussed after which it is possible to identify the imminent drivers and inhibitors that shape their development and adoption. With the imminent key market drivers and inhibitors of both the traditional, Sales and Purchase Agreements governed, and global, Master Sales Agreements governed, LNG market in place, it is time to assess their impact on the development of the LNG market.

Accordingly, the centre of attention of chapter 4 will fall on the third sub-question: Is it possible to predict the demand trends for the LNG spot market with future extrapolations? The knowledge that is gained from the Polynomial and Verhulst extrapolations of existing data on the relative importance of the LNG spot market warrant the need for a different research approach. The
subsequent scenario analysis serves to challenge our thinking about emerging issues and trends, information that is subsequently used to obtain insights on the performance of the LNG spot market in different market conditions or scenarios. The development projections of this chapter indicate that an understanding the perceived LNG market transition requires a different research approach.

The investigation will thus proceed with the model development in chapter 5, by satisfying the fourth research question: To what extent is it possible to use agent-based modelling to assess the transition towards a spot market for LNG? After the ascertainment that the Agent-Based Modelling paradigm is indeed capable of satisfying the Overall Thesis Question, this sections proceeds with the construction of the conceptual LNG-model. Note that this conceptual agent-based model is not yet restricted by modelling assumptions and thus that it is theoretically capable of modelling the entire LNG market through its building blocks: the LNG Agent, LNG Project, LNG Contract, and LNG Scenario. The required model focus and delineation are introduced in chapter 6.

In chapter 6, the conceptual Agent-Based LNG-model is integrated with the existing Agent-based modeling knowledge base of the Energy & Industry Group at the Technology, Policy and Management faculty of Delft University of Technology. The fifth research question is therefore: Under which conditions does a spot market for LNG arise from the social and technical interactions of the market if agent-based modeling is used to assess the impact of its key market drivers? In order to enable LNG Agents to make strategic and managerial decisions regarding the trade of LNG, a stylized model of contracting is introduced and implemented. The assumptions that are made to transform the conceptual LNG-model into the LNG-model are explicated here as well.

With the LNG-model in place it is time to run the simulations, the results of which are presented and discussed in chapter 7. First, the results of the aggregate simulation runs are discussed. This is followed by a exploration of the scenario extremes and other individual key market drivers and inhibitors.

After all five sub-questions are completed chapter 8 will provide the conclusions, recommendations, and reflection. The overall conclusions and answer to the Overall Thesis Question: To what degree and under which conditions will a spot market for Liquefied Natural Gas materialize? are formulated first. Recommendations about the modeling exercise and future improvements follow. Finally, the researcher will reflect on the graduation process in general and modeling process in particular. It is important to note that although this constitutes the final part of this thesis project, it is not the end of this research. The expansion of the existing knowledge base and new insights about the LNG-market are reusable and expandable by everyone that is interested in doing so.

After this introductionary segment of the forthcoming project, this report will now proceed with the first step of the analysis of the LNG market and its operating fundamentals.
2. LNG Market Fundamentals

The introductionary segment of this thesis has set the scene for this investigation. The problem statement, research objectives, and Overall Thesis Question can only be satisfied through a clear understanding of the LNG market fundamentals. The central research question of this chapter is therefore the first sub-question:

- What are the main technical and social factors that shape the LNG market?

Accordingly, this chapter will execute an extensive literature study that serves to create a clear blueprint of the LNG market. In accordance with the research method (§1.8), the use of the socio-technical framework is explicated first (§2.1). Thereafter, relevant technical (§2.2) and social (§2.3) trends of the LNG market are identified. In order to counter the natural tendency to view the technical and social trends as distinct and unrelated entities, a discussion of the interface between both type of trends is presented in §2.4. The insights gained from this literature study will then be used to answer the first sub-question and formulate preliminary conclusions (§2.5).

2.1 The Socio-Technical View on the LNG Market

Although the term “system” is universally used it means different things to different people. The dictionary defines a system as “a group of independent but interrelated elements compromising a unified whole” (Merriam-Webster 2008). Socio-technical systems form a subclass of systems in which the social and technical elements are strongly interconnected and constitute a coherent whole. The socio-technical research approach is already discussed in §1.8.1, where it was found that the two main principles of socio-technical theory are that the interaction of social and technical factors create the conditions for (un) successful system performance, and two that the optimization of the socio or technical increases the unpredictability of the system and does not necessarily lead to a gain in performance (Walker 2007).

This research considers the social subsystem to comprise of all human elements, ranging from individual people on a micro level to corporate businesses on a macro level. The most important characteristic of these human elements is that they show rational behaviour. In short this means that each human element maximizes its own reward by constantly selecting the option with the highest pay off in the circumstances (e.g. preference criteria and constraints) that it faces. In this study, the social subsystem consists of the various participants of the market for LNG. The technical subsystem on the other hand is made up of the human artefacts that support and interact with the social subsystem to fulfil the purpose of the system. These interactions between the social and technical subsystem consist of among other things, ownership relationships, contractual agreements, and information exchange. It is through these socio-technical interactions that the system is able to transform its input, through a series of processes and under the influence of various external factors, to the systems output. The socio-technical framework is provided for in (Figure 8).

It is important to use the socio-technical framework to describe the market for LNG because this counters the natural tendency to view the technical and social subsystem as distinct entities, while in reality they are closely interconnected. Hughes (1987) notes that “The essential idea of the socio technical systems literature is that technical systems are both socially constructed and society happening”. Thus, the complexity of socio-technical systems, its dynamics and potential development can only be captured when technology and society are analyzed in conjunction. With regards to the forthcoming analysis of the market for LNG this implies that it is not sufficient to simply assess the social and technical subsystem separately. Because in doing so this fails to explain why the LNG market is more than simply the sum of its (social and technical) parts. Further support for the use of the socio-technical theorem by this research can be found in Palmer (2006) who states that “the relationship between technologies and society is judged to be particularly strong in sectors where the infrastructure is durable and capital and technology intensive”. The market for LNG certainly fits this profile as high investments, complex technology, and a long project lifespan are key words in this industry.
Considering the research objectives of this study and the ascertainment that these can best be satisfied by viewing the LNG market through a socio-technical perspective, this chapter will now proceed with a discussion of the technical fundamentals of the LNG market.

2.2 The Global LNG Infrastructure

This study uses the notion of the LNG value-chain to assess the technical fundamentals of the LNG market. It is called a value-chain because all the segments of a LNG project are linked and interrelated. The chain analogy also implies that the overall success of the value-chain depends on its weakest link. It also means that all the components of a LNG project need to be in place before the actual production and delivery of LNG can commence, and hence before any money can be made. The term 'value' stems from the fact that at each segment of a LNG project value is created or put differently "investments are made to take natural gas from an unstable state to one in which optimal use of natural gas as a critical energy fuel and feedstock for materials can be achieved" (Foss 2007).

2.2.1 The LNG Value Chain

The LNG value-chain comprises of three main segments: the upstream (production, transportation to liquefaction, liquefaction), midstream (LNG sales and shipping) and downstream (LNG regasification, storage and transportation to the market, consumption) segment (Figure 13)

![Figure 13: The LNG Value-Chain Adjusted from (Griffin 2006).](image)

The indicative cost structure of the LNG value chain (Figure 14) shows that the majority of the required investment is used for the liquefaction of natural gas, a process that is located at the exporting country. LNG shipping costs are directly dependent on the distance to the market and vary accordingly. A comparatively small investment is required for the import of LNG through a regasification terminal. These estimates are in line with those of the EIA (2003) that estimates that the production of natural gas represents 15 to 20 percent of the costs, the liquefaction (including the treatment, loading, and storage) 30 to 45 percent, the LNG shipping 10 to 30 percent and the regasification (including the storage and distribution) the remaining 15 to 25 percent. It should be noted that the LNG market is recently experiencing a costs increase as it follows the general cost escalation of the global energy market, fierce competition for the required materials, and a shortage of skilled labor. According to the Center for Energy Economics (2007), the increase in LNG value chain costs between 2002 and 2006 amounted to about 30 percent.
2. LNG Market Fundamentals

The individual components of the LNG value-chain are discussed below. Please note that the following section does not aim to give an extensive overview of the technical details, rather it suffices to identify the general function of each of the LNG value-chains components. Important for the development of the market are the existing and forecasted capacity of the global LNG infrastructure. These constitute the physical boundaries of the current and future LNG market and with it the trade of LNG. As such, this section will discuss the natural gas production, the liquefaction of natural gas, the shipping of LNG, the regasification of LNG, and the consumption of natural gas.

Natural Gas Production
The first component of the LNG value chain is the exploration and production of natural gas. Exploration involves forming ideas of where natural gas might occur and the drilling of test wells. Obviously this is an important first step in the LNG value chain, because it determines the prospects for LNG production. There are also numerous technical challenges with the production of natural gas, for example natural gas might be produced in conjunction with oil and can contain contaminations such as higher-chain hydrocarbons and condensates. Considering the focus of this study however (e.g. the transition towards a spot market for LNG), these technical details are irrelevant and it suffices to identify the main producers, their prospects and possible new entrants.

Since LNG is a means of moving natural gas from the production fields to the consumer market, it will be interesting to look at the distribution of the world’s natural gas reserves as this gives a first indication of the main production areas (Figure 15). As of January 1\textsuperscript{st}, 2007 the world natural gas reserves stood at 181 Trillion Cubic Meters [TCM]. The Middle East holds the largest reserves at 73 [TCM] followed by Eurasia with 59 [TCM]. It is interesting to note that the main consumers (e.g. Europe, Asia, North America) only hold 28 [TCM] or 15 percent of the reserves, while they are responsible for over half of the global natural gas consumption.
In terms of the natural gas reserves of individual countries, the Russian Federation clearly holds the world’s largest proven natural gas reserves at almost 48 [TCM]. Iran and Qatar follow at a considerable distance with 28 [TCM] and 25 [TCM] respectively to claim the second and third spot. There is a clear gap between the top three and Saudi Arabia (fourth) and the United Arab Emirates (fifth). In fact, the three countries with the largest natural gas reserves hold over 55 percent of the world’s total natural gas reserves.

<table>
<thead>
<tr>
<th>Country</th>
<th>Proven natural gas reserves [TCM]</th>
<th>Share of world’s proven natural gas reserves [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russian Federation</td>
<td>47.65</td>
<td>26.3</td>
</tr>
<tr>
<td>Iran</td>
<td>28.13</td>
<td>15.5</td>
</tr>
<tr>
<td>Qatar</td>
<td>25.36</td>
<td>14.0</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>7.07</td>
<td>3.9</td>
</tr>
<tr>
<td>United Arab Emirates</td>
<td>6.06</td>
<td>3.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>114.27</strong></td>
<td><strong>63.0</strong></td>
</tr>
</tbody>
</table>

Table 1: Top 5 Countries that Hold the Largest Natural Gas Reserves (BP 2007).

Generally speaking, LNG is the preferred option to capitalize on ‘stranded’ natural gas reserves that are located at a large distance from potential markets or lack adequate pipeline distribution infrastructure. It is estimated that stranded gas makes up about 50 percent of the total natural gas reserves that are held by the ten countries with the largest natural gas reserves (EIA 2001). An additional requirement for LNG projects concerns the size of the natural gas reserves that is required to accommodate the production of LNG at a plateau level for 20 or 30 years. According to Flower (2005) LNG projects typically require gas reserves in excess of 280 [BCM] to accommodate the desired production levels for the duration of the project.

Liquefaction of Natural Gas

The liquefaction of natural gas is often considered to be the heart of an LNG project because it represents the largest single investment of the entire LNG value-chain (Figure 14). During the liquefaction process, natural gas is transformed from a gaseous state to a liquid one by cooling it to -161 degrees Celsius. Although the design of a liquefaction plant is influenced by a range of variables (e.g. gas composition, location, liquefaction capacity, etc.), the basic concept is nothing more than that of a giant refrigerator.

In 2006, the Pacific Basin was responsible for 42 percent (48.7 [MTPA]) of the global LNG production, followed by the Atlantic basin with 34 percent (39.8 [MTPA]), and the Middle East with the remaining 24 percent (27.9 [MTPA]) (data from (Flower 2007)). This indicates that a discrepancy currently exists between the regions that hold the world’s largest natural gas reserves and the regions that hold the largest liquefaction capacity. Although this comparison needs to be compensated for natural gas distribution through pipelines, it seems that there is considerable room for expansion of the liquefaction capacity in the regions that hold the largest natural gas reserves (e.g. the Middle East and Eurasia).
It turns out that the LNG production is a highly concentrated business in which the five largest LNG producers were responsible for 63 percent (73.1 [MTPA]) of the total LNG production in 2006. While Qatar (17.9 [MTPA]) is the single largest producer of LNG, there is a Pacific dominance in the top five of LNG producers with Indonesia (16.6 [MTPA]), Malaysia (15.5 [MTPA]), and Australia (10.1 [MTPA]). The top 5 is completed with 4th ranked Algeria (13.0 [MTPA]) (Flower 2007). It seems likely that this situation will change as current LNG producers are expanding their production capacities and potential new exporters such as Iran, Yemen, Russian Federation, Bolivia, Venezuela, and Peru are on the verge of entering the market for LNG.

Despite the minor differences in the estimates regarding the liquefaction capacity of LNG, there is a general consensus about the fact that the global liquefaction capacity is set to expand rapidly in the short to medium term. Forecasts by the Department for Business, Enterprise and Regulatory Reform of the UK demonstrate that the global liquefaction capacity is set to increase significantly in the coming 20 years. According to the business as usual scenario (chapter 4) the global liquefaction capacity will double between 2005 and 2015 from 252 [BCM/year] to 555 [BCM/year] and continue to rise to 650 [BCM/year] in 2025 (GlobalInsight 2007). It is clear that the Middle East and Africa are rapidly catching up with the Asia Pacific in terms of available liquefaction capacity (Figure 16). It is important to realize that the rapid increase of global liquefaction capacity coincides with a shift in regional importance in the LNG market. Both Africa and the Middle East are expected to overtake the Asia Pacific region in 2015 with available liquefaction capacities of 148 [BCM], 192 [BCM], and 146 [BCM] respectively.

![Figure 16: Liquefaction Capacity and Supply by Region (GlobalInsight 2007).](image)

In terms of individual countries, Qatar's liquefaction capacity expansion from 27.1 BCM in 2005 to 115 BCM in 2015 is remarkable and unique among the LNG producing countries. Nigeria (12.0 BCM in 2005, 33.7 BCM in 2015), and Australia (14.8 BCM in 2005, 26.4 BCM in 2015) follow at a considerable distance (PWC 2007). It is interesting to note that the geographic position and the vast natural gas reserves of the Middle East in general and Qatar in particular enables them to serve both the Pacific and Atlantic basin (Figure 21 & Figure 22). As such the Middle East can become the swing producer of the market for LNG. Ruester (2006) supports this claim and notes that “The Middle East, accounting for more than 40% of worldwide proven natural gas reserves, is expected to become the largest LNG exporting region and is currently evolving to a swing producer; deliveries to European as well as Asian markets are feasible without a significant difference in (transportation) cost”.

In addition to the projected expansion of the liquefaction capacity it is important to keep track of the liquefaction plants that are under construction. This is important because liquefaction plants under construction create spare capacities (e.g. liquefaction capacity that is not contracted) in liquefaction due to the build-up of long-term contracts. Other sources of spare capacity include the debottlenecking of existing plants, expiration of old long-term contracts without renewal, and

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3 Swing producer/supplier is a company or country which changes its gas output to meet fluctuations in market demand IEA (2002). Flexibility in Natural Gas Supply and Demand, International Energy Agency.
2. LNG Market Fundamentals

uncommitted liquefaction capacities. Spare liquefaction capacity proves to be an important source for the spot market for LNG, and according to the Clingendael International Energy Programme (2006) “the principal volumes traded in spot markets originate from temporary spare capacities in liquefaction”. Although spare capacity disappears when the contracts have reached their plateau level, the de-bottlenecking of existing plants will continue. Furthermore new plants will continue to be built and existing plants will be provided with capacity extensions, hereby ensuring a continues availability of spare liquefaction capacity.

LNG Shipping

After liquefaction and storage, the LNG is ready to be loaded onto specially designed LNG tankers where it is kept at atmospheric pressure and cryogenic temperature (−161 [°C]). The typical tanker measures some 275 [m] in length, about 43 [m] in width and 11 [m] in water draft and transports about 125,000-138,000 [m³] of LNG. In order to economize on scale, the new generations of LNG tankers that are used at the Rasgas and Qatargas projects are able to transport 215,000-245,000 [m³] of LNG. An overview of the LNG vessel fleet development is provided for in Figure 17. By the end of 2007, the world LNG fleet totaled 258 ships with a further 135 ships on order till 2012 (BWGas 2008). Consequently the world LNG fleet will reach 350 vessels by 2009 and future projections by Griffin (2006) show that the fleet will equal 450 vessels by 2015. This leads LNG shipper BW Gas ASA to conclude that the rapid expansion of the LNG fleet will outpace the growth in traded volumes of LNG (BWGas 2008). This is an important development, as the availability of sufficient transport capacity is one of the prerequisites for the spot trade of LNG.

![LNG vessel fleet development - 1965-2006](Informare 2008).

Another important characteristic of LNG shipping are the costs of transport per unit of energy cargo capacity. When compared to oil, LNG proves to be more expensive to transport. This is a result of more advanced vessel requirements and the lower energy content of LNG (as opposed to crude oil). Hayes (2006) estimates that LNG tankers are roughly seven times the cost of crude tankers per unit energy cargo capacity⁴. Obviously this makes it important to make the best use of expensive LNG tankers and to “keep the cargo tanks cold” for most of the time.

Regasification of LNG

When the LNG tanker reaches its destination, the cargo is discharged at the regasification terminal. On its arrival at the import terminal the LNG (whilst at atmospheric pressure) is pumped to a double-walled storage tank where it is stored until needed. At that time, LNG is regasified by warming it in a controlled environment. Once the natural gas is back in its gaseous state it needs to be regulated for

⁴ Based on a capital cost of 50 million [US$] for a Suezmax tanker with capacity for 150,000 tonnes of oil (nearly 6 Bcf of gas equivalent), and an estimated 170 million [US$] for a 138,000 [m³] LNG tanker (~3 [Bcf] of gas) (IEA 2003, IEA, 2004 #1878)
pressure before entering the further distribution network. Regasification terminals prove to be a relatively low cost segment of the LNG chain. Various estimates show that the regasification terminals represent a fraction, in the order of 10 percent, of the total cost of delivered LNG (EIA 2003; Hayes 2006). The single largest expense for a regasification terminal is the storage which accounts for around 40-50 percent of total terminal costs (FACTS 2007). Due to the strong tendency for economies of scale for this part of the terminal, the optimal size for a storage tank is the largest one available.

In 2005, global regasification capacity equaled 527 [BCM/year] of which 71 percent was located in the Asia Pacific, 16 percent in Europe, 11 percent in North America and 1 percent in South America (GlobalInsight 2007). Forecasts by the Department for Business, Enterprise and Regulatory Reform of the UK demonstrate that the global regasification capacity is set to increase significantly in the coming 20 years. Although the growth in relative terms is not as large as the liquefaction capacity, the global regasification capacity will double between 2005 and 2020, and further increase to 1139 [BCM/year] in 2025. Note that this implies that the current shortage of available LNG is diminishing and hence, production and consumption become more balanced. The fact that the Americas and Europe are rapidly catching up with the regasification capacity of the Asia Pacific is clearly shown in (Figure 18). While the Asia Pacific extends its regasification capacity from 327 [BCM/year] to 473 [BCM/year] (+27 percent), the regasification capacity of Europe, 84 [BCM/year] to 340 [BCM/year] (+404 percent), and North America, 60 [BCM/year] to 203 [BCM/year] (+338 percent), grow significantly faster.

![Figure 18: Regasification Capacity by Region (GlobalInsight 2007).](image)

In terms of individual countries, Japan remains the country with the largest regasification capacity (80 [BCM/year] in 2005, 103 [BCM/year] in 2025). The current second and third largest regasification countries however are losing ground. South Korea shows a modest growth (29 [BCM/year] in 2005, 31 [BCM/year] in 2025) and Spain (17 [BCM/year] in 2005, 53 [BCM/year] in 2025). More interesting however is the development of the regasification capacity in the US and UK. The US is currently a modest importer of LNG but its regasification capacity is set to increase more then seven times over the next two decades (17 [BCM/year] in 2005, 118 [BCM/year] in 2025). Complementing the top three in 2025 is the UK where the regasification capacity is set to increase more then fifteen times in the same period (5 [BCM/year] in 2005, 78 [BCM/year] in 2025).

**Natural Gas Consumption**

The consumption of natural gas constitutes the final component of the LNG value chain, and arguably the most important one since it finances the entire LNG project. In 2006, the global demand for LNG stood at 116.4 [MTPA] with Asia responsible for nearly 65 percent of the total LNG demand. Thus leaving Europe (27 percent) and America (9 percent) far behind. To a large extend, these differences in demand can be explained by the limited domestic reserves of natural gas (and other fossil fuels such as coal and oil) in many important Pacific consumer markets.

Although the Pacific Basin has traditionally been the most important market for LNG, the largest growth in LNG demand is expected in the Atlantic Basin. In accordance with other industry estimates, (PWC 2007) expects the US to become a major LNG importer with a demand of 75 BCM of LNG by 2015 (up from 18 BCM in 2005). Other major increases are expected in Spain, the UK, Italy, India,
China, and Portugal. It is interesting to note that the seven main growth countries for the import of LNG include four European countries. As such the Atlantic Basin is expected to experience an increase of LNG imports from approximately 43 BCM in 2005 to 150 BCM in 2015. Important drivers for this expected increase of LNG imports are the declining domestic reserves of natural gas in the OECD countries and the increased demand for natural gas. From a security of supply perspective, LNG is a particularly interesting option because it allows the importing country to diversify its export portfolio, and hence reduce the dependency on one single country (as is often the case with pipeline transport). Although there are differences in the forecasted LNG demand between (PWC 2007) and (GlobalInsight 2007), there seems to be a general consensus about the fact that the Atlantic Basin is set to become a more prominent player on the market for LNG.

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</tr>
</thead>
<tbody>
<tr>
<td>US</td>
<td>17.9</td>
<td>75</td>
<td>319</td>
<td>17</td>
<td>110</td>
<td>547</td>
</tr>
<tr>
<td>Spain</td>
<td>21.9</td>
<td>29.8</td>
<td>36</td>
<td>24</td>
<td>26</td>
<td>8</td>
</tr>
<tr>
<td>UK</td>
<td>0.5</td>
<td>21.0</td>
<td>3925</td>
<td>1</td>
<td>38</td>
<td>3700</td>
</tr>
<tr>
<td>Italy</td>
<td>2.5</td>
<td>19.7</td>
<td>685</td>
<td>2</td>
<td>18</td>
<td>800</td>
</tr>
<tr>
<td>India</td>
<td>6.0</td>
<td>16.9</td>
<td>179</td>
<td>6</td>
<td>18</td>
<td>200</td>
</tr>
<tr>
<td>China</td>
<td>n/a</td>
<td>12.0</td>
<td>n/a</td>
<td>n/a</td>
<td>21</td>
<td>n/a</td>
</tr>
<tr>
<td>Portugal</td>
<td>1.6</td>
<td>3.5</td>
<td>119</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Total</td>
<td>50.4</td>
<td>177.9</td>
<td>n/a</td>
<td>50</td>
<td>231</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Table 2: LNG importers, main growth countries (GlobalInsight 2007; PWC 2007).

The consumption of LNG is largely the domain of the power sector where natural gas is increasingly the fuel of choice. This is easily explained by the lower carbon content of natural gas (when compared to that of other fossil fuels) and the more stringent environmental constraints in the main consumption (OECD) countries. As such it is projected that the power sector, through the increased use of CCGT, will be responsible for the majority of the total incremental natural gas use to 2030 (EIA 2007). Because LNG is primarily used by the power sector (e.g. the Japanese power sector consumed approximately 70 percent of the countries total LNG imports in 2000) this study feels justified in its assumption that the power sector will be responsible for the largest share of incremental LNG consumption. The remainder of the LNG consumption is typically used to provide for space heating and thus often part of the operations of the same utility company.

2.2.2 Recent Technical Developments

This section complements the foregoing introduction of the LNG value chain with recent and ongoing technical developments that serve to overcome some of the issues that currently face the industry. These include but are not limited to permitting issues for new LNG infrastructure, rising costs of raw materials and labor, limited market access, stringent contracts, a low utilization rate of existing LNG infrastructure, gas incompatibility issues, and the lack of flexibility on the market for LNG. While there are a lot of ongoing technical developments in the LNG value-chain, this section limits itself to the ones that could act as a further stimulus for the spot trade of LNG.

Economies of Scale in the LNG Value-Chain

The first, and arguably, most important technical development is the exploitation of economies of scale\(^5\) throughout the LNG value chain. The pursuit of economies of scale has resulted in an upward trend in the capacity of the liquefaction plants (Figure 19), LNG vessels (Figure 20), and regasification plants. While the first generation liquefaction plants (1964 – 1972) featured liquefaction per train capacities of about 1 [MTPA] the size of these trains steadily increased. While a liquefaction plant in the 1970s and 1980s required at least three 2 [MTPA] trains to justify the investment of a greenfield LNG facility, the Damietta project in Egypt of 2005 featured liquefaction trains of 5.5 [MTPA].

\(^5\) Economies of scale refers to the notion of a reduction in the production costs of something that are brought about especially by the increased seize of the production facility or product (adopted and adjusted the definition from Merriam-Webster (2008). Merriam-Webster Online Dictionary.
recently the Qatargas II project introduced liquefaction trains of 7.8 [MTPA], or the equivalent of a scale increase of over 40 percent during the last 3 years.

![Liquefaction Train Capacity from 1964 to 2007 (Chawki 2006).](image)

The same holds for the LNG vessels that in 2005 featured a maximum capacity of 145,000 [m3]. The Q-flex and Q-max carriers that are ordered by the same Qatargas II project have planned capacities of 216,000 [m3] and 265,000 [m3]. For comparison, the first generation of LNG vessels had a capacity of around 40,000 [m3].

![Capacity of LNG Carriers from 1969 to 2004 (Chawki 2006).](image)

The pursuit of economies of scale and other technical improvements over the last years has caused a significant lowering of costs per unit produced throughout the 1990s to a low of 1.8 [$/MMBtu] in 2000 (CEE 2007). More recently however these past cost reductions are offset by a concurrence of rising costs for raw materials, a proliferation of LNG projects, and a tight construction market. Consequently the construction costs of an LNG project have increased by as much as 50 percent (GlobalInsight 2007). Despite this recent escalation of costs increases throughout the LNG value-chain, the rising demand for natural gas and declining domestic reserves make LNG an increasingly competitive commodity.

Having outlined the pursuit of economies of scale throughout the LNG value chain, it is now time to proceed with a more detailed analysis of the ongoing technical developments in the individual parts of the LNG value-chain. One common element in the selected technological developments is that their widespread adoption will increase the flexibility of the existing LNG infrastructure and will allow new players to enter the market.

**Innovations in LNG Liquefaction**

There are several developments underway with regards to the liquefaction of natural gas. The first is made possible by virtue of LNG’s own success, and consists of the possibility to expand existing liquefaction plants instead of starting of with a greenfield project. In doing so, it becomes possible to share existing facilities and infrastructure. This strongly reduces the required initial investment and the
costs per unit of LNG produced. Another development in liquefaction technology follows the opposite path of the scaling-up that is described above, namely that towards smaller liquefaction units. These are designed to be (somewhat) mobile in order to monetize smaller reserves of natural gas. “Typically, gas fields that were developed for LNG exports had minimum proven reserves of 500 BCM or above. However, small-scale liquefaction plants (i.e. 250 to 1,000 tonnes per day) are now being developed and tested” (PWC 2007). If this technique proves to be successful it would greatly expand the number of stranded natural gas reserves that is suitable for the production of LNG. Furthermore this technique requires lower initial investments and thus opens up the prospect of many more players in this part of the LNG value-chain.

Another interesting development is the creation of liquefaction hubs that are a result of depleting natural gas reserves in existing liquefaction projects. If this happens, it will be interesting for the owners of the liquefaction plant to attract new supplies of natural gas and continue the use of the existing infrastructure on a tolling basis. As such, this is an opportunity for new suppliers to enter the LNG export without the need to invest in liquefaction capacity. Price Waterhouse Couper (2007) believes that “In Indonesia, Malaysia and Australia, for example, it is likely that LNG liquefaction asset lives will be extended by becoming hubs for disparate gas supplies”. Also note that planning and permit issues for greenfield liquefaction plants might prove to be an extra stimulus for the continuation of existing liquefaction plants.

Offshore liquefaction is also in the development stage because it is able to reach stranded gas reserves that exist at a great distance from any shore line. In addition to stranded natural gas reservoirs, offshore liquefaction can also be used to process the associated natural gas of crude oil production. It has to be noted that the idea of onboard liquefaction was proposed during the 1970s to develop the Kangan natural gas field (Chen-Hwa 2006), and has come a long way since. Important issues that surround onboard liquefaction, such as fitting onboard liquefaction and open sea LNG transfer, have since been tackled through coordinate research by several major industry participants. Douglas and WestWood estimates that Floating LNG facilities is a business that is worth 8.5 billion US$ by 2015 (Douglas-Westwood 2009).

Innovations in LNG Shipping

Besides the growing capacity of LNG vessels, there are a number of other interesting developments in the LNG shipping industry that are aimed at 'keeping the cargo tank cold' for a longer time. Although there is an ongoing debate on the best propulsion for LNG vessels, the general objective is to increase the tonne mile potential\(^6\) of the fleet. In order to do so the cargo capacity and/or the ship speed is increased. An increase in the ton mile potential of the fleet means that more LNG can be shipped over larger distances. In addition to the improvements of the traditional LNG vessels, new modes of transport are also considered. In accordance with the possible small scale liquefaction of natural gas it is also possible that more flexible and small-scale LNG transportation arises. PWC (2007) foresees LNG transportation in ten ton containers that are up for this task. If small-scale transportation becomes a reality this would strongly increase the number of loading and offloading options.

Innovations in LNG Storage

Natural gas that is stored to facilitate seasonal demand and/or peak demand is typically stored in large depleted oil and gas fields or salt caverns. The increasing size of the market for LNG and the changing nature of the trade are likely to change the storage requirements. The Dubai LNG Trading Hub or “DUB” as it is often referred is one interesting development in LNG storage and is the first of its kind. DUB envisions a storage capacity of between 40 and 65 [BCF] and offers its customers the ability to store, trade and plan supplies of LNG over an extended period of time (BusinessWire 2007). Thus, the LNG trade becomes more flexible and is no longer tied to the inflexible transport arrangements. Another option is smaller and more flexible cryogenic storage that could be utilized for smaller communities or regions where no underground storage is available. Note that the DUB is not

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\(^6\) A unit of measurement of the freight transportation that is performed by the LNG vessel during a given period, (usually a year). This is obtained by multiplying the aggregate weight of each shipment in tons (during the given period) by the number of miles for which it is carried Merriam-Webster (1913). Webster’s Revised Unabridged Dictionary. C. G. M. Co.
2. LNG Market Fundamentals

the only LNG storage hub under consideration. Korea Gas Corporation (Kogas) and Oman's Ministry of Oil & Gas for example signed an MoU for a similar facility in the sultanate (APS 2006).

Innovations in LNG Regasification

The development of onboard regasification seems to be the most important development in this part of the value chain. Offshore regasification avoids some of the permitting difficulties that onshore regasification terminals face. Floating regasification also creates the possibility of facilitating seasonal LNG demand in regions where the utilization rate of an onshore regasification terminal would be unfeasible. An additional benefit is that LNG tankers can unload faster because there is no need to enter the port.

Onboard regasification comes in various forms; the first is the LNG Shuttle and Regasification Vessel (SRV), a modified LNG vessel that is equipped with regasification capabilities and a natural gas unloading system. There are also plans for Floating Storage and Regasification Unit (FSRU), which are enlarged SRV that are adapted for use as FSRU. These are permanently moored on a unloading buoy and receive LNG via ship to ship transfer (based on Tveitnes (2005)). Both types of vessels are equipped to unload the LNG at offshore LNG import terminals. In addition to smoothing the permitting process, onboard regasification units reduces the need for costly investments at the receiving port and can make LNG a viable option for destinations that lack a suitable seaport.

Changes In LNG Consumption

LNG is typically used as a fuel for natural gas driven power plants or distributed as city-gas on a commercial level. Using it as a transport fuel might prove to be another application, albeit a niche market. LNG is already applied in the public transport (LNG powered buses) and heavy machinery in Western Australia and might be interesting for other heavy fuel demand markets as trains, airplanes or shipping in the foreseeable future. Furthermore its use as a direct residential natural gas supply might be extended.

As a matter of course, economics determine the speed of adoption of the above-described technical developments. Considering the focus of this study however, the creation of liquefaction hubs, onboard regasification, and the LNG trading hub are interesting developments.

2.2.3 Global LNG Infrastructure

Having outlined both the LNG value-chain and the ongoing technical developments and innovations it is now time to turn focus to the existing and forecasted capacity of the LNG infrastructure. It is important make an assessment of the global liquefaction, shipping, and regasification capacity because these constitute the physical barriers of the LNG market. According to (PWC 2007) the total LNG trade of 2005 equaled 188.81 [BCM], the trade flows of which are graphically depicted in the LNG world map (Figure 21). On the import side Japan and South Korea dominate with 56.5 [%] of the global LNG import, The supply side is dominated by Qatar, Indonesia, Algeria, and Malaysia who together account for 59.3 [%] of the global production of LNG.

The future LNG world map (Figure 22) looks very different from that of 2005. In addition to a strong increase of LNG trade flows, which in 2015 will equal 459.48 [BCM], there will be shift of regional importance. On the supply side Qatar is expected to become the undisputed lead producer, while capacity expansions in Nigeria will bring Africa on par with the Asia Pacific (§2.3.1, Figure 19) as the second largest LNG production region. Increased imports by China and India and a steady increase of LNG demand from Japan and South Korea are the major changes of the Asia Pacific. Perhaps the most important difference however, is the rising LNG demand of the US in North America, and that of the UK, Spain, and Italy in Europe. Although the regasification capacity of Europe and the US does not overtake that of the Asian Pacific, its historic dominance is greatly reduced. PWC (2007) states that

Please note that "All trade movement figures associated with this table are directly derived from contracts currently in place (either as SPA, HOA or MOU) as at December 2006, according to Cedigaz data. No concession has been made for current contracts expiring before 2015 or for current HOAs or MOUs to be terminated."
the growth in imports by the US alone is expected to account for between a third and a half of the increase in global LNG volumes between 2005 and 2015.

Although the exact estimates vary (between amongst others, (Chabrelie 2003; Insight 2007) there is a general consensus that the LNG trade is set to expand rapidly in the upcoming years. The future forecast of Table 10 (§4.2.2) demonstrates the rising LNG demand on a global scale from the 2005 level of 194 [BCM] to a high of 523 [BCM] in 2030 in the conservative estimate or 693 [BCM] in the high growth scenario. It is also clear that the traditional dominance of the Asia Pacific is fading and that both Europe and the Americas are making up for lost ground.
2. LNG Market Fundamentals

This research refers to (Morikawa 2006; GlobalInsight 2007; Insight 2007) for a detailed overview of existing, proposed (e.g. signed SPAs/HOAs), and planned LNG production plants and receiving terminals.

2.3 Social Network of the LNG Market

The social network of the LNG market consists of the market participants (e.g. natural gas consumers, distribution & trade companies, production companies, etc) and their interconnections (e.g. contracts, ownership relationships, information exchange, etc). According to Nikolic (2009), the present state of social networks is the result of a series of discrete events and continuous optimization, which are determined by the actions, interests and influence of the stakeholders. While it is true that the spot market for LNG originated due to special circumstances in the 1990s, this fails to explain the rapid growth of LNG spot trade afterwards. Apparently, there is an increased demand for LNG spot trade that stems from the needs of certain market participants. In order to find out which stakeholders have an interest in the spot market for LNG, the following section seeks to identify the various stakeholder categories that are active on the market for LNG, their relationships and interdependencies.

2.3.1 Identification of Stakeholder Categories

The market for LNG attracts a large number of diverse companies, each with their own characteristics (goals, resources, expertise, etc.). This makes it impossible to assess each company individually and incorporate their unique views on the spot trade of LNG. Instead, this section identifies the main stakeholder categories for the market for LNG. According to Freeman (1984) “a stakeholder in an organization is (by definition) any group or individual who affect or is affected by the achievement of the organization’s objectives”. Based on this definition of Freeman, this study will define stakeholders as organizations that can affect or are affected by the transition towards a spot market for LNG. Furthermore it differentiates between those stakeholders that have a direct interest in this transition and are able to affect the spot trade of LNG, and those that are only affected by its consequences without being able to influence its development. Henceforward the first category will be called critical stakeholders and the latter ones non-critical stakeholders.

The various stakeholders with an interest in the LNG market are identified by tracking the natural gas from its upstream production as a primary resource to the downstream consumption as an energy service. The first step is the production of natural gas from stranded natural gas reserves by the Exploration & Production (E&P) Companies. This is usually covered by a joint venture between the
2. LNG Market Fundamentals

national oil company (NOC) of the host government and one of the international oil companies (IOC). When the natural gas is produced it is transported to the LNG export terminal where the natural gas is liquefied to LNG and stored to await further transport. Next, the LNG is shipped from the point of production to the point of consumption by the Logistics Provider. On arrival, the LNG is unloaded and stored before it is regasified by the Customers. The storage enables a constant of regasified LNG feed to the point of consumption. Finally, the natural gas is consumed by the Customer who in this study is represented by the utility company that uses it to provide energy services (e.g. electricity or city gas).

Despite the seemingly straightforward route of LNG through the market, the social network that constitutes the trade of LNG turns out to be complex. It is expected that the expansion of the LNG trade and the related increase of global LNG infrastructure will further increase the complexity of the LNG trade. In addition to market expansion, the dedicated LNG value-chains are starting to open up. As a result stakeholders are now participating in several parts of the LNG value chain to spread risks and exploit new opportunities. E&P Companies for instance invest in regasification capacity to ensure access to important consumer markets while liquefaction is undertaken on a tolling basis by the customers.

The different stakeholder categories that this investigation distinguishes thus include:

LNG Seller

The export project is typically covered by a joint venture of national oil company (NOCs), international oil companies (IOCs), and maybe LNG Buyers that integrate upstream (Nissen 2004). As such, state owned natural gas is produced with the expertise of the international majors and the risk of the investment liquefaction plant capital investment is shared. IOCs and NOCs have different interests to keep in mind; IOCs are more commercially driven while NOCs are driven by their public responsibilities. This results in a different corporate strategy; NOCs are generally unable or unwilling to remarket the produced natural gas themselves, let the LNG buyer arrange the transport of LNG, and are characterized by limited volume flexibility. The IOC’s on the other hand typically take a more active and flexible stance towards the marketing of LNG. Their multiple supply and transportation sources allow them to perform the remarketing of supply and transport themselves (based on Foss (2005)). Griffin (2006) notes that IOCs distinguish themselves by contractual flexibility that allows them to take advantage of opportunities that are created by virtue of their own asset portfolio which includes liquefaction, regasification and shipping assets. After the natural gas is produced it needs to be liquefied. This takes place at a liquefaction plant where the LNG is put into a temporary storage facility. The marketing of LNG is traditionally part of the IOCs tasks as they are in charge of supplying the produced LNG to the markets, either through traditional long-term contracts or through the spot market for LNG. Although this study recognizes the differences between IOC and NOCs it classifies the joint venture that covers the liquefaction, export, and marketing as the LNG Seller.

Logistics Providers

The most important logistical challenge of the LNG trade concerns the shipment of LNG from the point of production to the point of consumption. The role of LNG shipping is traditionally undertaken by either the LNG Seller or the Customers (LNG Buyer) as part of a comprehensive long-term contract. If the LNG is shipped under the responsibility of the buyer this is on a Free on Board (FOB) basis, and if the seller is responsible for the transport this is called ex-ship or on a CIF (Costs, Insurance and Freight) basis. New in this respect and increasingly involved in LNG shipping are specialist shipping companies that are not directly tied to the seller or buyer. These companies expect to make a profit from the transport of LNG under charter. Most ships however are still owned by the E&P Companies and large consumers. To put things into perspective; in 2005 the LNG vessel fleet consisted of just under 200 LNG tankers and only about a dozen of these were owned by independent shipping companies (Chidinma 2005). There is however an upward trend in both the seize of the LNG tanker fleet and the number of ship-owners, including LNG buyers, sellers and independent shipping companies (Figure 17). Griffin (2006) notes that “The small club of ship-owners that emerged in the 1980s and early 1990s as the leading LNG owners – including notably Bergesen Worldwide Gas, Leif

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8 It suffices at this point to differentiate the two (e.g. CIF and FOB), the importance of this distinction is discussed in chapter 5. 
2. LNG Market Fundamentals

Hoegh, Mitsui OSK Lines, NYK, K Line, MISC – has expanded and now includes new entrants as Teekay, OSG and Marran Gas.

Storage Operator
This stakeholder category will involve companies with logistical expertise on LNG storage and transportation. In general storage operators are highly specialized companies that are not involved in other parts of the LNG market. An exception in this matter is the potential development of LNG storage and trading hubs. One such development concerns a joint project by the Dubai Multi Commodities Centre, Techno Park, and LNG Impel that is aimed at realizing the world’s first LNG storage hub. The Memorandum of Understanding (MoU) was signed in June 2006 and is scheduled for completion in 2013. The total storage capacity would equal 40 to 65 [Bcf] (or in the range of 0.6 to 1 percent of the 2005 LNG trade levels) (NGI 2007). The Dubai Trading Hub anticipates a rising demand in North America, Europe and the Far East to be combined with a rising regional production. Consequently it aims to take advantage of the excellent geographic position to serve the flexibility needs of the market. Note that the DUB is not the only LNG storage hub under consideration. Korea Gas Corporation (Kogas) and Oman’s Ministry of Oil & Gas for example signed an MoU for a similar facility in the sultanate (APS 2006).

LNG Buyers
Buyers of LNG are monopoly franchised utilities (i.e. integrated utilities (Japan) or merchant gas transportation companies (Korea, Taiwan, Europe) (Nissen 2004). LNG Buyers constitute the final part of the LNG value chain and are therefore paramount to the realization of any LNG project. LNG Buyers can be found among the world’s large utility companies as natural gas is increasingly the fuel of choice in the power sector. In 2004, the power sector accounted for 31 percent of the world natural gas consumption and it is widely expected that it will account for the majority of incremental gas usage to 2030 (EIA 2007). In Europe for example the general consensus is that LNG imports will grow from the current 9% of total gas consumption to 25% by 2010/2020, while in North America LNG imports will increase from 2% in 2003 to 15% by 2020/2025 (IEA 2002). In the worlds largest LNG importer Japan, approximately 97 percent of the natural gas is supplied by LNG imports. One-third of this LNG is distributed as city gas and two-thirds is combusted for power generation (Shunzo 2002). The LNG demand of the power sector is expected to climb as the industrial sector shifts to electric power and direct natural gas use to take advantage of its environmental friendly characteristics and counter the high oil prices. Accordingly, this study categorizes the large utility companies and the merchant gas transportation companies as the LNG Buyers.

Trade Companies
This stakeholder category includes two associated roles: traders & merchants. Traders exploit the differences in supply and demand of LNG and form the category of stakeholders that is in charge of delivering the produced LNG to the market. Traders are intermediaries or negotiators for the market players that bring supply and demand together. According to Nissen (2006) a trader buys and sells energy commodities and transportation/transformation services, but owns no assets. Companies such as Enron and Dynegy are examples of traders that were active in the LNG trade without having the underlying upstream or downstream assets of the traditional market participants. Merchants on the other hand add value with asset services. Nissen (2006) defines an energy merchant as “a business entity that owns assets that transform or transport energy that takes title to the energy and is paid by the gross margin (output price minus input price). The combination of the two is labeled by this study as Trade Companies who buy or sell LNG with owned or controlled assets.

Governments
This stakeholder category involves a broad range of potential stakeholders in various countries and on various organizational levels. The host government of the NOC for instance might influence the conditions for an implementation agreement with the IOC, including the charged taxes and the production rights, and the timing of investments in LNG infrastructure. At the other end of the chain

9 Bergesen Worldwide Gas has recently been renamed to BW Gas ASA.
the LNG trade is confronted with the host government of the LNG importing country. A common aspiration for these governments is to pursue policies that guarantee a secure natural gas supply. LNG imports are often used to diversify the natural gas imports as they are not fixed a particular point of production as pipelines. In order to further reduce the dependency on one particular producer, the host government might decide to impose a limit on the share of LNG imports that come from one exporting country. In addition to geopolitical and strategic considerations, the LNG trade is also faced with the permitting issues of LNG import terminals, including regasification plants and LNG storage.

Financial Institutions
These are the financial institutions that are able to provide the capital that is required for the start up of a new LNG project and have the expertise to successfully manage the required financial services. A prerequisite for the financing of a LNG project might be the coverage of its production and off-take during a specified period of time. In addition to their ability to provide the capital that is required for an LNG project they possess the expertise to manage the financial aspects of such an enterprise.

2.3.2 Actor & Network Analysis
As part of the stakeholder analysis an actor and network analysis will now be conducted with the purpose of identifying the objectives, interests, and resources of each stakeholder category. These insights are critical to understanding the LNG trade. This section makes use of the following three consecutive steps to acquire the desired information:

1. Provide a description of the stakeholder’s interest in the LNG trade, their goals and objectives.
2. Categorize the stakeholders resources
3. Determine the LNG trade arrangements

The first step of this analysis involves analyzing the interests, goals and objectives, current state, desired state, and solutions per stakeholder category (§2.3.1). One of the prime interests of almost all actors is value creation and a financial return on investments. Governments are believed to have a broader interest in the LNG trade as they seek to increase the general welfare level. The goals and objectives of the stakeholders are primarily aimed at expanding current successful practices and to explore and exploit new opportunities that are offered by a growing and changing market for LNG. The market expansion and other changes are continuously creating discrepancies between the present state of the stakeholder and its desired future state. For example the LNG Buyer of LNG is currently tied to long-term contracts without the guarantee that there is demand for it, both ingredients for a mismatch between demand and supply. In the current market, storage capacity levels these differences. Ideally however, the LNG Buyer would want its supply of LNG to perfectly match its demand, without the need for storage and without compromising on the security of supply. The proposed solution in this case is to balance supply and demand through a base load of long-term contracts and level potential shortage in demand or surpluses in supply through the spot market for LNG.

<table>
<thead>
<tr>
<th>Stakeholder Category</th>
<th>Interests</th>
<th>Goals &amp; Objectives</th>
<th>Current State</th>
<th>Desired State</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG Seller</td>
<td>Value creation, Financial return, Revenue expansion, Market share expansion, Diversification</td>
<td>Additional and sustainable revenue flow through an expanded network of LNG infrastructure</td>
<td>Faced with increased competition on the LNG market,</td>
<td>Additional and sustainable revenue flow from expanding the LNG-trade and exploiting portfolio benefits</td>
<td>Expand LNG activities and obtain customer preference through the supply of tailored LNG supplies</td>
</tr>
<tr>
<td>Logistics Providers</td>
<td>Value creation, Diversification</td>
<td>Additional and sustainable revenue flow through an expanded transport capacity</td>
<td>LNG tankers are only effectively used for half of the time</td>
<td>Keeping the cargo tanks cold at all times</td>
<td>Swaps, faster loading / unloading, increased efficiency (ton mile potential)</td>
</tr>
<tr>
<td>Storage Operator</td>
<td>Financial return, Revenue contracts, Diversification</td>
<td>Additional and sustainable revenue through expansion of</td>
<td>LNG is temporarily stored after liquefaction and regasification</td>
<td>Increased possibilities to earn from the LNG trade</td>
<td>Innovative storage concepts, realization of transshipment</td>
</tr>
</tbody>
</table>
2. LNG Market Fundamentals

Table 3: Overview of the Stakeholders’ Interests, Goals, and Objectives.

<table>
<thead>
<tr>
<th>Stakeholder Category</th>
<th>Resources</th>
<th>Substitutability</th>
<th>Dependability</th>
<th>Critical Actor</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG Seller</td>
<td>Capital, market expertise, natural gas, LNG infrastructure: (liquefaction, transport, and regasification capacity)</td>
<td>Low</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Logistics Providers</td>
<td>Transport capacity, logistical experience, capital</td>
<td>Medium but decreasing</td>
<td>Medium and increasing</td>
<td>Yes</td>
</tr>
<tr>
<td>Storage Operator</td>
<td>Storage capacity, logistical experience, capital</td>
<td>Medium</td>
<td>Medium</td>
<td>No</td>
</tr>
<tr>
<td>LNG Buyer</td>
<td>Capital, bargaining power, LNG infrastructure: (liquefaction, transport, and regasification capacity)</td>
<td>Low</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Trade Companies</td>
<td>Capital, market expertise</td>
<td>High but decreasing</td>
<td>Low but increasing</td>
<td>No</td>
</tr>
<tr>
<td>Governments</td>
<td>Feedstock prices, natural gas resources, taxation, permits and operating licenses</td>
<td>Low</td>
<td>High</td>
<td>Yes / No *</td>
</tr>
<tr>
<td>Financial Institutions</td>
<td>Capital</td>
<td>Medium</td>
<td>Medium</td>
<td>No</td>
</tr>
</tbody>
</table>

* Depends on whether or not the government is involved on a local or national level (i.e. whether or not security of supply and demand issues are involved).

Table 4: Overview of the Stakeholders’ Resources.
According to the definition of a critical stakeholder that is used in this research, these are the stakeholder categories that have a direct interest in the transition towards a spot market for LNG and are able to influence its development. The non-critical stakeholder categories include the government (both from the exporting and importing countries), financial institutions, and storage operators. Note that the term 'non-critical' is not to say that the interests and influence of these actors are irrelevant for the LNG market as a whole. As this research aims to assess the transition of the market for LNG, it requires a more detailed analysis of the critical and non-critical stakeholders over time. The LNG market developments are set to change the traditional roles, practices, and importance of the original stakeholders. Thus, Table 5 provides a categorization of the stakeholder categories which also accounts for the anticipated market changes and their perceived impact.

<table>
<thead>
<tr>
<th>Low Substitutability</th>
<th>High Dependability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate Dependency</td>
<td>Critical Dependency</td>
</tr>
<tr>
<td>Storage Operator</td>
<td>LNG Seller</td>
</tr>
<tr>
<td>Trade Companies</td>
<td>LNG Buyer</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>High Substitutability</th>
<th>Minor Dependency</th>
<th>Moderate Dependency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial Institutions</td>
<td>Logistics Providers</td>
<td>Governments</td>
</tr>
</tbody>
</table>

Table 5: Stakeholder Dependency Matrix (Adopted from: Hanf and Scharpf, 1987).

The final step of this section is to provide an overview of the various trade arrangements from the stakeholders that facilitate the global LNG trade.

<table>
<thead>
<tr>
<th>Stakeholder Category</th>
<th>Trade Arrangements</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG Sellers</td>
<td>Natural gas sales agreement</td>
</tr>
<tr>
<td></td>
<td>Liquefaction tolling agreement</td>
</tr>
<tr>
<td></td>
<td>Cost Insurance Freight contracts</td>
</tr>
<tr>
<td></td>
<td>Sales and Purchase Agreements</td>
</tr>
<tr>
<td></td>
<td>Spot sales agreement</td>
</tr>
<tr>
<td></td>
<td>LNG price</td>
</tr>
<tr>
<td>Logistics Providers</td>
<td>Charter Agreement: Free On Board contracts or Cost Insurance Freight contracts</td>
</tr>
<tr>
<td>Storage Operator</td>
<td>Storage agreement</td>
</tr>
<tr>
<td>LNG Buyers</td>
<td>Natural gas sales agreement</td>
</tr>
<tr>
<td></td>
<td>Regasification tolling agreement</td>
</tr>
<tr>
<td></td>
<td>Spot sales agreement</td>
</tr>
<tr>
<td></td>
<td>Free On Board contracts</td>
</tr>
<tr>
<td></td>
<td>Sales and Purchase Agreements</td>
</tr>
<tr>
<td>Trade Companies</td>
<td>Spot sales agreement</td>
</tr>
<tr>
<td></td>
<td>Free On Board contracts</td>
</tr>
<tr>
<td></td>
<td>Liquefaction tolling agreement</td>
</tr>
<tr>
<td></td>
<td>Regasification tolling agreement</td>
</tr>
<tr>
<td>Governments</td>
<td>Taxation</td>
</tr>
<tr>
<td></td>
<td>Permits and operating licenses</td>
</tr>
<tr>
<td></td>
<td>Natural gas contracts</td>
</tr>
<tr>
<td></td>
<td>Natural gas price</td>
</tr>
<tr>
<td>Financial Institutions</td>
<td>Lending contracts</td>
</tr>
</tbody>
</table>

Table 6: Overview of the Stakeholders Rules Trade Arrangements.

With the actor & network analysis completed it is now time to create a mapping of the global LNG trading network that acts as the point of reference for the remainder of this investigation.
2.3.3 Global LNG Trading Network

The global LNG trading network that is illustrated in Figure 24 represents an overview of the current social network of the LNG market that is based on the stakeholder analysis (§2.3.1) and the actor and network analysis (§2.3.2). It shows how the different stakeholder categories interact and which trade arrangements are used in the LNG trade. The system delineation (red cubicle) displays the social interactions that this investigation believes to be key to understanding the transition of the LNG market.

![Global LNG Trading Network Diagram](image)

The natural gas flow shows that the LNG Seller can trade its LNG through a Sales and Purchase Agreement or on the spot market for LNG by a Spot Sales Agreement. The actual transport of LNG requires a shipping agreement to be in place which can either be the responsibility of the LNG Buyer (CIF) or LNG Seller (FOB) (Logistics Provider §2.3.1). The LNG Merchant Trader constitutes a new stakeholder category that enables liquefaction, shipping, and regasification through tolling agreements and manage trading and arbitrage (explained in §3.4).

2.4 Socio-Technical Interactions

While the LNG market originated out of a series of independent and disconnected projects (i.e. complete value-chains in this instance) with a corresponding straightforward way of contracting, current market development are making the LNG trade more complex. The market changes that are forcing the market participants to reconsider the traditional project arrangements are discussed here. In itself these developments are a concurrence of the technical and social trends that are previously discussed (§2.2, §2.3). The socio-technical trends that are identified by this investigation include:

Expanding Global Market for LNG

The expansion of the LNG market creates new trading opportunities by virtue of its own success. The expected capacity increase of the global LNG infrastructure is expected to increase the number of market participants and the volumes of traded LNG. This contributes to a more liquid market for LNG and could have far-reaching consequences for the way in which LNG projects are organized (§3.2 & §3.4). The traditional LNG project arrangement that encompasses all aspects of the LNG trade could be replaced by more flexible trade arrangements. The Logistics Provider for instance might decide to build a LNG tanker that is not tied to a LNG project or a LNG Buyer might initiate a new liquefaction plant without the complete contractual coverage of the to-be produced volumes.
Secondly, the growth of the market is expected to extend the operation of existing LNG infrastructure once the original contract has expired. This implies that liquefaction plants that have depleted their original natural gas reserves could provide natural gas liquefaction on a tolling basis. LNG tankers that were dedicated to a particular LNG project and were obliged to follow set point-to-point routes could decide to turn to the transport of LNG under charter. Both possibility enable new entrants to participate in the LNG trade without the need to make the initial investment and thus lower the typical barriers of entry to the LNG market.

Flexible Demand Requirements

Because LNG is typically used for power generation and space heating its demand is subject to seasonality, social habits, and exogenous forces. While the first two are repetitive demand patterns, and hence can partially be anticipated for, the last is of a more unexpected and uncontrollable nature. The restructuring and liberalization of the natural gas and electricity market have created a more unpredictable climate for the LNG Buyer which make it more difficult to commit to long-term high-volume project arrangements. This implies that there is an increased need for flexibility of supply that proves difficult to match with the traditional project specific contractual arrangements. Adjustments in the contractual agreements that are aimed at increasing the flexibility requirements of the market are expected to play an important role in satisfying these new market needs. In addition to contractual adjustments, the proposed LNG storage and trading hub could facilitate a more flexible LNG trade as it relieves the market from strict and inflexible supply schedules and allows market participants to balance supply and demand according to their real needs.

New logistical deployment schemes

A liquid market for LNG tankers is for many analysts a necessary pre-condition for the existence of a competitive LNG spot market. Market liquidity in this part of the LNG value-chain however means that the market needs to break with a tradition of LNG tankers that are locked-in by the LNG project, hold dedicated cargoes and follow set point-to-point routes. One of the main drivers towards a more liquid market for vessels can be found in the economics of dedicated tankers. Dedicated tankers are often used inefficiently because they are unable to deviate from their fixed routes and cargos to take advantage of arbitrage possibilities or to participate in cargo swaps. Furthermore many tankers make the return trip to the liquefaction plant empty, thereby further increasing the logistical expenses. “According to Amar Banwait, LNG Shipping Commercial Advisor for Shell, a typical utilization rate of seven dedicated vessels is around 80 percent. This equals a spare capacity of 1.4 vessels. In other words, the same project could be covered by six vessels, using short-term charters for any large variation in volumes. This could, according to Mr. Banwait, create savings of $155 million over a 15 year period based on assumptions of $120 million residual value and $11,000 per day operating costs” (Matthews, 2005).

In addition to the sub-optimal economic performance of dedicated tankers there is also no real competitive incentive to improve the tanker utilization rate in a vessel market that is bound to destination clauses and is financed for by a long-term contract. In order to improve the performance of the LNG vessel fleet it needs to become more flexible. Currently all the involved stakeholders (e.g. LNG Buyers Logistical Provides, and LNG Sellers) in this part of the LNG value-chain are developing their own fleets. Trade & Production Companies are developing their own fleets to take advantage of arbitrage opportunities within their own portfolio, whereas the independent logistical providers compete against each other for cargoes and manage the available fleet in such a way that shipping costs are minimized. Finally, large LNG Buyers such as Tokyo Gas Co. Ltd., and Tokyo Electric Power Co. are developing their own capacity to become less dependent on the Trade & Production Companies. Once in control of their own cargo, customers could re-sell purchased gas if economic incentives indicated that was the profitable strategy. The strategic and economic advantages that coincide with the ownership of independent tanker capacity are strong drivers for building LNG tankers on a speculative basis and optimize the current operations.

Upstream and Downstream Integration
In order to guarantee market access and security of supply several market participants, most notably the LNG Buyers and the LNG Sellers, are actively involved in downstream and upstream integration. Since the regasification of LNG is a relatively low costs part of the LNG value-chain, it becomes interesting for LNG Buyers to acquire regasification capacity as an entry to LNG supplies. For this reason "they may be willing to invest in or contract for regasification capacity without having secured LNG supplies to completely fill that capacity" (CIEP 2006). The other way around seems equally true as LNG Sellers are actively involved in the procurement of regasification capacity as a means to secure market access. Although both strategies are actively pursued, the market is characterized by excess regasification capacity. According to Dearman (2006) the global regasification capacity at the end of 2005 was about 1.8 times that of the global liquefaction capacity, while overall utilization rates equaled about 40 percent. Figure 25 provides a more detailed overview of the average utilization rate for regasification terminals and shows that average utilization rates are in the order of 50 percent. Despite the current spare capacity the global regasification capacity is set to increase and "based on existing capacity, terminals under construction, approved or that have applied for approval, world regasification capacity will reach 450 BCM at the end of 2008 and will continue to grow to 1350 BCM in 2013" (Platts 2008). The implications of the excess regasification capacity are twofold, one the one hand this implies that customers can absorb additional LNG volumes when it is attractive to do so. On the other hand it could lead to increased competition between customers to procure the relatively small amount of offered LNG.

![Figure 25: Utilization of regasification terminals 2005 (PWC 2007).](image)

With the relevant socio-technical interactions discussed it is time to summarize this chapter and provide an answer for the first sub-question.

### 2.5 The Central Factors of the LNG Market

With the technical fundamentals and social network of the LNG market in place, and after due cognizance of the interface between both, this section will provide an answer to the first sub-question:

- What are the main technical and social factors that shape the LNG market?

The discussion of the technical fundamentals of the LNG market showed that the LNG value-chain enables the physical trade of LNG through its individual components: the liquefaction plant, LNG tanker, and regasification plant. The cost structure of the LNG trade shows that the actual production of natural gas is responsible for 15 to 20 percent of the costs, liquefaction 30 to 45 percent, shipping 15 to 25 percent, and regasification the remaining 15 to 25 percent. This has resulted in discrepancies between the global liquefaction, shipping, and regasification capacities. Current estimates indicate that
the global liquefaction capacity in 2025 will amount to 650 [BCM] while the global regasification capacity is expected to reach 1387 [BCM], or more then double that of the global liquefaction capacity. Another important observation is the strong increase of the LNG tanker fleet which, according to industry expectations, will outgrow the global liquefaction capacity. Further technological developments along the LNG value-chain include the pursuit of economies of scale, technological innovations such as offshore liquefaction and regasification, and the projected introduction of a LNG storage and trading hub. As a matter of course economics will determine the speed and way in which the global LNG infrastructure will develop. Industry estimates show that while the LNG trade in 2005 equaled 189 [BCM], it is expected to reach 460 [BCM] in 2015, and a further 693 [BCM] in 2030.

The projected expansion of the global LNG trade means that existing roles of market participants are changing while new ones are emerging. The social network analysis of the LNG market used a stakeholder analysis to identify the market participants whose actions, interests, and influence shape the development of the LNG market. Both the Customers and E&P Companies were deemed of critical importance to the development of the LNG trade, while the Storage Operators, Governments, Trade Companies, and Logistics Providers were labeled as moderately important. Note that this categorization can change following the introduction of innovative storage concepts, new trading tools, or a different logistical deployment schemes. While the E&P Companies seek to expand their LNG activities and obtain Customer preferences through tailored LNG supplies, the Customer seeks to balance the benefits of secure long-term contracts with the flexibility of the spot market for LNG. The social network of the LNG market that is used for the purpose of this study is depicted in Figure 24.

As both the technical fundamentals of the market and the social network are related, the interface between the two indicates that the expansion of the global LNG infrastructure creates new trading opportunities. The traditional LNG trade in which the complete LNG value-chain is part of one large all encompassing trade agreement might give way to a multiple disaggregated project arrangements. Secondly, there are changing Customer preferences as a consequence of the liberalization of electricity and gas markets. This implies that the Customer is no longer able to benefit from their privileged position as a public or semi-public company and becomes more susceptible to market signals. This might influence the trade-off between security of supply concerns and the costs of the LNG supply. Due to global LNG infrastructure expansions it also becomes less attractive to have dedicated LNG tankers that follow point-to-point routes. The economics of tanker utilization dictate that it is more efficient to use LNG tankers where they are needed the most and shorten the routes through cargo swaps. It is estimated that this could generate a costs reduction of $155 million over a 15 year period for a typical LNG project. Finally, there is the impact of the asymmetrical capacity development of the LNG value-chain which creates a larger regasification versus liquefaction surplus. The implications of which are twofold: while Customers are able to absorb additional LNG volumes when this is desirable it also increases the competition between Customers to procure LNG.

These newfound insights of the LNG market fundamentals allow this study to turn the attention towards the LNG trading models, their characteristics, and drivers.
3. The LNG Market in Transition

This section aims to derive the key market drivers that contribute to or impede the development of a spot market for LNG. It is important to single out these key imminent drivers because their development will have a strong impact on the approaching spot market for LNG. The central research question of this chapter is therefore the second sub-question:

- What are the key market drivers that contribute to or impede the development of a spot market for Liquefied Natural Gas and how will these develop?

A prerequisite to answering this question is a general understanding of the economic principles by which the market operates. As such, the relevant economic theory on markets and market evolution is explicated first (§3.1). Secondly, the traditional LNG market with its long term contracts is analyzed along with evolution of the LNG market (§3.2). Next, the global LNG market is discussed and imminent key market drivers and inhibitors are identified (§3.3). This section concludes with the different trading models of the LNG spot market (§3.4) before answering the second sub-question (§3.5).

3.1 Economic Principles of the LNG Market

The discussion of relevant economic theory (§3.1.1) enables this investigation to establish market criteria (§3.1.2) that are subsequently to conduct a systematical analysis of the LNG market. Finally, the process of market evolution is discussed to understand the impact of the approaching spot market for LNG to the global LNG trade.

3.1.1 Market Theory Explained

The Encyclopedia Britannica (2008) describes markets as a means by which the exchange of goods and services takes place as a result of buyers and sellers being in contact with one another, either directly or through mediating agents or institutions. Traditionally, perfect competition is considered to represent the ideal market form in which the Invisible Hand\textsuperscript{10} ensures that the market attains equilibrium and the greatest benefit for society as a whole. The theory of markets that can be used to distinguish between different market forms, “is concerned with how scarce factors of production are allocated between the multitude of product markets in the economy” (Pass 1994). The distinction itself is made by looking at the following properties:

- degree of seller concentration (e.g. the number of suppliers and their relative size distribution),
- the character of the product (e.g. homogenous or differentiated product), and
- the existence of entry/exit barriers.

Thus, market forms other then perfect competition include monopolistic competition, oligopoly, and monopoly. If all firms are assumed to behave rationally and seek to maximize profits, perfect competition yields superior results over the other market forms. This conventional line of reasoning is known as the Neoclassical Economics (NCE), which the MIT Dictionary of Economics defines as “A body of economic theory which uses the general approach, methods, and techniques of the original nineteenth century marginalist economists...In particular, they studied the possibility of a set of market prices which ensured the equality of supply and demand in all markets. The idea of a perfectly competitive economy in equilibrium...is central the neo-classical scheme” (Pearce 1999). This makes NCE particularly useful for analyzing specific economic problems that involve the resources allocation process and price competition. However, NCE is often accused of ignoring the complexities of the real world because of its exclusive focus on pricing and competition and lack of attention to dynamic performance criteria. Kaufmann (2007) for example notes that “markets do not exist in nature but are human-made institutions that require real resources to create and operate. Furthermore, markets

\textsuperscript{10} The invisible hand was first coined by the economist Adam Smith, commonly seen as the founder of modern economists and refers to a hypothetical economic force that in a freely competitive market works for the benefit of all Merriam-Webster (2008). Merriam-Webster Online Dictionary.
operate only in the context of a body of working rules that determine the nature of the good or service being exchanged, the pool of potential traders and conditions of entry and exit, the procedures governing interaction between buyers and sellers and what methods and practices can and cannot be used, and the sanctions used to enforce obedience to the rules".

Institutional Economics (IE) represents an alternative framework for constructing economic theories that emphasizes the role of human made institutions in shaping of economic behavior\textsuperscript{11}. Institutional economics is "a type of economic analysis which emphasizes the role of social, political, and economic organizations in determining economic events...The emphasis on the role of institutions is a criticism of conventional economics which may be said to ignore the non-economic environment in which individuals make decisions" (Pearce 1999). North (1991) adds that "institutions consist of the constraints, formal and informal, on economic and political actors and markets to work as they should, need institutions to define the rules of the game". As such, IE goes beyond NCE in that it seeks to explain economic problems through the incorporation of social and cultural phenomena. In accordance with Tool (1995), this study recognizes that "modern markets are comprised of a large number of usually complex correlated patterns of behavior which organize and structure exchange activities" and beliefs that the transition of the LNG market needs to be analyzed in a broader context then that described by NCE. As such, it will use the four layer model of Williamson (1998) to analyze the development of the LNG market and the emerging spot market for LNG in a broader context. Williamson (1998) distinguishes between four levels of social analysis that govern economic behavior (Figure 26). It is important to mention that the different layers are interdependent on one another, Künneke (2006) notes that “institutions are not randomly developing, but the layers are interrelated in accordance with a certain logic. For example, lower layers may be considered to form the foundations for higher abstractions upwards in the model”.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
Level & Purpose \\
\hline
Level 1 & Often non-calculative: spontaneous developing in the social context \\
Social theory & \textbf{Frequency} \\
& \textbf{10}^2 to \textbf{10}^3 \\
\hline
Level 2 & Get the institutions environment right: 1\textsuperscript{st} order economizing \\
Economics of property rights & \textbf{Frequency} \\
& \textbf{10} to \textbf{10}^2 \\
\hline
Level 3 & Get the governance structure right: 2\textsuperscript{nd} order economizing \\
Transaction cost economics & \textbf{Frequency} \\
& \textbf{1} to \textbf{10} \\
\hline
Level 4 & Get the marginal conditions right: 3\textsuperscript{rd} order economizing \\
Operations economics & \textbf{Frequency} \\
& \textbf{Continuous} \\
\hline
\end{tabular}
\caption{The four layer model by (Williamson 1998).}
\end{table}

Embeddedness (e.g. level 1) represents the highest abstraction category and refers to the fact that institutions at this level are embedded in the human psyche through cultures, traditions, etc. It is important to realize that these institutions are extremely static and subject to change only a few times per century. Although undoubtedly important, the analysis of the social embedded institutions in this study will be limited to cultural differences. The institutional environment (e.g. level 2) represents the

\textsuperscript{11} As are for example Marxian economics, Keynesian Economics, and Austrian Economics.
formal juridical background and as such considerably more dynamic than the previous level. Changes in the juridical system typically take place within decades and is more influential than the embedded institutions. Although it is not among the primary objectives of this study, changes in the institutional environment that are likely to influence the development of the market for LNG, such as changes in regulatory regimes and security of supply concerns, will be discussed. Governance structures (e.g. level 3) concerns the formation of contracts and protocols between stakeholders. These arrangements typically last years rather than decades and is all about getting the governance structure right. Transaction Costs Economics (TCE) is considered to be the most appropriate theory to analyze the differences between governance structures and regards the transaction as the basic unit of analysis (Williamson 1981). Resource allocation and employment is the fourth and lowest level of Williamson's framework and deals with the actual distribution of resources and price formation. This level is the domain of NCE and Agency Theory.

The research objectives of this investigation make it important to understand how economic behavior is favored. Although all four levels of social analysis are indisputably important for the development of the LNG market, this study will focus on the governance structure to assess how the long-term contracts are gradually replaced by short-term trade arrangements but will use the principles of NCE for exploratory purposes. With the main market theoretical principles clarified, it is time to establish the market criteria.

### 3.1.2 Establishing Market Criteria

The market criteria that are drafted here will subsequently be used to identify the imminent key market drivers and inhibitors of the spot market for LNG. A ‘quick and dirty’ assessment of the market for LNG that makes use of the differentiating parameters from market theory shows that the number of suppliers of LNG is limited (market concentration), natural gas is not (yet) a homogenous commodity, and that there are substantial entry and exit barriers to participating in the LNG trade. The market structure that forms the best match with these characteristics is the oligopoly.

This has important implications for the development of the LNG market in that a limited number of market participants determine the course and speed of market development. If the LNG market structure were to resemble that of perfect competition instead, General Equilibrium Theory could be used to examine the behavior of supply, demand, and price formation. The limited number of market participants however rules out the use of Equilibrium Theory. Phelps (2004) notes “With small numbers of participants, general equilibrium models break down because they fail to allow for market power, and the potential gains of strategic behavior, of participants” and proposes auction theory to circumvent these shortcomings in markets with a limited number of players with minimal compromises to the explanatory power of the analysis. Jepma (2005) notes that “According to auction theories, auctions fully absorb all relevant information and their market participants behave fully rational. With respect to this, auctions resemble the theory of perfect competition. However, an important difference between the theories of auctions and perfection competition is that the number of buyers and sellers on an auction market could be relatively small, whereas perfect competition requires many participants. Another distinguishing fact is that auction theory, with the help of game theory, allows for the analysis of the behavior of individual market players, whereas perfect competition only assumes profit-maximization under the assumption that in equilibrium each participant’s marginal costs equal marginal benefits”.

In combining the criteria for a ‘perfect commodity market’ with the criteria for auction or auction-type markets of Phelps (2004), Jepma (2005) derives the following conditions to describe the functioning of a market:

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12 General Equilibrium Theory is attributed to Walras, who studied a theoretical economic system in which all consumers were utility maximizers and firms were perfectly competitive, the model shows that a unique stable equilibrium can exist under such conditions Weintraub, E. R. (1974). General Equilibrium Theory. London.
3. The LNG Market in Transition

- Market structure characteristics, in terms of level of horizontal and/or vertical integration among marketers, supply and demand elasticities, entry/exit barriers, and product homogeneity.
- Trade characteristics, which focus on trade flexibility, transportability of the commodity, storage capacity, dedication of the network to the commodity, technical tightness of the market.
- Price characteristics, concerning price uniformity on a national or international scale, price formation, and price volatility on the market.

From the analysis of a number of non-energy spot markets (currencies, coffee, and aluminum) Jepma (2005) concludes that the proper functioning of a market largely depends on the tradability of the commodity. Although this study agrees with Jepma (2005) that the trade characteristics of a commodity are indeed important for the effective functioning of a market, it finds it hard to neglect the existing interdependencies and rank them in any particular order. In a World Bank commissioned paper, Juris (1998) uses quite similar conditions to explain the industry structure and trading mechanisms that determine the efficiency of gas markets. It is argued that an efficient natural gas market performs three functions:

- It aggregates supply and demand to determine system demand and supply curves.
- It facilitates market clearing to determine the market price of natural gas.
- It signals the market value of gas.

Although Juris (1998) clearly focuses on the UK natural gas market, this study feels confident that the same conditions can be used to determine the efficiency of the LNG market. With the market criteria in place, it is time to look at the specifics of spot markets. Jepma (2005) notes that the conditions for a 'perfect' spot market include:

- Non-discrimination: all players face the same tariffs, conditions and procedures for market entrance.
- High transparency: information on tariffs, conditions, procedures and energy transport capacity is publicly available.
- Large competition: a considerable number of players have access to the market and there are no or no strong levels of horizontal and vertical concentration of particular players.
- Effective functioning of the market: there is a high liquidity in terms of traded volumes and sufficient capacity in terms of physical availability of the commodity natural gas, transport, and flexibility in terms of storage, line pack, production swing, quality conversion, interruptible customers, and imports.

Although all four of the above-mentioned conditions contribute to the realization of the perfect spot market, some conditions are deemed more important than others. Jepma (2005) notes that “Some conditions have a more fundamental or structural impact while other conditions are more facilitative and do not place serious obstacles to the functioning of a commodity market”. The high transparency and non-discrimination conditions for instance can be enforced by the respective regulatory regime and hence are of a more informational (as opposed to structural) nature. With regards to the perfect competition it is noted that although this is indicative for a market with perfect competition, it is certainly not a prerequisite for the well functioning of a spot market. “After all, a large number of real life (well functioning) commodity spot markets are faced with horizontally and vertically integrated market players” (Jepma 2005). It is important to realize that the spot market for LNG is not required to resemble the perfect spot market but that it suffices to have a well functioning spot market for LNG in place. This makes the effective functioning of the market the most important condition for the development of the spot market for LNG as it describes the “physical and structural market characteristics determining the flexibility, tradability, transportability, and efficiency, and in essence determines the potential liquidity of the markets” (Jepma 2005).

With the criteria to describe the functioning of the market, the efficient functioning of the LNG market, and the conditions for a perfect spot market in place, this research will look at the market evolution next.
3. The LNG Market in Transition

3.1.3 The Evolution of the LNG Market

According to economic literature, market development in energy markets takes place through several stages. While the demand and supply are initially matched through long-term bilateral contracts between the buyers and sellers, the situation changes when the market matures. “As the volume of trading increases, bilateral trading becomes inefficient because markets become nontransparent and trading imposes high transaction costs on market participants” (Juris 1998). Brokerage replaces the bilateral trade but the market essentially remains in an advanced form of bilateral trading in which the aggregated demand and supply is traded among market participants. If trading volumes continue to increase, trade becomes concentrated at one or several trading points and brokerage is replaced by spot market trading. Once the spot market is in place it is soon complemented by trade instruments that allow market participants to manage the risk of volatile prices. This section provides an overview of the process of market evolution for the LNG market (Figure 27).

The LNG market developed out of a series of independent regional projects in which the risks were covered by long-term contractual agreements between members of an oligopolistic market. The institutional economic literature interprets these long-term contracts as a device to avoid the risks of opportunistic behavior in deals that involve high sunk investments, as is the case in the LNG market. Ruester (2006) notes that the main drivers for rising transaction costs are to be found in the asset specificity, uncertainty, and frequency of the transaction. Consequently, these conditions also determine the most applicable contract structure, a higher asset-specificity of investments for instance will lead to a more hierarchical contract structures, as opposed to market exchange (Neuhoff 2005). The international LNG trade that existed in the early days of the LNG industry consisted of little more then several segregate projects with independent pricing. The size of these market regions was further limited by the prohibitive costs of transporting LNG over long distances. This situation changed in the early days of this decade when the cost-price balance broke the so-called ‘tyranny of distance’ and made Middle Eastern LNG economically viable into the US gas market (Baily 2007). The development of the major LNG trade movements between 2005 and 2015 (Figure 21 & Figure 22) demonstrates that the once isolated regional Atlantic and Pacific markets become more tightly connected. Development projections show that this trend is set to continue and increase the international competition for LNG supplies between its main markets: the United States, Europe, and the Asia Pacific.

Once the international trade of LNG picks up, there will be increased price connectivity between the various markets. Tusiani (2007) notes that the development of LNG pricing seems to develop similar to the oil pricing in that strongly related regional prices (Henry Hub, Zeebrugge) will interact in the same way as benchmark crude oils. Despite the many differences between the crude markets and the market for LNG it is interesting to note that the crude markets moved away from long-term bilateral contracts and towards a truly fungible market because of excess ullage in the system (e.g. market) that acted as a safety-valve against unexpected supply or demand swings (strongly based on (BG 2007)). Put differently, the spare capacity in the infrastructure created a situation in which the long-term bilateral contracts were made redundant. Instead the market participants could turn to a liquid market to accommodate their supply and demand swings. Trade flexibility is therefore depicted as the third step of the market evolution.

The flexibility of the LNG trade is further enhanced by the ongoing process of liberalization in the power sector and natural gas sector in many European and Asian countries. This liberalization process is based on the premises that competitive markets provide lower prices and better services for consumers than planned markets are capable of. Before the liberalization of the power sector, utilities
received a fixed return on investments while operating costs were passed on to the consumer. As such, there was no real incentive to negotiate low prices or flexible contracts for the delivery of natural gas. The restructuring of the gas market follows the same principles and “envisions free market competition among buyers and sellers to set commodity prices for ‘gas-to-gas competition’” (Jensen 2004). Another important change that enhances the trade flexibility involves a significant lowering of costs throughout the LNG chain. Industries estimate believe that the costs through the chain have halved (Nissen 2002), thereby strongly reducing the risks of initiating a new LNG project. Hence, this provides the opportunity to relax the rigid contractual terms included in the SPA and makes it possible to start a project without full coverage of the production volume.

It is argued that trade flexibility, and the transactions that is creates allows for the gradual establishment of reference prices in the different markets. This is also known as the creation of international indices which are crucial for the process of price discovery. Price discovery is “the process of uncovering an asset’s full information or permanent value” (Figuerola-Ferretti 2007). As such, these benchmark LNG prices could serve as a more relevant index for LNG contracts then the conventional oil linked prices that are included in the SPA and identify the regions of excess demand and supply more clearly. “Information on price discovery is important because spot and future markets are widely used by firms engaged in the production, marketing and processing of commodities. Consumption and production decisions depend on the price signals from these markets” (Figuerola-Ferretti 2007). Hence, market determined prices will aid market participants to make their investment decisions in a more efficient manner.

Finally, and this is the last step in the evolution of the market, comes the development of trade instruments that allow for the management of price risks. Price volatility\textsuperscript{13} turns out to be a significant risk for traded natural gas, especially if this is compared to the time-legged oil indexed prices that are typically used in the SPA. Limited transport flexibility and difficulties with LNG storage further increase this volatility. The EIA (2002) notes that “Price volatility is inevitable in competitive markets. It is a fact of economic life in all commodity markets. When the industry operates close to full capacity, small changes in supply and/or demand or relevant news items or sound bites may cause strong market pressures and substantial price increases or decreases”. The price volatility of individual traded markets (e.g. the Atlantic and Pacific Basin) can translates itself into price differentials (geographic, summer-winter) that are even more volatile (CIEP 2003).

In order to manage these risks market participants can turn to the spot market during periods of volatile prices. It is also possible to take advantage of the price differentials between markets through short-term transactions (spot agreements, swap agreements). The spot market for LNG might also support the use of other trade instruments such as derivatives and financial trading. This completes the transition from long-term contracts towards a LNG market that is more flexible and responsive to market signals. The Deutsche Bank summarized its view on the evolution of the LNG market as follows "'Old LNG' was all about the volume risk, the requirement to find a buyer for all your gas sales before launching a project. 'New LNG' is all about the price risk, the willingness to bet that the long-term marginal cost of supply will be lower than the prevailing US gas price for the life of your project.” (Brito 2007)

Before this research continues with the assessment of the current spot market for LNG, a description of the traditional LNG market will be provided for.

\textsuperscript{13} Volatility - A measure of the variability of a market factor, most often the price of the underlying instrument. Volatility is defined mathematically as the annualised standard deviation of the natural log of the ratio of two successive prices; the actual volatility realised over a period of time (the historical volatility) can be calculated from recorded data.
3.2 The Traditional LNG Market Described

The functioning of the LNG market is first assessed through the perfect commodity market criteria (§3.2.1). Next, the traditional long-term contracting of the LNG trade is discussed (§3.2.2) along with market issues that impede the unchanged prolongation of their use (§3.2.3).

3.2.1 Is the LNG Market a ‘Perfect’ Commodity Market?

The identification of the market structure, trade, and price characteristics allows this investigation to systematically explore the LNG market.

Market structure characteristics

Market structure characteristics include horizontal/vertical integration among marketers, supply and demand elasticities, entry/exit barriers, and product homogeneity. These conditions have the ability to create market power which creates inefficiencies in the market.

In accordance with the theory of TCE, Ruester (2006) argues that the increased transaction costs along the LNG value-chain induce a higher degree of vertical integration. As vertical integration brings multiple components of the LNG value-chain under the effective control of a single entity, it enables cross-subsidization. The supply and demand elasticity are rather low, as high sunk costs and asset specificity promote the continued production and consumption of LNG until the investment is recovered. Although dual fired power plants have the potential to increase the elasticity of demand, the current investment climate favors single fired power plants. The supply and demand elasticity thus remain low and counter the threat of market power. Entry and exit barriers to a market determine if the market participants are free to enter and exit a market at will. Entry barriers prevent new companies to enter the market at will, while exit barriers prevent incumbent companies to leave the market. Entry and exit barriers typically arise when there is a high asset specificity and large economies of scale. Participating in the LNG trade requires high upfront investments in specialized technology and once a project is operating it is expensive to shut it down making both the entry and exit barriers considerable. Finally, the homogeneity of LNG which has important implications for the market as it determines if price is the only differential for market participants or not. There are various LNG specifications that impede the interchangeability of LNG and resource allocation process of the market.

Trade characteristics

The effective functioning of a market requires a tradable commodity which is determined by the flexibility of supply and demand, the ease of transport and storage, network dedication, and the technical tightness of the market (e.g. the balance between demand and supply).

Jepma (2005) notes that “the tradability of a commodity, and thus the liquidity in the market and arbitrage opportunities, depends on its transportability and the flexibility of its supply and demand structure”. Surplus capacity throughout the LNG value-chain means that there are no, or limited physical barriers that prohibit the exchange of LNG. Flexibility in the LNG value-chain however, does come at a price as unused infrastructure is expensive. Another important determinant of the tradability of a commodity is the transportability, which for the purpose of this study is defined as the transportation costs per unit of energy cargo capacity. If the costs of LNG transport are high, this reduces its tradability as it becomes more expensive to deviate from fixed trading routes. It is estimated that the transportation costs for LNG are roughly seven times as expensive as those of crude oil (§2.1). The tradability is further influenced by the storage capacity of the commodity. LNG is stored in specially designed double walled tanks which are used to facilitate demand and supply fluctuations. Increased flexibility for the consumer means that the dependency on storage to meet seasonal demand fluctuations can be reduced to the point of managing mismatches between supply and demand on the market instead of through fuel switching or curtailments (Nissen 2002). The liberalization process of electricity and natural gas markets are considered as important instigators of increased flexibility demands. For the producers of LNG, increased storage provides the opportunity to reduce the costs of “bilateral flexibility”. This means that a increased utilization of storage and shipping throughout the year enables a constant annual production pattern (Nissen 2002). If the
global LNG infrastructure is able to accommodate the perceived flexibility requirements, this strengthens the tradability of LNG.

**Price characteristics**

Price characteristics include price uniformity on a national and international scale, price formation, and price volatility. Together these conditions determine if the price enables the market to allocate the commodity to where this is needed the most. Juris (1998) notes that "whether the changes in the LNG market mean that it is becoming more competitive and flexible depends on whether the price of LNG is the signal that affects the balance between demand and supply".

Important in this respect is the price uniformity on a national and international scale. Currently there are multiple LNG pricing mechanisms in the world, including oil indexed pricing and netback pricing from natural gas pipelines. As such, price uniformity for LNG has not yet been realized as there are multiple pricing mechanisms in the main consumer regions: North America, Europe, and the Asia Pacific. Finally, there is the price volatility of LNG that has the potential to blur long-term price trends that should be used to make adjustments in the supply and demand balance of LNG. If the supply and demand of a commodity are closely matched the market is tight, and pricing becomes volatile or susceptible to minor changes.

It turns out that the LNG market does not satisfy the perfect commodity market criteria and that alternate contract arrangements are required to trade LNG. These are discussed next.

### 3.2.2 SPAs of the Traditional LNG Market

The ‘Traditional’ LNG business model is designed to incorporate, among other factors, high upfront and front-end loading investments, limited competition, and isolated markets. In order to cover the risks that are involved with initiating new LNG infrastructure, a special kind of business structure and financing needed to be developed. In the LNG industry this special arrangement takes the form of a long-term Sale and Purchase Agreement or SPA. The risks of a LNG project and the tools or arrangements that are used to cover them are depicted in Table 7. In industries with long asset lives and a large proportion of sunk investments there is a need to reduce the uncertainty of the project (Williamson 1998) which can be realized through vertical integration of the market participants or in the form of long term contracts (Hirschhausen 2004). This explains the popularity of SPAs in the global LNG trade as it is designed to take away security of supply concerns of the LNG buyer and generate an acceptable ROI for the LNG seller. The SPA incorporates, among other things: quantity commitments, pricing mechanisms, and the contract duration. It is also important to realize the conditions that are not specified by the SPA, the most important of which is the transport of LNG. Although the responsibility of LNG transport is typically assigned in the terms of a SPA, the shipping itself requires separate agreements that are negotiated outside the SPA. Also excluded from the SPA is the receipt at the regasification terminal. Jensen (2003) notes that the operation of the receipt and regasification terminal is downstream of the point of delivery and therefore outside the scope of the SPA.

In order to work effectively, the SPA requires that the terms of the contract are coordinated with all commercial agreements involved in an LNG project (BakerBotts). The SPA is typically negotiated between a government owned, or at least strongly influenced, utility company (e.g. the Customer or LNG buyer) and a joint venture between one of the international majors and a national oil company (e.g. the Production & Marketing Company or LNG seller). The ROI of the undertaking could more or less be guaranteed by the fact that the LNG buyer was able to pass on some of the projects risk to their tied end-use customers. Tusiani (2007) notes that "under the rules generally in place at that time, utilities’ earnings were a function of their invested capital base, and provided that if the costs of LNG supply acquisition were deemed reasonable, the costs of LNG supplies would be treated as a direct pass-through to the end-use customer". Although this combination allowed for favorable financing terms for the LNG project it surely did not do justice to the competitive nature of an efficient market. These trading conditions allowed the market to neglect projects flexibility requirements and potential interchangeability issues for LNG.

<table>
<thead>
<tr>
<th>Nature of Risk</th>
<th>Type of Risk</th>
<th>Who is Exposed to</th>
<th>Tools or Arrangements</th>
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3. The LNG Market in Transition

<table>
<thead>
<tr>
<th>Them?</th>
<th>A. Volume</th>
<th>A1. Interruption Production &amp; Marketing Company</th>
<th>The Production &amp; Marketing Company buys gas on the short-term market or swaps gas with other Production &amp; Marketing Companies, in order to meet his commitments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A2. Committed quantities exceed demand Customer</td>
<td>The Customer takes the gas or pays for it</td>
<td></td>
</tr>
<tr>
<td>B. Price</td>
<td>B1. Oil price used for indexation is very low Production &amp; Marketing Company</td>
<td>The Production &amp; Marketing Company fixes a minimum level for the oil price in the indexation mechanism</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B2. Oil price is below producer expectation Production &amp; Marketing Company</td>
<td>Takes the risk</td>
<td></td>
</tr>
<tr>
<td>C. Regulatory</td>
<td>No access to regasification facilities Production &amp; Marketing Company</td>
<td>The client is committed to take the gas and to open access to the regasification facilities</td>
<td></td>
</tr>
<tr>
<td>D. Financial</td>
<td>No access to financing tools Both</td>
<td>The TOP contract serves as a mortgage</td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Nature and type of risks for long-term TOP contracts (Mazighi 2004).

The risk sharing logic of the SPA is perhaps best captured in the phrase 'the buyer takes the volume risk and the seller takes the price risk' (Jensen 2003) and covered by additional obligations for the contract partners.

The Take or Pay (TOP) clause obligates the buyer to purchase a predetermined volume of LNG or pay for non delivery, and hence guarantees the seller of sufficient off take for the duration of the project. “Typically the contract will provide for an Annual Contract Quantity (ACQ), which is the quantity of LNG, usually expressed in millions of British thermal units (MMBtu), that the buyer must take or pay for if not taken” (Tusiani 2007). Jensen (2003) notes that the TOP typically obligated the LNG buyer to take a minimum of 90 percent of his annual contract quantity. This clause ensures that the seller is able to make optimal use of the liquefaction plant because it allows a complete year round capacity utilization. There are however some specific requirements adjustments that need to be incorporated in the contract. First of is the fact that the TOP obligations of the buyer are complicated by the fact that its demand is difficult to predict for the duration of a SPA of 20 years or longer. The buyers demand for LNG for instance is likely to grow in the course of time, the market might have distinct seasonal swings, and the demand variability is influenced by through the uncertainties that surround economic cycles. In order to circumvent these difficulties most contracts feature a ramp-up period that allow the buyer to steadily grow into its plateau ACQ and allows the seller to ensure that the liquefaction plant is working effectively. Other adjustments with regards to the ACQ include: volume flexibility or downward adjustments, round-up/round-down provisions, excess quantities, makeup quantities, and force majeure quantities (Tusiani 2007). Interesting for this study are the excess quantities that arise from a performance improvement (either willfully incorporated in the design or through genuine improvements). These excess quantities turn out to be a highly profitable feature that makes them interesting for buyers and sellers alike.

If the TOP clause is there to protect the seller, the Price Escalation clause protects the buyer in that it requires the seller to agree to a predetermined price ceiling, and hence establishes a fixed maximum price for the delivered LNG. Often when a price ceiling is negotiated the seller is eager to establish a price floor to protect its investment. Put differently ”In the standard SPA, quantity risk is allocated to the buyer, who assumes a take-or-pay obligation to assure utilization of the chain. Price risk is taken by the seller. Pricing is oil-indexed, which requires a “social contract” in which regulators, customers, and politicians agree that the utility can charge enduses customers on that basis“ (Nissen 2002). Although the actual implementation of this clause differs between projects the basic principle remains
the same and ensures that fluctuations in the energy price are minimized. Regional differences turn out to be a deciding factor in the price formation of the SPA as there are clear differences between the Asia Pacific, Continental Europe, and the US and the UK (Figure 28). The Pacific Basin is heavily reliant on LNG because it lacks any sizable domestic natural gas resources and has great difficulties with the realization of pipeline imports. On a local scale the market operates on a port-specific basis with limited onshore interconnection and distribution possibilities. As such LNG prices are set with reference to crude oil price that takes the form of a linkage with the Japanese Crude Cocktail (JCC). The recent volatility of the oil prices however has created the need to mitigate for price extremes. Perhaps the best known dampening factor is the incorporation of an "S" curve factor that provides a floor and cap on the price through a reduction in the change rate of the price above and below a threshold price for crude oil.

In Europe, LNG plays an essential role in the diversification of supply sources. It is considered to be an important alternative for natural gas supplies from the Russian Federation. At present however, LNG only accounts for a small share of Europe’s total gas supply (7.5%). "There is considerable interconnection between national markets, but historically only as a matter of long-distance transit rather than trade and efficiency" (Insight 2007). In Continental Europe, the LNG price is often indexed to the Brent crude, but competition from both indigenous natural gas and pipeline imports makes the pricing mechanism more competitive than its Asian Pacific counterpart. North America is currently a modest importer of LNG (§2.2) with the majority of its natural gas demand supplied through pipelines. The US natural gas market is the most dynamic in the world and prices its LNG relative to gas market price indices to ensure that LNG is competitive in its current marginal role. "The market itself is highly interconnected, liquid, efficient and transparent, enjoying high degrees of flexibility and storage" (Insight 2007). The Henry Hub (a point at which 16 intra and inter-state natural gas pipelines meet in southern Louisiana) is the main pricing point for natural gas in the United States (Griffin 2006).

Additional conditions of a SPA include a Destination Clause that prevents the buyer from reselling purchased LNG to third parties when conditions are in favor of doing so. This practice ensures that any resale margins are for the account of the LNG seller. Furthermore there is the practice of profit sharing mechanisms that reduce the incentive to remarket LNG. All these contract conditions help to explain why early LNG project were referred to as ‘floating pipelines’ that envision a self-contained system in which dedicated tankers shuttle in between a specified LNG plant and its destination. The preference for long term contracts is exemplified in the projected mid/long term LNG contracts (Figure 29). As of 2006, the total volume on mid to long term contracts amounted to 166 MT (compared with a spot market of slightly less than 22 MT (Flower 2007)). The Asia Pacific region clearly has the largest volumes of LNG committed to long-term SPAs, with Europe a distant second, and only very limited mid/long term contracted LNG volumes by North America. Note that the decrease of contracted volumes in Figure 29 is explained by the fact that it only shows the actual contracted LNG (i.e. those expressed in SPAs, and hence excludes the LNG that is not yet under contract (i.e. those expressed in a Memorandum Of Understanding (MOI) or Letter Of Intent (LOI)).
3. The LNG Market in Transition

The traditional business model of the LNG market that is based on SPA contracting has enabled LNG to become a viable alternative for pipeline natural gas. However, the success of the global LNG trade and the changes that coincide it have uncovered certain issues that are increasingly difficult to incorporate in the SPA. These market issues and their projected development are discussed next.

3.2.3 Market Issues of an Evolving LNG Market

The dynamics and success of the LNG trade have uncovered market issues that were traditionally neglected by the SPA. In an attempt to foster competition and facilitate the free flow of natural gas between producer and consumer countries, the European Commission has enforced its competition laws on the LNG trade. As such, it has restricted the use of Destination Clauses in SPAs. This restriction has already caused Nigeria LNG to remove destination clauses from existing and future contracts with European customers in December 2002 while Russian Gazprom agreed in July 2002 to drop the destination clause from all futures contracts (IEA 2004). Griffin (2006) notes that "Increasingly, sale and purchase agreements with buyers in liquid markets include cargo diversion clauses, which provide for cargoes to be diverted to higher priced gas markets at the election of the buyer or seller upon agreed advance notice". The bargaining position of the buyer and seller in these situations is strongly dependent on which party has obtained the transport responsibility.

Arguably the largest impact on the evolution of the SPA is the restructuring and liberalization process of the natural gas and electricity market in the US, UK, Continental Europe, and most of the Asian Pacific. Although there is a difference in the speed of adoption of the proposed changes, the general principle of introducing market competition holds everywhere (§3.1.3). Jensen (2003) notes that "The theoretical model for the restructuring of the gas -and electric power- industries represents the antithesis of this highly-structured, risk-averse form of industrial organization. The restructuring process...is predicated on the assumption that the traditional form of government monopoly or regulated public utility operation of electricity and gas is inefficient and that a system that introduces market competition inherently provides lower prices and more desirable service options for consumers. It envisions free market competition among buyers and sellers to set commodity prices for gas - "gas-to-gas competition". This implies that the customer can no longer afford to pay for redundancy in the LNG value-chain to cover its security of supply concerns.

The consequences of the deregulation and liberalization process of the energy sector and LNG procurement are illustrated in Figure 30. The restructuring of the market means that the LNG buyer is faced with increased competition which translates itself to a smaller and more uncertain LNG demand, and hence more stringent flexibility requirements. This contrasts with the interests of the LNG seller, as the pursuit of economies of scale (§2.2.2) creates larger LNG projects. Consequently, there is a growing mismatch between the desired contract terms that are advocated by the LNG buyer and seller which makes it more difficult to initiate a new LNG project. Despite the smaller volume commitments
per LNG buyer, the demand for LNG is growing due to a larger customer base (§3.1.4). The changing customer base and demand requirements make it more difficult to attract the required capital for new LNG projects. In the current market it is no longer automatically true that the LNG seller is able to close the deal with a LNG buyer that favours substantial government backing which enable to enter long-term SPAs. The solution that Tusiani (2007) mentions for this problem are ‘Sellers step-in rights’ that, in the case of a buyer that defaults on its TOP obligations, guarantees access to the buyer’s terminal and pipeline transportation contracts.

Figure 30: Impacts of Electricity & Gas Deregulation on LNG Procurement (Koide 2000).

Finally, there are changes with regards to the use of and access to LNG shipping. Although shipping is not included on an operational level in the terms of the SPA, the responsibility for the transportation is covered. If the LNG buyer is responsible for the transport the point of delivery is the loading port and the cargo is called Free On Board (FOB). Otherwise, the seller takes the transport responsibility and the point of delivery is the unloading port. If this is the case than the cargo is called Cost Insurance and Freight (CIF). Transport responsibility gives its owner leverage to benefit from cargo diversions. The dedicated nature of the early LNG projects ensured that LNG tankers were fully integrated in the LNG project (e.g. floating pipelines). Because tankers were often at the discretion of the buyers’ trade, and security of supply issues did not allow them to take any chances, it proved difficult to make use of unused LNG tankers. If the LNG tanker for example, lay idle through the exercise of downward flexibility clauses, force majeure, or the ramp-up period, the SPA prohibited its use on other routes. This seems to be changing now as Tusiani (2007) notes “However, as the commercial model has changed and the industry has developed more spot and short-term trading, the contractual terms appear to be moving towards the more standard formats that are characteristic of the oil tanker industry”. In addition to different forms of transportation contracts that are aimed to ‘keep the cargo tanks cold’ for as long as possible there is also the possibility of speculative ship building to trade on the short-term market. The growing uncommitted tanker fleet and the prediction that the shipping capacity will outgrow demand avoids the need to make long-term commitments and allows the parties involved to simply turn to the charter market. Tusiani (2007) notes that “for transient business opportunities, not controlling shipping and incurring the attendant fixed costs may in fact be an advantage”.

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Having clarified the traditional SPA governed trade of LNG, it is time to turn focus to the short-term LNG trade of the ‘Global’ market for LNG that circumvents the limitations of the SPA.

3.3 The Global LNG Market Described

The global LNG market is used to describe the LNG trade that is not governed by long-term SPAs but by short-term more flexible trade arrangements. First the basic principles of the spot market for LNG are discussed (§3.3.1) after which current status of this alternate LNG trading is assessed (§3.3.2).

3.3.1 Basic Principles of the Spot Market for LNG

Spot markets are commonly defined as real-time commodity markets for the sale and delivery of products. This immediately illustrates the main difference between spot trade and the trade through long-term contracts: the time horizon on which the transaction takes place. Unlike other spot markets (including crude oil, currencies, etc.) where the immediate delivery of the product is a given, this is not the case for LNG. Due to the lack of transparent pricing and the limited number and scale of assets in the industry, immediate delivery is rare. Consequently, spot LNG trades often refers to the delivery of multiple cargoes over an extended period (Tusiani 2007). Thus, for the purpose of this study and in accordance with Cornot-Gandolphe (2005) and Boyoung (2006), the spot market for LNG includes spot transactions and short-term contracts for the delivery of multiple cargoes of less than one year. Although the time horizon of the transaction is still far of from real-time, this represents a significant change in a market that used to be covered by long-term contractual agreements with duration of 25 to 30 years. This implies that there are three different types of trading models that complement the traditional SPA and are referred to as spot transactions in this investigation:

- Short-term contracts (i.e., up to about one year) – for example, to cover a mismatch in the commissioning dates for liquefaction and regasification terminals that will eventually be linked by a long-term supply contracts.
- Spot cargoes – for example, a cargo that becomes available as a result of the originally intended regasification terminal being affected by some type of short-term force majeure incident.
- Swaps (strictly speaking, a separate topic) – where two buyers or two sellers agree to swap cargoes.

The big advantage of the LNG spot trade is that it can accommodate the LNG industries need for increased flexibility without the need to enter long-term contracts. "An important feature of spot markets is that they enable marketers to instantly find other market parties to match deficits in the markets (i.e. immediately required products) with elsewhere existing surpluses, without entering into long-term agreements" (Jepma 2005). Or as a Congressional Research Service (CRS) Report for Congress puts it "The existence of a viable spot market is important because it allows consumers the flexibility to sell off excess supply to eliminate surpluses, and acquire additional supplies to ameliorate shortages as well as aiding in price discovery. These activities are central to the market process and the key to achieving lower prices and driving down costs." (Pirog 2004).

Important in this respect will be the liquidity of the market which refers to the ability of the market to match buyers and sellers. Market liquidity is important because it facilitates efficient competition and thereby encourages the optimal allocation of both LNG and LNG infrastructure investments to where this is valued the most. Market liquidity can "aid security of supply by reducing the investment risk and enable the market to balance efficiently by encouraging new entry and hence diversity, by allocation price and quantity risk to those with the greatest appetite for it, and by enabling the demand side to respond to high prices in the short and long term" (GlobalInsight 2007). Market

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14 Liquidity in the sense of ‘trading liquidity’ reflects the ability to transact quickly without exerting a material effect on prices...Liquidity is optimally achieved when myriad buyers and sellers are ready and willing to trade. The trading is enhanced by market-makers and speculators alike. Underlying this concept is that while buyers and sellers have different views on the most likely outcomes--that is, after all what generates trading--they largely can agree on the distributions of possible outcomes for which they demand risk-based compensation Warsh, K. (2007). Market Liquidity: Definitions and Implications. Institute of International Bankers Annual Washington Conference, Washington, D.C..
liquidity however, is not an absolute concept and can be seen varying degrees in traded markets. The following three states along a continuum of market liquidity can be distinguished and are graphically depicted in the continuum of liquidity (Figure 31):

1. Low-end: trading activity of a sort is seriously constrained
2. Intermediate: trading is being actively conducted but with some limitations
3. High-end: full liquidity - the ‘perfect market’ as understood (and expected) by financial players

![Figure 31: The Continuum of Liquidity (based on (GlobalInsight 2007)).](image)

Market liquidity is an important prerequisite for the spot trade of LNG because it means that the number of buyers and sellers that are ready and willing to participate in the trade of LNG is large enough (e.g. guaranteeing the availability of sufficient demand and supply for LNG) to enable the short-term trade of LNG. It also implies that the market can absorb the consequences of a single transaction without altering the market price. The importance of price transparency for the spot market is also evident as it allows LNG to be traded at “market prices” and shows market participants where the LNG is needed the most. The indicator for market liquidity is the ratio between traded volumes and delivered volumes: the ‘churn’. The Energy Charter Secretariat (2007) notes that “a churn of at least 15 is usually considered to be the threshold for a liquid market”. The most liquid natural gas market is located at the Henry Hub in Louisiana (US) with a churn of about 100, indicating a high liquidity. Despite being the most liquid natural gas market it still far of from the crude oil market where the churn of WTI and Brent is about 500. Thus, the liquidity of the LNG market and the crude oil market are still far apart. According to Cornot-Gandolphe (2005) “Some structural factors make it unlikely that LNG will easily develop the liquidity that exists in the oil market: the cost of transporting (and producing) LNG, the capital intensity of projects, which requires long-term contracts and makes it difficult to justify permanent spare capacity on economic grounds”.

Patel (2007) argues that the position on the continuum of liquidity for the wholesale natural gas sector is determined by four factors, which according to this investigation apply to the LNG market as well:

- The number of market participants that are active on the market
- Price transparency
- Volumes traded
- The number of trades that take place

For the actual operational processes of the spot market, the reader is referred to appendix IV. With the basic principles of the spot market for LNG in place it is time to apply them to the existing spot market for LNG.
3. The LNG Market in Transition

3.3.2 LNG Spot Trade in a Global Market

Although the spot trade of LNG originated in the middle of the 1990s, it really took off in the wake of the 1997-1999 Asian financial crises. Due to the economic slowdown, buyers (mainly Japanese utility companies) could no longer meet their TOP obligations and the resulting surplus liquefaction capacity resulted in uncommitted LNG volumes that could be sold on a short-term or spot basis to Atlantic Basin customers. Tusiani (2007) notes that the recent focus on the spot trade of LNG can be explained by the economic nature of the business, in which high fixed costs create a situation in which marginal volumes (which generally manifest themselves as spot trades) represents virtually pure profit to be allocated among the participants of these trades. The subsequent market deregulation and the reemergence of the US LNG market acted as a further stimulus for the spot trade of LNG. The LNG spot market will be systematically analyzed through the most important criteria of a ‘perfect’ spot market: the effective functioning of the market (§3.1.2). The two prerequisites to the effective functioning of the market; sufficiently high market liquidity (1) and the availability of sufficient capacity in the LNG value-chain (2) will be discussed. This is supplemented with a miscellaneous category that does not fit the original classification but are nevertheless important for the effective functioning of the market. This analysis also allows this investigation to identify the key imminent market drivers and inhibitors of the LNG spot market.

Market Liquidity of the LNG Market

Market liquidity serves as a ‘vital sign’ for traded markets and is fundamental for fostering competition (Insight 2007) and it rises when one of the following four conditions improves: the number of market participants, price transparency, volumes traded, and the number of trades (§3.3.1).

- Number of market participants

In a liquid market there are myriad buyers and sellers that are ready and willing to turn to the market to meet their contractual commitments. In addition, it allows new entrants and market participants without the portfolio flexibility of established market participants, and hence a higher sensitivity to fluctuations in demand and/or supply, to cover potential imbalances. GlobalInsight (2007) notes that “the ability to rely on efficient spot markets for marginal portfolio balancing, obviates the need for total portfolio self-sufficiency and capital investment for the last percent of reliability, both of which become increasingly expensive at the margin”. The number of market participants that are active on the LNG spot market is growing and has doubled for the number of importers and tripled for the number of exporters between 1992 and 2004 (Figure 32). New liquefaction capacity is being added in, among other countries, Egypt, Trinidad and Tobago, Venezuela, Nigeria, Angola, Russia, Iran and Qatar. New regasification capacity is being added in, among other countries, China, Canada, Portugal, USA, Spain, and Mexico.

- Price transparency

Figure 32: Number of Importers, Exporters, and Players of the LNG Spot Market (Boyoung 2006).
Price transparency enables market participants to make rational trading decisions that are based on market signals. Unlike crude oil, LNG is not priced on an international but regional basis. The differences in regional pricing mechanisms (§3.2.2) and the fact that the actual LNG price is often incorporated in a confidential SPA make LNG pricing non-transparent. However, “as regional gas markets develop, natural gas pricing mechanisms move from a supply-based cost-plus formula to a demand-based alternative product price-based escalation formula and, eventually, to a spot or futures market gas price market index” (Griffin 2006). The LNG spot market has experienced the re-emergence of the US and to a lesser extent the UK as importers. These large and liquid gas markets, in which the price for natural gas is entirely based on supply and demand, have established a LNG price that is related to liquid gas market indices, and hence have made LNG pricing more transparent.

Volumes traded & the number of trades that take place

The ratio between the traded volumes of LNG over the consumed volumes of LNG is an important indicator for market liquidity. “Spot trading liquidity exists to varying degrees in different commodity markets, from essentially none at all (churn factor < 1 x) to ‘perfect markets’ (churn factors 40 x or more)” (Insight 2007). In general liquidity is associated with churn factors above 15 (Keyaerts 2009). According to this standard the UK gas market remains at the intermediate stage of liquidity. The US natural gas market, where the Henry Hub trades with a churn factor of 100 and NYMEX natural gas contracts trade with a churn factor of 30, is the most liquid gas market in the world. This in contrast to the natural gas markets of the Asian Pacific and Continental Europe which experience rather low market liquidity. Although “trading hubs have been developed in Continental Europe by the gas in Zeebrugge, Bunde and for the Netherlands (TTF)...liquidity in these hubs has remained rather low, with a churn in the order of 5” (ECS 2007). Keyaerts (2009) notes that “The UK based National Balancing Point (NBP), the Belgium based Zeebrugge Hub and the Dutch Title Transfer Facility (TTF) are the main European hubs and have churn factors estimated at maximally 10-15, 4-6 and 4-6, respectively”.

Global Insight (2007) notes that “In such low-liquidity trading conditions, it is possible that a range of market participants find they can satisfactorily conduct all the business they wish to, to manage their portfolios satisfactorily and meet all their obligations – including periodic dealings with other players (perhaps even competitors), of a very short-term or ‘spot’ nature. However, it is likely that only established participants could thrive in such conditions. New entrants without extensive portfolios would find it difficult, probably expensive, and indeed commercially dangerous to be dependent upon individual negotiations with incumbent competitors for rectifying each and every short-term portfolio imbalance”. This might change due to a rapid growth of spot LNG trades since the early 1990s. In absolute terms the LNG spot market has grown from 1.1 [BCM] in 1992 to 14.8 [BCM] in 2003. By 2005, spot LNG trades exceeded 23 [BCM] and accounted for almost 13 percent of the total LNG trade. It is interesting to note that the Atlantic Basin, although only a modest LNG importer in comparison to the Asian Pacific Basin, trades 17.2 [BCM] on the LNG spot market compared to 5.6 [BCM] to the Asian Pacific Basin. In terms of individual countries that import spot LNG, the USA clearly leads the way, followed by Spain, South Korea, and Japan.

Figure 33: Emergence of Spot LNG Trade (based on (Flower 2008) & Figure 34: Spot LNG Transactions in the World (Morikawa 2006).
For functional purposes, e.g. to establish where the LNG spot market operates on the ‘Continuum of Liquidity’ (Figure 31), this study needs to assess if market participants are able to resolve their portfolio imbalances in a reliable manner in the traded market. In doing so, it adopts the qualitative test of trading liquidity of Global Insight (2007) that states that in a functional liquid market (or well functioning spot market) “a market participant with a portfolio imbalance of a ‘normal’ size can reliably expect to be able to clear this imbalance in the traded market, over the space of at most a few days, at prices essentially in line with reported market prices at that time”.

Capacity of the LNG value-chain

The availability of sufficient capacity in the LNG value-chain constitutes the second prerequisite for the effective functioning of the market. This study argues that a well functioning LNG spot market requires a physical availability of surplus LNG, the availability of necessary logistics, and a short-term demand for LNG.

- Physical availability of surplus LNG

Given the continuing, though diminishing, dominance of SPAs in the LNG trade it is important to identify the sources of spot LNG in advance. Note that these uncommitted LNG volumes constitute the physical boundaries of the LNG spot market. Before the strong increase of the LNG spot market in the mid nineties, spot trade was perceived to be a necessary evil and basically supply driven. Under these circumstances the primary source for spot LNG was liquefaction capacity that was not yet committed under long-term SPAs. There are various sources of uncommitted liquefaction capacity, including scheduling, seasonality, and the execution of downward allowances. Scheduling refers to the process of putting a new or revised liquefaction plant into use. As such, it includes the de-bottlenecking of the liquefaction plant, a process that refers to the elimination of the bottlenecks in the liquefaction process through marginal investments and the utilization of the production margin that is usually included in the EPC to guarantee the plants design requirements. Another source of uncommitted liquefaction capacity is the build-up period that is experienced in SPAs for new plants (Figure 35). Although the seller usually desires a flexible off-take during the initial production life of the LNG plant, it takes little time to produce at the plants design capacity. The buyer on the other hand needs time to build up market demand and reach the plateau ACQ of the SPA. The difference between the two in the early stages of the SPA, results in so called wedge quantities or uncommitted LNG that needs to be sold on a short term basis.

Seasonal patterns create spot LNG volumes if this is included in the SPA (as opposed to a continuous off-take throughout the year). South Korea is a prime example of a seasonal LNG demand because of its high residential heating demand in winter and the lack of domestic storage. This forces the LNG seller to find alternative customers for its uncommitted LNG. The same holds for the exercise of downward allowances which occur if the LNG buyer exercises its rights to reduce the contracted quantity of LNG for the upcoming year. The demand and supply for LNG spot volumes can also be the result of force majeure. The unplanned nuclear power plant of Tepco for instance has reportedly caused a pull of an additional 12 million [MT/year] from Japan (Hari 2008).
3. The LNG Market in Transition

In addition to the uncommitted LNG volumes that are inherent to the trade of LNG but limited in seize, the market is developing new business strategies to adapt to market changes. One of these strategies is the commitment to start a LNG project before the complete liquefaction capacity is sold. Unlike the inherent sources of uncommitted LNG, this trend has the potential to lift the LNG spot market from its marginal role and turn into a true alternative for SPAs. There are two trends that make it hard to commit the entire liquefaction capacity before the start of a project: increase in seize of the liquefaction plant (§2.2.2) and the smaller volume commitments from buyers (§3.2.3). Examples of this trend are already found in the Malaysia LNG Tiga, Australia’s NWS Train 5 (Tusiani 2007), and Sakhalin II Phase 2 project (Ball 2004) for which the go-ahead for construction was given, despite a significant volume of uncommitted production capacity.

There are also inhibitors that impede the existence of LNG spot volumes. There are different LNG specifications (different calorific values) around the world which limits the interchangeability of the LNG. This problem can be addressed through LPG stripping and nitrogen injection to guarantee the compatibility with the network in which the LNG needs to be injected. This process is illustrated in Figure 36 and applied to the UK natural gas market as an example. Hull (2003) notes that the UK Gas Safety Regulations (1996) define an acceptable operating envelope for gas specifications through a ‘Dutton Chart’. In this example there are two specifications of LNG that are outside the operating envelope, and hence would require quality adjustments to ensure they are acceptable and get into the acceptable quality window. It is generally expected that this technical problem will be overcome within the coming years and that LNG will become a truly homogenous commodity.

![Figure 36: Different LNG grades plotted on a Dutton Chart and the effect of quality adjustment (Hull 2003)](image)

Contractual constraints such as the TOP clause, price escalation clause, destination clause, and price sharing mechanisms (§3.2.2) make it difficult for buyers and sellers to participate on the LNG spot market. An active role on the sellers side is constrained by the so called “Club Rules” that are often included in the long-term SPAs and give long-term buyers a first call on additional capacity which could otherwise be placed on the spot market, while buyers are constrained by destination clauses which prevent them from freely reselling on the spot market the cargoes purchased under term contracts (Boyoung 2006). This situation seems to be changing however, as contract flexibility is one of the prime targets for LNG buyers when purchase contracts are negotiated or renegotiated.

Finally, and arguably the most important constraint for the availability of spot LNG are the security of supply obligations of the LNG buyers. The main users of LNG today are Japanese and Korean utility companies that are to a large extent dependent on LNG imports to meet their energy demand. This absolute requirement for reliable supplies means that these companies are willing to pay a premium in order to secure the supply of LNG on a long-term contracted basis. In some cases the buyer company will pay a further premium for additional flexible supplies to cover high seasonal demand (Law 2005). This dedication to security of supply means that a considerable amount of LNG effectively becomes unavailable for the LNG spot market and insensitive to the market price. While the process of
liberalization has the potential to reduce the importance of security of supply obligations, it is to be expected that its influence will be strongest in Europe where alternative sources of energy can be called upon. The effects in Asia, and most noticeably Japan and Korea, will be limited in the short to medium term.

- Availability of the necessary logistics

This condition refers to the required surplus capacity in the LNG infrastructure that is important for the development of the LNG spot market. In the midstream segment the availability of surplus shipping capacity is considered to be an important prerequisite for the development of the LNG spot market. Sufficient flexibility in the transport of LNG guarantees suppliers of spot LNG that they can deliver. While many new LNG vessels are still ordered for specific projects, the liquidity of the shipping market is improving. Boyoung (2006) notes that the shipping capacity has usually not been a bottleneck because of the fact that ships are ordered ahead of the liquefaction process, there is a rise of speculative orders, and older ships are released from their long term contracts. Similar expectations lead LNG shipper BW Gas ASA to conclude that the rapid expansion of the LNG fleet will outpace the growth in traded volumes of LNG (Figure 37). Note that the creation of excess tanker capacity through purchases of new build tankers is considerably more expensive, e.g. a 25% spare capacity may cause about a 21% increase in tanker costs, then the extended use of tankers that are out of their original SPA (Jensen 2004).

Despite the presence of surplus shipping capacity, the strong growth of the LNG vessel fleet has created a new threat in the form of ship compatibility issues. The development of new and larger ships, exemplified by Qatar that selected LNG tankers with a capacity of 245,000 cubic meters (pictured on the front-page), means that certain ports and regasification terminals become incompatible with the LNG tankers. Currently there is no standardization of terminal and tanker design to ensure maximum interoperatability (Griffin 2006). As such, there is less flexibility in the delivery of LNG because ports are unable to accommodate all ships until a global standard arises and the incompatible facilities are upgraded. The availability of surplus regasification capacity for spot transactions is considered to be a more stringent constraint. Although the global regasification capacity far exceeds the liquefaction capacity, and hence the utilization rate is far below the theoretical maximum, the delivery of spot transactions remains problematic. This is mainly due to scheduling constraints, storage constraints, and downstream pipeline constraints that prohibit spot cargoes to be unloaded.

- Demand characteristics

The existence of a short term demand for LNG triggers the development of the LNG spot market and effectively pays for the entire process. The spot market for LNG has traditionally been used to satisfy
market imbalances that result from discrepancies between the actual demand for LNG and the contracted supply of LNG on a long-term basis. Seasonal patterns can also create peak demand for LNG if the buyer is unable or unwilling to purchase the required quantities under long-term contracts. According to Boyoung (2006) this resulted to around 40 spot purchases in South Korea for 2004/2005. The restructuring and liberalization process of the energy sector (§3.2.3), and the uncertainties that accompany it, have made it more difficult for buyers to commit themselves to long-term SPAs.

The short term LNG demand is constrained by market access difficulties for the LNG seller. Despite the surplus of regasification capacity it turns out to be difficult to place regasified LNG into the market for non-incumbent players and deliver it to the buyer. Note that the creation of an annual surplus capacity in receipt terminals of 25% involves about a 10% increase in the costs of regasification (Jensen 2004). This leads Wood Mackenzie to believe that it will continue to be difficult to place short-term volumes into markets without securing a matching contract with an end user. Griffin (2006) notes that the ability to arrange short-term and spot sales depends on having, or being able to source at short notice, available regasification capacity that gives access to the relevant downstream market. Unforeseen costs such as pipeline transport and storage should also be taken into account. A final inhibitor is the creditworthiness of traders that are active on the LNG market. “Asset light” players such as Enron and Dynnergy entered the LNG market provided risk management services to both the buyers and sellers of LNG. According to Jensen “The bankruptcy of Enron and the subsequent financial problems of the marketing companies as a group have raised questions about the creditworthiness of companies that are not backed by solid physical assets and suggests that they may not be the players in LNG that they once were expected to be” (Jensen 2003).

Miscellaneous

This category is added to the original classification and includes market drivers and impediments that do not fit one of the other categories but are nevertheless considered to be important for the well functioning of the LNG spot market.

Although this study does not intend to give an elaborate overview of the regional differences between the Atlantic Basin and the Asian Pacific Basin, the importance of access to alternate sources of natural gas for the LNG spot market is too large to be ignored. The fact that the OECD countries of the Atlantic Basin have alternative sources of natural gas supply (e.g. for Continental Europe, pipeline gas from Russia and for the USA pipeline gas from Canada), made it possible for buyers to turn to the LNG spot market when the price was right. Hence, the Atlantic Basin spot market is price driven. Asian Pacific customers on the other hand are unable to meet their demand through alternate sources of natural gas. Thus Asian Pacific buyers use the LNG spot market out of necessity rather than opportunity to cover shortage in supply that result from unexpected circumstances or delays in the signing of new long-term SPAs. Ball (2004) notes that price follows rather than drives short-term imports in the Asian Pacific, a feature that is closely related to security of supply concerns. Under these circumstances the Asian Pacific has created a relationship driven LNG spot market in which the spot trade of LNG is part of the service that sellers offer to their long-term customers. Tusiani (2007) notes that long-standing relationships are extremely important (driven by the potential for additional long-term sales) and that spot deliveries are often agreed to between existing sellers and buyers at the underlying contract price.

Government policy can act as a market driver or as a constraint pending on the governments’ interests. It is conceivable that foreign policy towards certain countries stimulates or prohibits the trade of LNG. The US is an interesting case as possible supplies from Iran are precluded from placing volumes in the US market (Law 2005). Another problem arises with the construction of new regasification plants and possible objections by the public and general safety concerns with regards to the flow of LNG into certain terminals. However, government policy can also act as a stimulus for LNG trade as it encourages competition. Sourcing constraints are another stimulus for LNG trade because this encourages importing countries to diversify their LNG supply to reduce the dependency on a single exporter. Brinded (2003) notes that Spain has enacted energy laws that limits a company from importing more than 60% of gas from a single country. Finally, there is the development and implementation of new technologies which can prove to be a facilitator for the LNG spot market.
These include: liquefaction hubs, onboard regasification and storage, and the LNG storage hubs (§2.2.2).

3.3.3 Imminent Key Market Drivers & Inhibitors

The foregoing discussion of the LNG spot trade in global LNG market has identified the key market drivers and inhibitors for the LNG spot market. These are categorized as economic, technical, and institutional drivers and inhibitors. An overview is provided below including the assumptions (marked with A) with which this study proceeds.

- Economic drivers and inhibitors
  This condition refers to the willingness of market participants to participate in the short-term trade of LNG. The decreasing capital costs in the LNG value-chain reduce the risks of initiating a LNG project without the complete coverage of the anticipated output, hereby enhancing the availability of uncommitted volumes and spare LNG infrastructure. This development coincides with changing customer preferences. In order to remain competitive customers require that the delivered LNG can compete with alternative fuels. The restructuring and liberalization process of the natural gas and electricity market, and the introduction of competition and uncertainty forces customers to become more market oriented. This creates a smaller and more uncertain LNG demand, and hence more stringent flexibility demands. Note that a general assumption of this study will be that the global demand and supply for LNG will continue to grow as the gap between regional shortages and surpluses for natural gas widens.

  - Demand characteristics
    - A: demand becomes more flexible
    - A: volume commitments become smaller
    - A: demand is inelastic
    - A: seasonality of demand
  - Capital costs
    - A: economies of scale trend continues
  - Global demand and supply will increase

The indicator for this category is the liquidity of the market that is tested through the qualitative test of trading liquidity that this study adopts from (Insight 2007). It states that in a functional liquid market (or well functioning spot market) “a market participant with a portfolio imbalance of a ‘normal’ size can reliably expect to be able to clear this imbalance in the traded market, over the space of at most a few days, at prices essentially in line with reported market prices at that time”.

- Technical drivers and inhibitors
  The LNG spot market also requires spare capacity in the LNG value-chain. The availability of uncommitted shipping and free access to regasification are necessary to accommodate the spot trade of LNG. As more regasification terminals are equipped with LPG stripping and nitrogen injection LNG is set to become a truly homogenous commodity, and hence interchangeable. Technological innovations could greatly increase the capacity of the global LNG infrastructure in all parts of the value-chain. It could also equip the market with new opportunities for storage, and in doing so enhance the spot trade of LNG.

  - Physical availability of surplus LNG
    - A: LNG is a homogenous commodity
    - A: inherent uncommitted liquefaction capacity is constant
  - Availability of necessary logistics
    - A: shipping capacity outgrows liquefaction capacity
    - A: regasification capacity outgrows liquefaction capacity
    - A: there are no incompatibility issues throughout the LNG value-chain
    - A: market access is guaranteed through Third Party Access
  - New technology
    - A: LNG storage hub will be realized
    - A: Floating regasification and liquefaction will be realized
The indicator for this category is the surplus capacity in the LNG value-chain with regards to the proportion of global shipping and regasification capacity in relation to the global liquefaction capacity.

- Institutional drivers and inhibitors
The emergence of organized liquid markets for trading and shipping are believed to be key for the realization of a well functioning spot market. The liquidity of the market is determined by the willingness of market participants to adapt short-term trading models. This acts as a self reinforcing process as the liquidity of the market is dependent on the number of market participants, and the willingness to participate (and hence the number of market participants) depends on the liquidity of the market. This study believes that the standardized contract for the spot trade of LNG, the MSA, will reduce the transaction costs of spot agreement and accelerate its use.

- Market liquidity
  - Number of market participants is growing
  - Price transparency, there are four pricing regimes: Henry Hub, National Balancing Point, Brent indexed, and the Japanese Crude Cocktail

- Long-term contract, the SPA
  - Take or pay clauses amounts to 90 [%] of the Annual Contracted Quantity, a share that is gradually reduced
  - Destination clauses will be removed
  - Build-up period is constant

- Short-term contract, the MSA
  - Are the industries standard for short-term contracts, spot contracts, and swap agreements
  - MSAs are available to market participants and become active through a signed Confirmation Memorandum.

- Government policy
  - Security of supply concerns are mitigated
  - Permitting issues are resolved within 1 year

The indicator for this category is the proportion of LNG (e.g. the volumes traded, and the number trades that take place) that is traded under long-term SPAs in relation to the amount that is traded under short-term MSAs.

As a matter of course, the nuances of the different regional markets will determine the eventual impact of these three conditions on the effectiveness of the LNG spot market. The imminent market drivers and inhibitors that are identified here will subsequently used to describe the trading models that are designed to incorporate them.

3.4 Different Trading Models of the LNG Spot Market

It has already been noted (§3.3.1) that the LNG spot markets includes short-term contracts, spot cargoes, and swaps. This section seeks to explain the use of these trading models in practice because market participants increasingly turn to them to optimize their assets. Or as Tusiani (2007) observes “the opportunities that are created by the spot LNG market and by the increasing possibilities of cargo diversions and swaps are becoming more aggressively used by LNG sellers to maximize their sales volumes and by LNG buyers to manage their market fluctuations”.

3.4.1 Short-term Contracts, Spot Cargoes & Cargo Swaps
The short-term contracts and spot cargoes are designed to take advantage of arbitrage possibilities that emerge between the regional LNG markets. Arbitrage opportunities emerge when the price differential between two markets is large enough to cover the incremental costs of a cargo diversion. The costs of acquiring short-term incremental shipping turns out to be one of the key factors in this process, especially when the distances between buyers and sellers is large. Of course there are other concerns as well, including scheduling concerns for liquefaction, the search for a replacement cargo, and access to the regasification terminal. If all factors are taken into consideration however, the LNG
cargo will go to the market that offers the highest netback. Put differently, arbitrage ensures that the LNG is delivered to the market with the largest appetite for it. The majority of the spot LNG trade occurs in the Atlantic Basin (§3.3.2). Jensen (2004) notes that arbitrage in the Atlantic Basin primarily involves supplies from Trinidad and Tobago and Nigeria to markets in the US and Europe (primarily Spain). Another pattern of arbitrage is that between Northeast Asian markets and Atlantic Basin market through shipments from the Middle East. It is to be expected that the Middle East, and especially Qatar, will become the most prominent supplier of spot LNG as it is both willing and able to serve both the Atlantic Basin and Asian Pacific Basin markets.

The dominance of the Atlantic Basin is confirmed by the contract commitments of Figure 39 which illustrates the contract commitment for probable and firm LNG projects between 2002 and 2010. It is evident that a large part or 85 [%] of the incremental liquefaction capacity is committed on third party contracts, while only 15 [%] are uncommitted. The Atlantic Basin accounts for the majority of uncommitted volumes as would be expected. Note that the uncommitted volumes also include self-contracted volumes, where the seller contracts with his own marketing affiliate in order to achieve downstream integration. Jensen (2004) notes that "If these system sales are intended to serve previously-determined integrated markets, they may be less flexible than their appearance as "uncommitted" volumes would suggest". The principles of price arbitrage are discussed in appendix IV which also includes examples of price arbitrage in the Atlantic and Asian Pacific Basin.

Cargo swaps are usually not driven by price considerations but by the desire to optimize logistical dispositions. As such, they make it possible to avoid cross-shipping that is still commonplace in the industry today with fully loaded LNG tankers passing eastbound and westbound in the Straits of Gibraltar (and northbound and southbound in the Suez Canal). The high costs of LNG shipping means
that rationalization of these trades offer the possibility for substantial profits. Swaps are usually conducted in the context of a wider transaction that includes two or more cargoes to be traded under the same agreement. One possibility involves the reduction of shipping distances (and associated costs) through a swap of LNG cargoes between sellers and buyers. In the following example Seller 1 is contracted to deliver LNG to Buyer 1, while Seller 2 is contracted to deliver LNG to Buyer 2. If the accumulative distance between Seller 1 and Buyer 2 and Seller 2 and Buyer 1 is smaller than the original transport distance, it becomes interesting to perform a swap because this results in a cost reduction that can be shared among the respective parties (Figure 40). Another possibility concerns the usage of swaps to solve scheduling concerns. For example Seller 1 is obliged to deliver LNG to Buyer 1 in March, but is unable to meet its obligation due to maintenance. Likewise for Seller 2 who is obliged to deliver LNG to Buyer 2 in April but faces the same problem. In this instance it is conceivable that Seller 2 delivers Buyer 1 its LNG for March, and Seller 1 delivers Buyer 2 in April. There are of course some related risks to the use of swap agreements that need to be tackled before they can be implemented. One risk for the participants of the swap is that of non-performance by one of the involved parties. Thus, it should be known in advance who takes the responsibility for the delivery of LNG from Seller 1 to Buyer 2 and likewise from Seller 2 to Buyer 1.

![Basic Swap Structure](image)

Figure 40: Basic Swap Structure.

The next section will discuss how standardized contracts can overcome some of the issues that are related to the use of short-term spot contracts including swap agreements.

3.4.2 Outlook for the Spot-Short-Term Contracts

While many short-term spot contracts are negotiated on a case by case basis, this is not the best approach to minimize the transaction costs of the agreement. Griffin (2006) notes that it is better “to have in place a master sales agreement between the seller and buyer, setting out the standard terms intended to apply to any sale between those parties, and then a confirmation notice which set out, on a sale-by-sale basis, the terms to apply to that particular sale (e.g., price, quantity, quality, name of tanker to be used, applicable demurrage rate, delivery data and downstream market). As well as settling these practical matters, the parties should, before entering a confirmation notice, check that the risk allocation set out in the master sales agreement is compatible with the upstream and downstream projects”. This corresponds to the findings of Baker Botts which states that MSAs typically consist of a main Master Sales Agreement (MSA) that sets forth the “General Terms and Conditions” and a shorter “Confirmation Memorandum” attached as an appendix to the MSA. While the General Terms and Conditions contains key terms that will apply to all sales under the MSA- such terms do not result in an obligation to purchase or sell LNG. While each executed Confirmation Memorandum constitutes a separate agreement between buyers and sellers to purchase one or more cargoes of LNG (Miles 2007). An important difference between the MSA and SPA is that it concerns the transaction of a single cargo (spot sale) or multiple cargoes over a relatively short period of time (short-term sales).

In short MSAs are the industries answer to come up with a contract that encompasses its flexible trading models. Miles (2007) notes that MSAs can be used in the following ways:

- Outlet for Excess Cargoes
  - MSAs permit sales of LNG produced in excess of committed SPA sales for an LNG liquefaction project
- Source of Supply
  - Buyers of LNG might source additional cargoes from MSAs to meet seasonal or temporary LNG demand
Some regasification projects are being built partially in reliance on LNG supplied pursuant to MSAs. In a Sellers' market for LNG with tight supplies and SPA destination flexibility, MSAs provide Buyers with the possibility of sourcing supply for one or more cargoes based on a "call" for cargoes that reflects a partially liquid supply market.

- **Destination Flexibility**
  - Suppliers might use MSAs to sell extra cargoes at higher prices to alternate destinations experiencing seasonal peaks in demand and/or short term price differentials.

Miles (2007) concludes with the observation that MSAs facilitate short-term and spot purchases and sales of LNG cargoes that are increasingly important to LNG liquefaction and regasification projects and are an important part of the evolving LNG market, including the development of a spot market for LNG. Based upon the findings of this section, this study assumes that the standardization trend for MSA is set to continue and become the equivalent to those of the International Swaps and Derivatives Association arrangements of other commodity and currency markets. As such, it will view the MSA as the counterpart of the SPA.

### 3.5 Key Market Drivers and Inhibitors, an Overview

With the economic principles of the LNG market, and an overview of the traditional and global trading models that adhere to these principles in place, this section will provide an answer to the second sub-question:

- What are the key market drivers that contribute to or impede the development of a spot market for Liquefied Natural Gas and how will these develop?

The discussion of market principles demonstrated that understanding the governance of the LNG market is key to assess if and how the approaching spot market for LNG is replacing the long-term trade of LNG. The subsequent establishment of market criteria for a "perfect" commodity and spot market acts as the starting point for a systematical analysis of the LNG market. The process of market evolution showed that long-term bilateral trading in a growing market imposes ever higher transaction costs on the market participants. If trading volumes continue to increase, trade will concentrate at one or several trading points and brokerage is replaced by spot market trading. Once the spot market is in place it is soon complemented by trade instruments that allow market participants to manage the risk of volatile prices.

The systematic analysis of the market structure, trade, and price characteristics of the LNG market showed that the LNG market structure does not resemble that of the 'perfect' commodity market. Market power is a serious threat to the efficient functioning of the market which is countered by the low supply and demand elasticities. The tradability of LNG is determined by the availability of surplus capacity in the LNG value-chain, the ease of transport, and the flexibility requirements of the market participants. In terms of price and price transparency LNG pricing is moving away from regional pricing towards price uniformity and transparency on an international scale. Thus becoming the relevant signal for the identification of regions of excess demand and supply and a reliable tool for market participants to base their investment decisions on.

The contract arrangement that governed (and continuous to govern the majority of) the LNG trade is the Sale and Purchase Agreement (SPA). The SPA covers the risks of a LNG project as it coordinates all commercial agreements between the buyer and seller. This risk sharing logic is perhaps best captured in the phrase ‘the buyer takes the volume risk and the seller takes the price risk’ (Jensen 2003), which are guaranteed by additional Take or Pay obligations, destination clauses, and price sharing mechanisms. The success of the market and the changes that coincide however, uncovered certain issues that were traditionally neglected by the SPA. Competition laws have restricted the use of Destination clauses. The restructuring and liberalization process of the natural gas and electricity market are considered to be the antithesis for to the traditional highly structured, risk adverse LNG trade. Changing demand and supply requirements create a mismatch between the contract terms that
are advocated by buyers and sellers alike in which a smaller and more flexible demand compete with the realization of larger, economy of scale driven, LNG projects.

In addition to alterations in the conditions of the SPA, short-term more flexible trade arrangements of the “Global” LNG market are becoming increasingly popular. Although the LNG trade is currently positioned at the low-end to intermediate state of market liquidity, market participants are able to resolve their portfolio imbalances in a reliable manner in the traded market. The subsequent assessment of the LNG spot market was conducted with the most important criteria of a ‘perfect’ spot market: the effective functioning of the market. By looking at the two prerequisites to the effective functioning of the market; sufficiently high market liquidity (1) and the availability of sufficient capacity in the LNG value-chain (2) and a miscellaneous category this investigation was able to uncover the imminent market drivers and inhibitors of the spot market for LNG. These are categorized as economic, social, and institutional drivers and inhibitors and is illustrated in Figure 41. The different trading models of the LNG spot market that are designed to operate in the global LNG market include short-term contracts, spot cargoes, and swaps. It becomes interesting to turn to the spot market if the price differential between two markets is large enough to cover the incremental costs of a cargo diversion or if there are opportunities to optimize logistical dispositions. The counterpart of the SPA and the trade arrangement that facilitates these short-term spot trades of LNG cargoes is the is the Master Sales Agreement.

![Figure 41: Interplay between Economic, Technical, and Institutional Drivers of the Spot Market for LNG.](image)

With the principles of the "Traditional" SPA governed and “Global” MSA governed LNG market in place and an overview of the imminent key market drivers and inhibitors it is time to assess their impact on the development of the LNG market in chapter 4.
4. Future Analysis

"Change is the law of life. And those who look only to the past or present are certain to miss the future" John F. Kennedy (1917-1963)

Until this point it has been consistently argued that the spot market for LNG is able to act as a viable supplement to the long-term LNG trade. There are however differences of opinion about the future role and importance of the spot market for LNG. The central research question of this chapter is therefore the third sub-question:

- Is it possible to predict the demand trends for the LNG spot market with future extrapolations?

Accordingly, this chapter performs a mathematical extrapolation of the relative importance of the spot market for LNG in a global context that is based on data from multiple market publications (§4.1). Thereafter, a scenario analysis is executed in which the impact of several major external trends on the development of the LNG market is analyzed (§4.2). The resulting quantitative estimates and scenario insights are subsequently used to answer the third sub-question and draw preliminary conclusions (§4.3).

4.1 Future Extrapolation of the LNG Spot Market

This section commences with an overview of industry projections for the future share of the LNG spot market after which it performs a Polynomial and Verhulst future extrapolation.

4.1.1 Industries Estimates

The fact that the LNG spot market is still some way of becoming a genuine spot market is widely recognized in the industry. This makes it interesting to look at some of the industries estimates regarding the future seize of the LNG spot market and the speed of its development. Listed below are some of these industries estimates.

- There is an overall consensus that LNG spot trade may amount to 15-30% of global LNG trade (IEA 2004).
- In the future about 30% of LNG business will be traded on the spot market according to Petronas President and Chief Executive Officer Mohamed Hassan Marican (FinancialTimes 2004).
- Short-term or spot trading in liquefied natural gas will expand to account for 20 percent of the market by 2012 according to global broker and commercial advisor for the energy and ocean transportation industries Poten & Partners (GulfTimes 2008).
- Spot cargoes are growing in frequency on the world LNG stage...projecting a 30% market share in the next decade from about 10% of global LNG trade in 2005 according to the director of energy for Dubai Multi Commodities Centre (DMCC) Tilak Doshi (NGI 2007).
- The share of this new form of trade in global LNG trade, which increased from 2% in 1998 to 12% in 2005, is expected to reach 25% to 30% within the next decade according to the Head of Research at the Arab Petroleum Investments Corporation Ali Aissaoui (Aissaoui 2006)
- Trading of one-off cargoes not covered by long-term contracts will probably grow by more than 10 percent a year according to Senior LNG Consultant at Poten and Partners Daryl Houghton (GulfTimes 2008).

While opinions vary, the general view is that the LNG spot/short-term market will continue its recent growth and reach approximately 30 [%] of the global LNG market in the upcoming decade. This
constitutes a significant increase from the current 13 [%] and represents an important step towards the development of the global LNG market. The speed with which the LNG spot market is expected to grow raises the question to what extend this market is able to displace the long-term SPAs that currently dominate the industry. Often cited constraints to its development include LNG quality issues, contractual constraints, security of supply concerns, and scheduling concerns. For a more detailed discussion of these inhibitors, this study refers to §3.4 and §3.5. What is important to recognize here is that these constraints, although undisputedly important to overcome, do not stand alone in realizing a change towards a more flexible market structure.

An interesting view is that the momentum of the LNG spot market can act as a self-reinforcing process in that expectations about its future development influence the decisions on whether or not to become active on the LNG spot market. This is the central claim of Brito and Hartley (Brito 2007) who state that "while exogenous changes in costs or demand are critical to promoting a change in market structure, there is also a substantial endogenous component. Expectations about the evolution of the market influence investments and trading decisions and can make the change in market structure much faster and more abrupt". The role of expectations that influence market outcomes is illustrated through a stylized model of contracting in the LNG market that is based on the ideas developed by Diamond (1985) and Diamond and Maskin (1979).

The diamond model of the LNG market is discussed in more detail in chapter 5 where it serves to describe the different states of its market participants and the effects on the contract negotiations and investment decisions. More interesting at this point are the conclusions that can be drawn from the use of this multi equilibrium model. First off is the observation that firms that perceive changes in strategic opportunities, alter their investment behavior, and hence further change the market structure for other firms in the industry. The result of which could be a surprisingly rapid decline in the number of firms that seek long-term contracts before investing in production, which in turn makes this strategy more attractive for other firms as well. Secondly, the model suggest that reduced shipping costs and more extensive demand for LNG are important sources of change because they enhance the probability of making a good match. Finally the model suggests that an increasing role for spot markets in trading natural gas will play a critical role in assisting the transition away from substantial reliance upon traditional long-term contracts.

With the industries outlook for the LNG spot market in place and the observation that expectations of the future market structure can in itself influence the pace of its development it time to assess the recent growth of the LNG spot market.

4.1.2 Future Extrapolation

This section seeks to identify a certain pattern in the growth of the LNG spot market (demand forecasts for the global LNG market can be found in §2.2.3).

Jensen notes that the future of the long-term contract, and hence the future of the short-term spot contract, is most likely to be decided by the market participants themselves, as they seek to balance the rewards of a more open and competitive market with the investment risks inherent in this capital-intensive business. The more enthusiastic advocates of the fully-competitive market model see the growth of short-term trading in LNG as the wave of the future, and one that signals the demise of the traditional LNG contract“ (Jensen 2004). In order to estimate the potential of the LNG spot market a future extrapolation has been executed, the results of which are illustrated below.

Data for the subsequent analysis has been obtained from a variety of sources (EIA 2005; Morikawa 2005; Boyoung 2006; Flower 2008; Morikawa 2008)\(^{15}\). This serves to protect the forthcoming analysis from different interpretations of the short-term spot trade and incomplete market data. As such, it also acts as the first validation. The first extrapolation makes use of a polynomial equation to extrapolate the data (Appendix II), the results of which are illustrated in Figure 42. With the use of Microsoft Excel Solver, this study was able to calculate the polynomial equations that belonged to each

\(^{15}\) Please note that Morikawa (2005) obtains the data from Cedigaz whereas Morikawa (2008) obtains the data from Petrostrategies.
In order to determine the goodness of fit between the data points and the graph (or equation for that matter) the R-square was also calculated. For details regarding this analysis, this study refers to Appendix II. The following example illustrates this extrapolation process for the data of (Flower 2008):

- Polynomial equation: \( Y = 0.0796 \times X^2 - 0.2317 \times X + 2.2129 \), where
  - \( Y \) = LNG spot market share, and \( X \) = the number of years
  - R-square for this equation equals 0.9657, which is a near perfect fit
  - In 2010, \( X = 18 \) (data available from 1993), results in \( Y = 23.83 \% \)

This future extrapolation predicts a strong increase of the LNG spot market share within the next decade. Except for the equation that is based on the data of (Boyoung 2006), the forecasts show that the LNG spot market will account for approximately 40 percent of the global LNG market by 2015 (e.g. Flower 39%, EIA 46%, PetroStrategies 42%, and Cedigaz 41%). Although this is above the industries estimates (§4.1.1) of 30 percent, the difference seems acceptable as the graphs are fairly close to the data points. The explanatory power of the polynomial extrapolation beyond 2015 however seems limited as the growth spirals out of control beyond 2015. This is exemplified by the fact that the Boyoung-equation predicts that the LNG trade will be entirely based on spot contracts by 2019, while the equations of Flower (2029), EIA (2027), PetroStrategies (2028), and Cedigaz (2029) follow suit with similar predictions before 2030. In contrast to the short-term extrapolation (till 2015), this long-term forecasts are deemed unrealistically because it is unlikely that the spot-market will completely replace the long-term contract market, especially on such a short notice. Hence, there are limitations to the use of the polynomial extrapolation.

One of the problems of the polynomial equation is that it allows the LNG spot market share to increase without any limitations. This contradicts with real life where unprecedented growth is eventually slowed down by a lack of sufficient resources. This problem is connected to the field of population ecology that deals with the dynamics of species populations and how these populations interact with their environment (Odum 1959). It is the belief of this study that an analogy between population ecology and the growth of the LNG spot market provides interesting insights. The increase of a population typically coincides with a slowing growth rate that can be attributed to a number of factors including crowding (lack of space to reproduce), lack of resources (limited food supply), or build up of waste (toxicity) (Mahaffy 2001). Hence, the population eventually reaches its equilibrium state or carrying capacity of its environment. In this analogy the population is replaced by the LNG spot market while the slow down of its growth can be attributed to the same factors: crowding, lack of resources, or a build up of waste.
Among various models, the model described by Pierre-François Verhulst in 1838 is the common model for population growth. Kornovskii (1999) notes that “One may state that the Verhulst equation is the standard object for both mathematical ecology and nonlinear dynamics”. This model is formalized by the following differential equation:

- Verhulst equation: \( \frac{dP}{dt} = r P \left( 1 - \frac{P}{K} \right) \), where
- \( r \) = growth rate, \( P \) = initial population, \( t \) = time, and \( K \) = carrying capacity of the environment
- As such, there is an early unimpeded growth rate (\( r P \)) that is limited by the competition for resources (\( 1 - P / K \)) as time proceeds
- Hence, as the population matures it approaches the steady state or equilibrium carrying capacity of the environment (\( K \))

As such, a more refined future extrapolation was executed, again with the use of Microsoft Excel Solver, to extrapolate the data with the Verhulst’s equation. In order to determine the goodness of fit between the data and the equation in this extrapolation the Mean Squared Error (MSE) needed to be minimized. As the name suggests the MSE measures the average of the square of the “error”, which in turn is the amount by which the estimator differs from the quantity to be estimated. The difference occurs because of randomness because the estimator doesn’t account for information that could produce a more accurate estimate (Lehmann 1998). An MSE of zero means that the equation and data match perfectly. For details regarding this analysis, this study refers to appendix II. The following example illustrates this extrapolation process for the data of (Flower 2008), the results of which are illustrated in Figure 43:

- Verhulst equation: \( Y = \frac{(K_B*P0_B)}{(P0_B+(K_B-P0_B)*\text{EXP}(-r_0*X)), where}
- \( Y \) = LNG spot market share, \( K_B \) = Carrying capacity, \( P0_B \) = Initial market share, \( r_0 \) = Growth Rate, and \( X \) = Number of years
- Mean Squared Error = 0.90
- In 2010, \( X = 18 \) (data available from 1993), results in \( Y = 24.54 \% \)

The major difference between the Polynomial and Verhulst’s extrapolation are the limitations to growth that are induced by the equation. As such, the Verhulst equations reach a certain equilibrium state (\( K \)) which represents the eventual market share of the LNG spot market. Unlike the fairly balanced results of the polynomial forecasts, there are some distinct differences in the outcomes of the Verhulst forecasts (Figure 43 & Table 8). The Boyoung-equation is once again different then the others in that it displays an unprecedented growth of the LNG spot market which results in an equilibrium state where the LNG spot trade accounts for 67 percent of the global LNG market. It should be noted that the MSE for the Boyoung Verhulst equation is significantly larger then the others and hence, its results are less significant.
The equations of PetroStrategies and Cedigaz on the other hand are more pessimistic and only reach a LNG spot market share of 11 and 18.4 percent respectively. It should be noted that the data from these sources was limited and covered the period of 1995-2005 (PetroStrategies), and 1996-2006 (Cedigaz). As such, the results seem biased towards the limited spot trade of 1997 and 1998. This explains the rather low carrying capacity of the LNG market for these extrapolations. Finally there are the Verhulst equations of Flower and the EIA which are nearest to the industries estimates of §4.1.1 and result in a market equilibrium where the LNG spot market accounts for 43.5 and 41.3 percent respectively. The significance of these extrapolations is further improved by the complete data from both sources and the low MSE.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Boyoung</th>
<th>Flower</th>
<th>EIA</th>
<th>Cedigaz</th>
<th>Petrostrategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Market Share</td>
<td>0.5</td>
<td>1.1</td>
<td>0.9</td>
<td>1.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Growth Rate</td>
<td>0.31</td>
<td>0.23</td>
<td>0.24</td>
<td>0.42</td>
<td>0.75</td>
</tr>
<tr>
<td>Carrying Capacity</td>
<td>67.2</td>
<td>43.5</td>
<td>41.3</td>
<td>18.4</td>
<td>11</td>
</tr>
<tr>
<td>MSE</td>
<td>2.98</td>
<td>0.90</td>
<td>1.19</td>
<td>0.61</td>
<td>1.65</td>
</tr>
</tbody>
</table>

Table 8: Final Results of the Verhulst Extrapolation.

This future extrapolation concludes with the observation that the share of the LNG spot market is set to grow rapidly within the next decade and is likely to stabilize in the long-term (e.g. 2030) at an equilibrium state that exceeds the current share of the LNG spot market. However, this study also feels that the discrepancies between the different extrapolations and industries estimates regarding the future importance of the LNG spot market are reason to perform a more detailed analysis. As such, the next section will explore different scenarios for the development of the LNG spot market.

4.2 Scenario Analysis

To implement a certain degree of cautiousness into this analysis a scenario analysis is executed that assesses a number of possible scenarios for the development of the LNG spot market. It should be noted that scenarios serve a different purpose then forecasts (§4.1) in that they are designed to challenge our thinking about emerging issues and trends, not to forecast them. This study uses scenarios to obtain insights about the performance of the LNG spot market in different market circumstances. Hence, the objective of this section is to look at a number of possible futures and predict how the market participants adjust their tactics and strategies accordingly.

4.2.1 Identification of Major External Trends

In order to illustrate how the scenarios have been drafted, a so-called "scenario-logic" is constructed below (Figure 44). This scenario-logic depicts the main external trends that surround the development of the LNG spot market. Note that these are major external trends that are beyond the influence of any particular country or business, and therefore form a significant unpredictability for the LNG spot trade. Each trend forms an axis of the scenario-logic which, although strictly speaking represents a continuum, is assumed to reflect the extremes. Consequently there are eight (2^3) possible scenarios in this scenario analysis which believes that the following three trends are decisive for the future of the LNG spot trade:

- **Demand for LNG**: the future natural gas demand from the power sector is seen as the deciding factor for this trend. The extremes of this axis are labeled as ‘Surging’ and ‘Modest’ and depend on the decision of how to satisfy the increased need for power. The balance between newly built nuclear plants, coal and gas fired plants, sustainable power will together have a major impact on the demand for LNG. This study assumes that the demand for power increases, while the growth rate is interrelated with the global economic climate. It further assumes that the demand for LNG in a particular market can always be satisfied and that security of supply concerns are an issue of price.

- **Availability of LNG**: this study adopts the prospective availability of LNG from (Insight 2007) that was in turn determined by existing sources, those under construction and, as far as possible, projects identified but not yet moving forward. The extremes of this axis are labeled as ‘Abundance’ and ‘Constrained’. The production of LNG seems more then capable of
meeting the demand projections in terms of resources but the actual global liquefaction capacity might be constrained due to geopolitical considerations and inherent project delays.

- Technological Innovation: the extremes of this axis are static and dynamic. Dynamic technological innovations refer to groundbreaking developments in LNG infrastructure (§2.2.2) that come available to the market participants. This contrasts with a static technological world where the availability of LNG infrastructure remains limited to the traditional LNG value-chain.

![Diagram showing the scenario logic with axes for demand for LNG, availability of LNG, and technological innovation.](image)

Note that these trends correspond to the conclusions of chapter 3, which stated that the demand characteristics, physical availability of surplus LNG, and technological innovations are among the key market drivers for the LNG spot market. In the operation of the model (chapter 6) these trends are the exogenous variables which contrast with the endogenous variables that are determined by the interactions of the model.

The logic behind this assumption is that most Customers are reluctant and/or unable to adjust their natural gas consumption to changes in the natural gas price while Production & Marketing Companies are encouraged to continue production by the high sunk cost and asset specificity of their investment (§3.2.1). The important difference between the scenario analysis of this study and that of (Insight 2007) is the addition of technological innovation as a external trend. This might accelerate the expansion of the LNG market (circumventing permitting issues, gaining access to former inaccessible natural gas reserves) but could also make the spot trade of LNG more attractive. Interesting in this respect is the development of a LNG storage and trading hub (§2.3.2) that would enable market participants to trade LNG over an extended period of time.

### 4.2.2 Outlook for the Scenarios

The scenario logic of Figure 44 displays the scenario space with a total of 8 possible scenarios. As this study is explorative of nature it is only interested in the scenario extremes (Table 9). Note that a nil-scenario is added to the analysis that refers to the intersection of the three external trends which is subsequently used for the verification and validation of the findings (chapter 8).

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Demand for LNG</th>
<th>Availability of LNG</th>
<th>Technological Innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 0</td>
<td>Neutral</td>
<td>Neutral</td>
<td>Neutral</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>Surging</td>
<td>Abundance</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>Surging</td>
<td>Abundance</td>
<td>Static</td>
</tr>
</tbody>
</table>
4. Future Analysis

Table 9: Overview of the Possible Scenarios in the Scenario Space

In order to derive the endogenous demand (regasification capacity) and supply (liquefaction capacity) projections for the different scenarios of Table 9, this study uses Scenario A ‘business as usual, continuation of trends’ (Table 10) as the point of reference. As the business of usual scenario implies that there are no deviations from the current trends it corresponds to scenario 0 of this study. In order to calculate the variations among the different scenarios, a correction factor is calculated and used (for details this study refers to Appendix II) that amounts to 30 percent. Meaning that a modest demand for LNG relates to a 10% decrease of the relative growth rate of the nil2scenario, whereas a surging LNG demand relates to a 20% increase of the relative growth rate of the nil2scenario. The discrepancy between the impact on both ends of the axis, is to be found in the underlying assumption of this study which states that the global market for LNG is set to expand.

Table 10: Development Projections for Regasification and Liquefaction in Scenario A (Insight 2007).

Table 11 provides an overview of endogenously determined regasification and liquefaction capacity for the nil2scenario. Note that this corresponds to the values of scenario A (Table 10). Furthermore it includes the most optimistic scenario (scenario 1) in which a surging LNG demand coincides with an abundant availability of LNG and dynamic technological innovations. The respective regasification and liquefaction capacity in this scenario are 60% higher then those of the nil2scenario. This contrasts with the least optimistic scenario (scenario 4), in which a modest demand for LNG coincides with a constrained availability and static technological innovations. In this scenario the regasification and liquefaction capacity is 70% lower then those of the nil2scenario. For the complete overview of the regasification and liquefaction capacity in the various scenarios this study refers to Appendix II.

<table>
<thead>
<tr>
<th>Region</th>
<th>Year</th>
<th>Regasification Capacity</th>
<th>Total Import</th>
<th>Liquefaction Capacity</th>
<th>Total Export</th>
<th>Unit of Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>2005</td>
<td>527</td>
<td>194</td>
<td>252</td>
<td>194</td>
<td>[BCM/year]</td>
</tr>
<tr>
<td>Global</td>
<td>2010</td>
<td>862</td>
<td>383</td>
<td>403</td>
<td>366</td>
<td>[BCM/year]</td>
</tr>
<tr>
<td>Global</td>
<td>2015</td>
<td>1022</td>
<td>523</td>
<td>555</td>
<td>485</td>
<td>[BCM/year]</td>
</tr>
<tr>
<td>Global</td>
<td>2020</td>
<td>1071</td>
<td>582</td>
<td>617</td>
<td>536</td>
<td>[BCM/year]</td>
</tr>
<tr>
<td>Global</td>
<td>2025</td>
<td>1139</td>
<td>627</td>
<td>650</td>
<td>577</td>
<td>[BCM/year]</td>
</tr>
</tbody>
</table>
With the demand projections in place, it is now time to answer the fourth sub-question.

4.3 Future Extrapolations and the LNG Market

The mathematical extrapolations and subsequent scenario analysis enable this research to answer the third sub-question:

- Is it possible to predict the demand trends for the LNG spot market with future extrapolations?

This chapter commenced with an overview of some general industry estimates regarding the future importance of the spot market for LNG. Despite differences in the exact estimates, there is an overall consensus about the continuing expansion of the spot market for LNG which is expected to reach approximately 30 percent of the global LNG trade. The subsequent Polynomial extrapolation the relative importance of the spot market for LNG that is based on existing market data indicates that 40 percent of the LNG business will be traded on the spot market by 2015. The unlimited growth assumption of this extrapolation technique however, renders the results unusable for a longer time horizon as the growth rate spirals out of control. In order to circumvent these shortcomings a different extrapolation technique was put into practice: the Verhulst extrapolation. Working with the basic principles of population ecology this technique proposes that the growth rate is eventually slowed by a lack of sufficient resources. The extrapolation results of the most complete data sets and best data fit indicate that approximately 42 percent of the LNG business will be traded on the spot market by 2030.

The subsequent scenario analysis was implemented to challenge our thinking about emerging issues and trends with a potentially high impact on the development of the LNG spot market while simultaneously implementing a certain degree of cautiousness in this research. The scenario-logic indicated that there are three external trends with the ability to shape the future of the spot market for LNG: the demand for LNG, the availability of LNG, and the technological innovations in the market. By relating different variations of these external trends with the business as usual scenario from Global Insight (Insight 2007) this study was able to derive the endogenous demand (regasification capacity) and supply (liquefaction capacity) projections for the LNG market until 2025.

Although this future analysis is believed to be an effective approach to acquire future demand trends for the spot market for LNG, this research approach fails to satisfy the research objectives of this investigations. This warrants further research and leads this investigation to conclude that insights about the development of the spot market for LNG requires a different modeling approach. The selection of this modeling approach and the creation of a conceptual model will be the center of attention in chapter 5.
5. Setting the Scene; the Conceptual LNG-Model

Although the future analysis of the previous chapter allowed this investigation to come to grips with the potential role of the spot market for LNG in a global context, it failed to provide insights in the conditions under which this potential is or is not realized. The central research question of this chapter is therefore the fourth sub-question:

- To what extent is it possible to use agent-based modelling to assess the transition towards a spot market for LNG?

Accordingly, this chapter commences with the selection of a modeling paradigm that is capable of satisfying both the Overall Thesis Question (§1.5) and the Research Objectives (§1.6). After comparing the different modeling paradigms on their respective merits it is clear that the Agent-Based paradigm is the one that suits the need of this study best. As such, a more elaborate discussion of the Agent-Based paradigm and what it entails to be an agent follows (§5.2). Thereafter, the conceptual model of the LNG market and its individual components is presented (§5.3). Finally, an answer to the fourth sub-question is formulated along with some preliminary conclusions (§5.4).

5.1 Selection of the Modeling Framework

Although modeling takes various forms, they share one common goal; understanding the world through a simplification of reality. This research will focus on the use of simulation techniques to model the LNG market. The dictionary defines simulation as the imitative representation of the functioning of one system or process by means of the functioning of another (Merriam-Webster 2009). The purpose of simulation is to obtain a better understanding of some selected features of the system. Consequently it can be used for prediction purposes, developing new tools, substitute human capabilities, and for discovery and formalization (Gilbert 2005). Simulation modeling, in which a set of rules defines how the system changes over time from a given present state, is advocated by this study because of its ability to tackle complex time dynamic problems.

5.1.1. Overview of Modeling Paradigms

Within simulation modeling there are four main paradigms; system dynamics, dynamic systems, discrete events, and agent-based simulations. This section provides an overview of these modeling paradigms that is based on earlier comparative studies (Shalizi 2003; Borshchev 2006; Schieritz 2007). Furthermore it discusses the advantages and disadvantages of each paradigm and relates the findings to the proposed simulation of the LNG market.

In order to differentiate between the different modeling paradigms (Borshchev 2006) looks at the levels of abstraction in simulation modeling. According to this abstraction scale, the lowest level represents the domain of physical models in which great emphasis is given to the lifelike representation of individual objects. This is the domain of automotive control systems and traffic micro models. In contrast, the highest level of abstraction involves problems that are approached in terms of aggregate values and global trends. Examples include the modeling of population dynamics, ecosystems, and marketplaces. The second differentiating condition is that between continuous and discrete problems. Continuous problems deal with uninterrupted processes whereas discrete problems work mostly with discrete time, i.e. jump from one separate state to another. An overview of the different paradigms, related problems, and their respective positions on the abstraction scale is illustrated in Figure 45.
It can be seen that the Dynamic Systems paradigm is located in the low right quadrant of Figure 45, which means that it is suitable for continuous problems with a low level of abstraction. Both the Discrete Event paradigm and the Agent Based paradigm are able to tackle problems with overlapping levels of abstraction. The Discrete Event paradigm can be used at a low and middle abstraction level, whereas the Agent Based paradigm covers the whole abstraction range. System Dynamics is usable for continuous problems with a high level of abstraction. Each paradigm is more elaborately discussed below.

System Dynamics Paradigm

According to its developer, Jay W. Forrester System Dynamics (SD) is “the study of information-feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decisions and actions) interact to influence the success of the enterprise” (Forrester 1958). The SD paradigm is used to tackle complex feedback problems in which parameter X affects parameter Y while parameter Y also, often through a series of causal relations, affects parameter X. Hence, it is not possible to assess both relations independently as only the study of the whole system, and hence a general understanding of all its interactions, leads to meaningful results. Forrester notes that “In building a system dynamics model, one starts from the structure and the decision-making rules in a system. Usually there is little debate about structure and the major considerations in decisions. When a model has been constructed from the accepted structure and policies, the behavior will often be unexpected” (Forrester 1994). This makes SD well equipped for the modeling of continuous processes at high abstraction levels. Sweetser (1999) notes that "SD is well suited to modeling continuous processes, systems where behavior changes in a non-linear fashion, and systems where extensive feedback occurs within the system”. Consequently, SD is often used for problems that relate to ecosystems, population dynamics and strategic policy analysis.

Dynamic Systems Paradigm

Dynamic Systems (DS) is commonly referred to as the ancestor of the SD paradigm and contrasts with it in that integrated variables are represented on an operational level. As such, these variables represent a direct physical meaning (location, concentration, size, etc) and are inherently continuous. Borshchev (2006) notes that the mathematical diversity and complexity in dynamic systems domain can be much higher than in SD. The need of DS to develop a mathematical model of the major system components makes it well suited for the modeling of physical control systems (for example automotive control systems). However, as it ignores the social component of the system it will not be considered for the modeling of the LNG market, as the aim of this analysis is to uncover the behavior of the market participants in a dynamic social-technical environment.
5. Setting the Scene; the Conceptual LNG-Model

Discrete Events Paradigm

Discrete Events (DE) concerns the modeling of a system as it evolves over time through a representation in which the state variables change instantaneously at separate points in time (Law 1991). As such it is based on the concepts of entities, resources and block charts that describe entity flows and resource sharing. Although there is a wide range of DE tools available, they all work according to the same notion of pushing entities through blocks and tracking the changes of the system. Note that the discrete approach of DE is opposite to the continuous approach of system development that is advocated by SD and DS. Sweetser (1999) notes that “A good DES model can replicate the performance of an existing system very closely and provide a decision-maker insight into how the system might perform if modified, or how a completely new system might perform. To achieve this fidelity to the performance of a real world process, a DE model requires accurate data on how the system operated in the past, or accurate estimates on the operating characteristics of a proposed system”. Although DE is suitable to assess the impact of modifications on a system, this study does not have access to the required accurate and complete data on the operations of the LNG market. It is noted that DE is more appropriate to use for “the detailed analysis of a specific, well-defined system or linear process such as a production line or call center. These systems change at specific points in time: resources fail, operators take breaks, shifts change, and so forth.” (Sweetser 1999). Because of the discrepancy between the LNG market and the problems that the DE paradigm tackles, it is not further pursuit in this study.

Agent-Based Paradigm

“In agent-based modeling (ABM), a system is modeled as a collection of autonomous decision-making entities called agents. Each agent individually assesses its situation and makes decisions on the basis of a set of rules” (Bonabeau 2001). The ABM approach to simulation is unique in that it is essentially decentralized; this is to say that there is no central place that describes the overall behavior of the system, the system is modeled as a collection of autonomous decision making parts instead. As such, agents act in their own best interest, and hence follow their own set of interaction rules. These decisions are of course subject to the environment in which the agent operates. Bonabeau (2001) notes that “ABM is, by its very nature, the canonical approach to modeling emergent phenomena: in ABM, one models and simulates the behavior of the system’s constituent units (the agents) and their interactions, capturing emergence from the bottom up when the simulation is run”. As such, ABM is commonly referred to as bottom-up modeling, whereas the other paradigms are more top-down oriented. Thus, ABM is a powerful paradigm to capture complex and dynamic behavior without the requirement to poses detailed knowledge of the model interdependencies. Or in the words of Srbljinović (2003) “What makes agent-based models particularly appealing and interesting is that consequences on the collective level are often neither obvious, nor expectable, even in many cases when the assumptions on individual agent properties are very simple. Namely, the capability of generating complex and intriguing emergent properties that arises not so much from the in-built rules of individual agent behavior, as from the complexity of the network of interactions among the agents”.

5.1.2 Agent-Based versus System Dynamic Paradigm

From the above-mentioned description of each of the paradigms it follows that the DS and DE paradigm are both unsuitable for this study. The top-down paradigm that is used by both assumes that there is complete information about the system, its components, relations, and interdependencies. As the focus of this study is emergent behavior in the LNG market, a phenomenon that cannot be known in advance, this rules out the use of DS and DE. Thus a choice will be between either the SD or the AB paradigm. This study draws upon the work of Schieritz (2007) to illustrate the major differences between AB and SD. The main difference between the Agent-Based (AB) and SD paradigm is perhaps best captured in the title of Schieritz and Milling (2007) “Modeling the Forest or Modeling the Trees; A Comparison of System Dynamics and Agent-Based Simulation”. The AB approach to simulation is unique in that it is essentially decentralized; this is to say that there is no central place that describes the overall behavior of the system. Instead Agent-Based Models (ABM) model a system (e.g. the forest) as a collection of autonomous decision making parts (e.g. the trees) as opposed to SD that models the forest as one entity. An overview of the main differences is provided for in Table 12. The first and most obvious distinction between AB and SD is the basic building block. For SD this is the feedback loop whose interactions with other feedback loops creates
the emergent behavior of the system. For AB the basic building block is the agent whose interactions with other agents create the overall systems behavior. More interesting for this study however are the differences between the unit of analysis, level of modeling, and adaptation. The importance of the handling of time, the mathematical formulation, and origin of dynamics are deemed to be less important as the AB paradigm has no clear proposition (handling of time), lacks a universally accepted formalism (mathematical formulation), or does not emphasize the process at all (origin of dynamics).

### Table 12: System Dynamics versus Agent-Based Simulation (adopted from Schieritz 2007))

<table>
<thead>
<tr>
<th></th>
<th>System Dynamics</th>
<th>Agent-Based Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic building block</td>
<td>Feedback loop</td>
<td>Agent</td>
</tr>
<tr>
<td>Unit of analysis</td>
<td>Structure</td>
<td>Rules</td>
</tr>
<tr>
<td>Level of modeling</td>
<td>Macro</td>
<td>Micro</td>
</tr>
<tr>
<td>Perspective</td>
<td>Top-down</td>
<td>Bottom-up</td>
</tr>
<tr>
<td>Adaptation</td>
<td>Change of dominant structure</td>
<td>Change of structure</td>
</tr>
<tr>
<td>Handling of time</td>
<td>Continuous</td>
<td>Discrete</td>
</tr>
<tr>
<td>Mathematical formulation</td>
<td>Integral equations</td>
<td>Logic</td>
</tr>
<tr>
<td>Origin of dynamics</td>
<td>Levels</td>
<td>Events</td>
</tr>
</tbody>
</table>

While the unit of analysis for the SD paradigm is the structure, this needs to be known in advance. As such, it is fixed and the behavior of the system changes as a consequence of changes in the model structure. AB on the other hand facilitates changes during the simulation. Here the macro system behavior is a result of interacting agents with dynamic decision rules. The level of modeling is clearly different for SD and AB, as the modeling the forest or modeling the trees analogy exemplifies. According to Davidsson (2000) “in macro simulations the set of individuals is viewed as a structure that can be characterized by a number of variables, whereas in micro simulations the structure is viewed as emergent from the interactions between the individuals”. This is important because it characterizes the main difference between SD and AB. “If a System Dynamics study is to analyze an emergent phenomenon it would capture this phenomenon by modeling its properties, its structure. That is, the emergent phenomenon itself is modeled. In an Agent-based model, however, it evolves in the course of the simulation” (Schieritz 2007). This makes it clear that SD models form an aggregate view that represents the characteristics of its components through average properties, while AB takes the opposite stance as it models through autonomous decision making agents. While SD predetermines the characteristics of the system, AB lets it evolves from the agents interactions.

To summarize, this study mentions the most distinct advantages of the AB paradigm as opposed to the SD paradigm that is strongly based on (Cederman 1997; Bonabeau 2001; Srbljinović 2003).

- ABM is able to captures emergent phenomena that result from the interactions of individual agents whereas the behavior of the SD paradigm is the result of a predetermined structure.
- ABM provides a natural description of the system because it describes and simulates a system that is composed of “behavioral” entities, e.g. the market participants.
- ABM is flexible, it is easy to add agents or tune the complexity of the agents (including behavior, learning abilities), whereas the structure of the SD model is fixed and consequently more difficult to adjust.
- ABM provides the possibility of modeling more “fluid” or “turbulent” social conditions when modeled agents and their identities are not fixed or given, but susceptible to changes of individual agents, as well as adoption of their behavior.
- ABM provides the possibility of modeling bounded rational agents, making decisions and acting in conditions of incomplete knowledge and information whereas SD models require a general understanding of all the interactions in advance.
- ABM provides the possibility of modeling processes that are out of equilibrium.

Accordingly this study believes that the AB paradigm is best equipped for the modeling of the transition of the LNG market as it is particularly useful for modeling systems that are composed of interacting agents, and exhibit emergent properties (that is properties arising from the interaction of the agents that cannot be deduced simply by aggregating the properties of the agents) (Axelrod 2006). The development of the LNG market satisfies both properties as it was created due to interaction of a wide variety of market participants, each with their own technical restrictions, in a given economic and
social climate. This means that modeling it requires the ability to describe the behavior of parts of the system (i.e. the technical and social fundamentals of the LNG market) and assess the resulting system behavior that emerges from the interactions of these smaller autonomous parts. Thus the bottom-up ABM approach provides a means to supplement the existing quantitative analysis of the LNG market with a more qualitative study that creates new insights about the approaching spot market for LNG and the conditions under which such a market actually develops. The next step demonstrates how to put the ABM paradigm into practice.

5.2 Agent-Based Modeling

Before this study turns focus to the conceptual model of the LNG market it believes that it is necessary to discuss ABM, and what it entails to be an agent in greater detail.

There is no universally accepted definition of an agent as there is much debate and little consensus about what it entails to ‘be’ an agent. According to complexity theory pioneer Stuart Kauffman an agent is “a thing which does things to things” (Ball 1999). This perhaps somewhat vague definition does not fail to demonstrate the most important feature of an agent, namely that an agent has the ability to perform a certain action through which it influences other agents. Shalizi (2003) supplements this definition and states that “an agent is a persistent thing which has some state we find worth representing, and which interacts with other agents, mutually modifying each others’ states”. Schieritz (2007) argues that it is more appropriate to speak of a continuum of agency as a universally accepted definition is currently missing and hence, it is not clear what it entails to be an agent or non-agent. Instead it is argued that the number of agent characteristics that an entity possesses and the degree to which these are developed, determines the degree of agency. The properties of an agent that can be found in literature are illustrated in Table 13.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proactiveness, Purposefulness</td>
<td>Ability to take the initiative in order to achieve goals</td>
</tr>
<tr>
<td>Situatedness</td>
<td>Agent is embedded in its environment and senses and acts on it</td>
</tr>
<tr>
<td>Reactiveness, Responsiveness</td>
<td>Ability to react in a timely fashion to changes in the environment</td>
</tr>
<tr>
<td>Autonomy</td>
<td>Ability to control own actions and internal state</td>
</tr>
<tr>
<td>Social Ability</td>
<td>Ability to interact and communication with other agents, sometimes even awareness of other agents</td>
</tr>
<tr>
<td>Anthromorphy</td>
<td>Having human-like attributes, e.g. beliefs and intentions</td>
</tr>
<tr>
<td>Learning</td>
<td>Ability to increase performance overtime based on previous experience</td>
</tr>
<tr>
<td>Continuity</td>
<td>Temporally continuous running process</td>
</tr>
<tr>
<td>Mobility</td>
<td>Ability to move around in the simulated physical space, sometimes even between different machines</td>
</tr>
<tr>
<td>Specific Purpose</td>
<td>Designed to accomplish well-defined tasks</td>
</tr>
</tbody>
</table>

According to this research however, Wooldridge (1999) provides the most practicable and useful definition of an agent when he states that “An agent is an encapsulated computer system that is situated in some environment and that is capable of flexible, autonomous action in that environment in order to meet its design objectives”. As with the agency continuum, this definition leaves some room for interpretation, as it does not differentiate between agents and intelligent agents and fails to specify both the environment and autonomous action. Wooldridge (1999) however, notes that autonomy is meant “in the sense that agents are able to act without the intervention of humans or other systems: they have control both over their own internal state, and over their behaviour”. As for the environment it is noted that “in most domains of reasonable complexity, an agent will not have complete control over its environment. It will have at best partial control, in that it can influence it”.

Jennings (1999) further clarifies this definition and states that agents are:

- clearly identifiable problem solving entities with well defined boundaries and interfaces;
- situated (embedded) in a particular environment, they receive inputs related to the state of their environment through sensors and they act on the environment through effectors;
5. Setting the Scene; the Conceptual LNG-Model

- designed to fulfill a specific purpose, they have particular objectives (goals) to achieve;
- autonomous, they have control both over their internal state and over their own behaviour\(^\text{16}\);
- capable of exhibiting flexible problem solving behaviour in pursuit of their design objectives, they need to be both reactive (able to respond in a timely fashion to changes that occur in their environment) and reactive (able to act in anticipation of future goals).

Having clarified the characteristics of agents, it is clear that multiple agents are required to simulate the transaction of the LNG market. After all it is through the interaction of multiple competitive agents with varying perspectives and decision rules that the system evolves. Thus the ABM can best be seen as "a collection of agents and their states, the rules governing the interactions of the agents, and the environment within which they live" (Shalizi 2003). Jennings notes that interacting agents do so in the context of an organizational relationship. "This context defines the nature of the relationship between the agents... and consequently influences their behaviour... In many cases, these relationships are subject to ongoing change: social interaction means existing relationships evolve and new relations are created" (Jennings 1999). Drawing the agents, their interactions, and organizational relationship together results in the following illustration of ABM (Figure 46).

The proposed ABM for this study works with the above-mentioned assumptions about agents, their interactions, and organizational relationship and uses computer simulation to generate results that uncover the emergent behavior of the system as a whole. The goals of ABM are diverse and Axelrod (2006) argues that ABM researchers pursue one of four goals:

- Empirical understanding: Why have particular large-scale regularities evolved and persisted, even when there is little top-down control?
- Normative understanding: How can agent-based models be used as laboratories for the discovery of good designs?
- Heuristic: How can greater insight be attained about the fundamental causal mechanisms in social systems?
- Methodological advancement: How best to provide ABM researchers with the methods and tools they need to undertake the rigorous study of social systems through controlled computational experiments?

As this investigation seeks to uncover the fundamental causal mechanisms that shape the evolution of the LNG market, and in doing so uncover the potential for the LNG spot trade, its primary goal is heuristic. However, this is not to say that spill over effects aid empirical and normative understanding while simultaneously aid the methodological advancement of ABM research.

This section has clarified the most important component of the AB the agent, and its characteristics. With these guiding principles in place it is time to discuss the conceptual model.

\(^{16}\) Having control over their own behaviour is one of the characteristics that distinguish agents from objects. Although objects encapsulate state and behaviour (more accurately behaviour realisation), they fail to encapsulate behaviour activation or action choice. Thus, any object can invoke any publicly accessible method on any other object at any time. Once the method is invoked, the corresponding actions are performed. In this sense, objects are totally obedient to one another and do not have autonomy over their choice of action.
5.3 The Conceptual LNG-Model

The first step towards a conceptual model of the LNG market is to create a mapping of the LNG market in a structured fashion. This study proposes to develop an ABM that is to be built on the modeling framework for transitions in the energy domain (Chappin and Dijkema 2008) which is based on the earlier developed knowledge base of the Energy & Industry group, Faculty of Technology, Policy and Management, at Delft University of Technology (Chappin 2006; Nikolic, Chappin et al. 2008; Nikolic, Dijkema et al. in print). The conceptual model is captured in Figure 47 where it can be seen that the system representation consists of the LNG Agent, LNG Project, LNG Contract, and LNG Scenario. These constitute the basic building blocks of the conceptual model and represent the social and technical network of the LNG market. The actions of the LNG agent are influenced by the ruling market conditions which are a product of the LNG scenario and transition design factors. The remaining components of the conceptual model are explained in further detail below.

Figure 47: Conceptual LNG-model.

Before this study commences with the conceptualization of the LNG agent (companies engaging in the LNG trade), LNG project (containing the physical elements of the LNG value-chain), LNG contract (containing partnership details between agents) and LNG scenarios (containing the outlook for the LNG market) it will first determine the right focus of the forthcoming simulation.

5.3.1. Focus of the Model

It is important to align the focus of the proposed ABM with that of this thesis’ research objectives (§1.6). This ensures that the ABM provides the insights that this research is after and prevents the ABM from optimizing a sub-optimality. From the conceptual model overview it becomes clear that the LNG agent controls the LNG project. This control occurs on three distinct levels: strategic, managerial, and operational. The adjusted ‘three layer model’ that was originally developed by Dijkema and adopted by among others (Chappin 2006) structures the decision making process of the LNG agent. The three layer model is a useful framework to structure the relations and communication in socio-
technical systems as the LNG market. Strategic management represents the top layer of the model and concerns itself with the strategic investments and disinvestment decisions of the LNG Agent. As such, it determines the long-term strategy for the LNG agent. It is the strategical level that makes the (dis)investment decisions or decides on the preferred trade arrangement. In doing so it effectively controls the second (i.e. managerial) and third (i.e. operational) level decision making. Decisions on the managerial level are made on a medium-long time-scale and include matters as the timing of investments and the contract negotiations. Operational decisions deal with the exchange of goods and services between LNG agents and operate on a day-to-day basis.

This study argues that the decisions that are made on a strategic and managerial level shape the development of the LNG market. As such it will focus on these two relations and communication levels. This also implies that the decisions that are made on an operational level are compromised and adhere to the assumption that the exchange of goods and services follows those that are drafted in the contract. Interesting in this respect are the basic principles of stylized models in contracting that were pioneered by Diamond (1979) and Diamond and Maskin (1980) and adopted by Brito and Hartley (Diamond 1984; 2007) to assess the market transition of the LNG market. In the paper “Expectations and the Evolving World Gas Market” the change in the LNG market is regarded as a shift in the timing of investment and contract negotiation. It suffices at this point to note that the perceived transition is from the Traditional LNG market where firms search for trading partners and sign long-term contracts before investing in infrastructure to the Global market structure that entails producers who invest in infrastructure before they have buyers for all of their anticipated output, and buyers invest in infrastructure without having firm contracts for all their expected gas needs. Complimentary to these strategical changes there is a spot market that facilitates flexible trading by short-term contracts, multilateral trades, swaps, and switches in trading partners (§3.4).

Now that this study has established that the focus of the ABM should be on the strategic and managerial level of the LNG agents, it is time to continue with the conceptualization of the LNG Agent.

5.3.2. LNG Agent

The most complicated component of the ABM is the LNG Agent (Figure 49) that controls the LNG project in a dynamic environment. The LNG Agent can own multiple LNG Projects and build a portfolio of LNG Projects that encompasses the complete LNG value-chain. Alternatively, it can specialize in one part of the LNG value-chain and cooperate with other LNG agents to complete the value-chain and trade LNG. The LNG agent needs to makes its decisions on three levels (§5.3.1.): strategic, managerial, and operational. In order to measure the performance of the LNG agent a credit level is added to the LNG agents that keeps track of the payments.
LNG Agents’ Strategic Decisions

Strategic decisions of LNG Agents are made with a long-term perspective in mind. Categorized as strategic decisions in this ABM are the investment and trade decisions. For the investment decision the LNG Agent needs to assess its environment to determine in which type of LNG project it wants to invest. It also decides on the timing of its investment. Brito (2007) considers the timing of investment to be the indicator for a LNG market transition. Traditionally, LNG agents only invest in LNG projects under the condition that a long-term contract covers the uncertainties that are involved in such an undertaking. This guarantees a sustained return of investment during the life span of the project. Investments that are made in the alternative market structure commence without the complete coverage of the LNG project involved and are willing to postpone the search for a suitable partner during or after the realization of the project. The trade strategies of the LNG agent refer to the unique preferences of the LNG agent involved that shape its long-term strategy. It is conceivable that certain LNG agents can afford to be more risk prone then others or have different preferences due to their existing portfolios.

LNG Agents’ Managerial Decisions

On a managerial level of decision making the LNG agent is involved in the contract negotiation process and on a continuous search for improved partnerships. As the owner of a LNG project, the LNG agent is responsible for its performance or Return on Investment (ROI). In order to generate value from its LNG project the LNG agent needs to connect all three components of the LNG value-chain, either through SPAs or MSAs. If any LNG project is not linked with its corresponding components of the value-chain it is the LNG agents’ responsibility to create a partnership with a complementary LNG project. Another possibility is that a LNG agent has managed to form a partnership that turns out to be suboptimal in the current market. The benefit of forming a new contract might at some point be large enough to breach a running contract even if a certain form of compensation needs to be paid. This exemplifies the importance of a continuous search for new partnerships. This model envisions two types of individuals who are distinguished by type only in that each partnership, in this case a contract, requires exactly one partner of each type. For example, a LNG Agent with a liquefaction plant in place can form a partnership with an LNG Agent that owns a regasification terminal and one with an LNG agent that owns a LNG tanker. The fact that the complete LNG value-chain is now in place allows the LNG to be produced, transported, and consumed.

LNG Agents’ Operational Decisions

The operational decisions that are made by the LNG agent refer to the day-to-day operations of the LNG project. Ensuring that the LNG project meets its design requirements and delivers the required output is an important prerequisite for the LNG trade. Maintenance is also part of the operational decisions and can cause the LNG project to be out of service for a certain period. It should be noted that the operational decisions are not the primary focus of this thesis and are assumed to follow the exchange of goods and services that are stated in the LNG Contract.

LNG Agents’ Credit Level

Finally, there is the credit level of the LNG agents which keeps track of the costs and revenues, and hence is the indicator for the economic performance of the LNG Agent.
The LNG Project represents the technical or physical network of the LNG market in the ABM. This study argues that each LNG Project contains four differentiating parameters (Figure 50) technology, ownership, status, and state. The technology refers to the type of LNG Project while the ownership relation represents the link between the LNG project and its owner the LNG Agent. Finally, there are the status of the LNG Project which describes the operational mode and the state which contains information about the current partnerships.

![LNG Project Diagram]

**Figure 50: Conceptual Visualization of the LNG Project.**

**LNG Projects’ Type**

The technology describes the type of LNG project and the possibilities include those of the traditional LNG value-chain (§2.3.1): the liquefaction plant, LNG tanker, and regasification terminal. It is also possible for the LNG Agent to select more innovative technologies (§2.3.2) such as the LNG Shuttle and Regasification Vessel (SRV), a modified LNG vessel that is equipped with regasification capabilities and a natural gas unloading system, Floating Storage and Regasification Unit, Floating Liquefaction, LNG, and Storage and Trading Hubs. Note that the model will be setup in such a way that it is possible to add more innovative technologies when this is deemed necessary or desirable.

**LNG Projects’ Status**

The status of the LNG project refers to its operational mode. This study distinguishes between LNG projects that are in the planning stage, under construction, operational, and dismantled. The duration of the planning stage is closely related to the contract negotiation process of the LNG Agent. Although the construction period is highly dependent on local circumstances Brito (2007) estimates a typical build-up period of 15 months. Although the operational period varies between LNG Projects, a liquefaction plant is designed to accommodate a plateau production level for 20 to 30 years. During the dismantling period a LNG Project is unable to sustain its production unless it is being refitted.

**LNG Projects’ State**

The state of the LNG Project shows how it is connected to other complimentary LNG Projects of the LNG value-chain. This provides the owner, the LNG Agent, with the required information for its strategic and managerial decisions.

**LNG Projects’ Ownership**

The ownership represents the link between the LNG project and its owner the LNG agent. From the actor and network analysis (§2.3) it became clear that owners of LNG infrastructure include the national and international oil majors, independent shipping companies (BW Gas ASA, Leif Hoegh, Mitsui OSK Lines), utility companies (Kogas, Mitsui), and trade companies (Vitol, Tractebel).

It is important to note that the LNG agents’ timing of investment is related to the available technologies, the ownership relation, the state of the LNG project, and its status.

**5.3.4 LNG Contract**

The LNG Contract (Figure 51) formalizes the relationship between the LNG Agents that own the LNG Projects that are involved in the agreement. Furthermore it contains the contract specifications.
5. Setting the Scene; the Conceptual LNG-Model

The LNG Contract contains two complimentary LNG Projects, the owners of which need to sign the LNG Contract before it becomes valid and activated. The specifications of the contract are important because they are in control of the LNG Projects by assigning the LNG flow and its value. The contract duration is also part of the contract specifications and refers to the duration of the agreement when this is not dissolved due to force majeure.

5.3.5 LNG Scenario

The LNG Scenario module (Figure 52) contains two parameters: the market drivers and inhibitors and the external trends. Market drivers and inhibitors refer to the conditions that facilitate or restrict a transition of the LNG market structure (§3.3.3). The external trends on the other hand are beyond the influence of any particular LNG Agent and form a significant unpredictability for the development of the LNG market (§4.2).

LNG Scenarios Market Drivers & Inhibitors

Although there are different LNG specifications, this study assumes that LNG can be treated as a homogenous commodity (§3.3.2). Flexibility demands are becoming more important as the liberalization of electricity and gas markets have changed the requirement of LNG Agents. Technological improvements, such as the exploitation of economies of scale, enable LNG Agents to adjust their strategical and managerial practices and are seen as an important promoter of change. It should be noted that this study is aware of the fact that a change in market structure might be hard to realize through changes in the above-mentioned exogenous market drivers alone. In accordance with Brinded (2003) it beliefs that the momentum of the LNG spot market can act as a self-reinforcing process in which expectations about the future market structure are likely to influence the investment decision and contract negotiation process of the LNG Agents.

Arguably the most important constraint for a transition in the LNG market are the security of supply concerns of the LNG Agent (§3.3.2). The absolute requirement for reliable supplies of some LNG Agents that act as a promoter for the SPA governed LNG trade. This dedication to security of supply (most noticeably by Japanese and Korean utility companies) means that a considerable amount of LNG effectively becomes unavailable for alternate contractual agreements and insensitive to the prevailing market conditions. Permitting issues make it more difficult to expand the number of LNG Projects, and thus hinder market growth and development. Finally there is the issue of market access which limits the free exchange of LNG and hence, favors the Traditional trading model.

LNG Scenarios External Trends
It is widely expected that the demand for LNG will continue to increase in the future due to declining domestic reserves in the main consuming countries (OECD) and increased demand. If the LNG market is to accommodate this increasing demand it needs to expand the current LNG infrastructure in all parts of the LNG value-chain. It is likely that this expansion coincides with an increase of the number of LNG agents that are active on the market. This has a number of implications for the LNG trade as it increases the probability of meeting a suitable partner, reduces the average transport distance between the points of supply and demand, and reduces the costs of a breached contract. In the midstream segment the availability of surplus shipping capacity is considered to be an important prerequisite for the development of the LNG spot market because it guarantees LNG Agents that they can transport the LNG from the point of production to the point of consumption (§3.3.2). Technological innovations such as the FSRU and LNG Storage & Trading hub enable change because these technologies provide opportunities that are lacking in the traditional LNG value-chain. Storing LNG for example offers LNG Agents the ability to store, trade and plan supplies of LNG over an extended period of time. For more information on the technologies that reach beyond the traditional LNG value-chain this study refers to §2.2.2.

5.4 ABM and the LNG-Market a Good Match?

The conceptual Agent-Based model of the LNG market allows this investigation to provide an answer to the fourth sub-question:

- To what extend is it possible to use agent-based modelling to assess the transition towards a spot market for LNG?

The prerequisite to the creation of a conceptual LNG-model is the selection of a suitable modeling paradigm. After a first comparison of the modeling paradigms it was clear that the Agent-Based and System Dynamic paradigm prevailed. The subsequent comparison between both indicated that the bottom-up modeling approach that is characteristic of the agent-based modeling paradigm is preferable to the top-down oriented System Dynamics approach. A small analogy with the modeling of a forest helps to explain the rational behind this choice. Instead of unraveling the complexities of a forest through the building of a model which represents the entire ecological system (System Dynamics), the Agent-Based paradigm advocates the modeling of its autonomous parts the trees, and proposes to look at the interactions and emergent behavior of multiple trees to unravel the complexities of the forest. The smallest autonomous building block of any Agent-Based model is thus the agent (or tree in the analogy). Although there is no universally accepted definition of an agent, there are certain characteristics that each agent adheres to, these include: autonomy, social ability, learning, situatedness, and responsiveness.

The ascertainment that Agent-Based Modeling can indeed be used to provide the Overall Thesis Question with an effective answer while simultaneously satisfying the Research Objectives warrant the development of the conceptual LNG-model. This investigation proposes to use the smallest autonomous, yet meaningful, component of the LNG market as the basic building block for the conceptual model: the actors of the LNG market (§2.2) which are henceforward called LNG Agents. Quantitative insights about the development of the spot market for LNG will be obtained by modeling a collection of autonomous decision making LNG Agents and looking at their interactions and emergent behavior. As such, it envisions LNG Agents (companies engaging in the LNG trade) that invest in LNG Projects (containing the components of the LNG value-chain), negotiate about LNG Contracts (containing the details of a partnership), in a given LNG Scenario (containing possible futures of the LNG market) as a suitable starting point for a model of the LNG market that is equipped to satisfy the objectives of this investigation.

As any model seeks to understand the world through a simplification of reality, it is extremely important to set the right model focus. This study argues that the decisions that are made by the LNG Agents shape the development of the LNG as they seek to balance the rewards of more open and competitive LNG trade with the inherent risks of realizing capital intensive LNG Projects. This balancing act determines if long-term SPA governed LNG trade or short-term MSA governed LNG trade prevails. Although the agent-based paradigm is theoretically capable of simulating the complexities of the LNG market this investigation has opted to focus the model development on the strategic and
managerial decisions of the LNG Agent as these are considered to be the crux to understanding the development of the LNG trade. Transforming the conceptual LNG-model into reality will be the center of attention of the next chapter.
6. LNG Spot Market Simulation

The conceptual Agent-Based LNG-model will be turned into an explorative model of the LNG market that is used to assess the impact of the imminent key market drivers and inhibitors (§3.5) on the strategic and managerial decisions of the LNG Agent (§5.3.2). The central research question of this and the next chapter is therefore the fifth sub-question:

- Under which conditions does a spot market for LNG arise from the social and technical interactions of the market if agent-based modeling is used to assess the impact of its key market drivers?

Accordingly, the practical integration of the conceptual LNG-model with the existing Agent-Based modeling knowledge base of the Energy & Industry Group at the Technology, Policy, and Management faculty of Delft University of Technology is discussed first (§6.1). This study advocates the use of a stylized model of contracting to enable the LNG Agents to make strategic and managerial decisions regarding the trade of LNG (§6.2). Next, the conceptual LNG Agent (§5.3.2) LNG Project (§5.3.3), LNG Contract (§5.3.4) and LNG Scenario (5.3.5) are integrated with the existing agent-based knowledge base and turned into working components of the LNG-model (§6.3 to §6.5).

6.1 LNG-Model Overview

Turning the conceptual LNG-model into reality requires more than one software package. The LNG-model will therefore make extensive use of the existing knowledge base of the Energy & Industry group, Faculty of Technology, Policy and, Management, at Delft University of Technology. ABM are constructed through the integration of multiple software packages. Please note that for the purpose of this study the mathematics and modeling software package Maple 12 is added to the original software package. Maple 12 is used to integrate the adopted Diamond model of contracting with the existing ABM knowledge base and enables the LNG-model to generate the quantitative knowledge that it set out to uncover.

![Figure 53: Software Tools for Agent-Based Modeling (adjusted from (Chappin 2006)).](image)
6. LNG Spot Market Simulation

Protégé, the first software package “implements a rich set of knowledge-modeling structures and actions that support the creation, visualization, and manipulation of ontology’s in various representation formats” (Protégé 2009). The ontology is a specification of a conceptualization meaning that it is a description of the concepts and relationships that can exist for an agent or a community of agents (Gruber 1993). As such it provides the formal language or vocabulary that the ABM can adopt to describe the agents and their technologies. The ontology that is defined in Protégé serves as the input for the actual model which is written in Java structure and code on the Eclipse platform (for the overview of the methodology the reader is referred to appendix III). “Eclipse is an open source community, whose projects are focused on building an open development platform comprised of extensible frameworks, tools and runtimes for building, deploying and managing software across the lifecycle” (Eclipse 2009).

Newly added to the existing software tools for ABM is the mathematical package Maple 12. This software package enables the simulation to incorporate a mathematical component that can be used to update the agents’ knowledge about its environment. Note that this is not necessarily a one time event and can be used throughout the simulation when this is required. In order to perform the required calculations it uses the java structure and code from eclipse to set the model parameters. These can also be adjusted during the simulation if this is desirable. While the actual code is written on the Eclipse platform it is processed by Repast. This agent-based modeling toolkit simplifies the model creation (Repast 2009). Chappin notes that “Java based libraries of Repast provide possibilities for the user to set parameters, run and operate simulations and create output” (Chappin 2006).

The results of the ABM are subsequently stored in a database that is accessed with the fifth software package MATLAB. MATLAB is a numerical computing environment that also allows for data analysis and visualization. MATLAB is used to interpret and present the simulation results. Because of the requirements of the simulation run the LNG-model is setup on a computer cluster that is designed for High Performance Computing or HPC. The HPC of the E&I Group consists of multiple computers that are linked together which gives the computing power of approximately 500 modern personal computers. This makes the HPC especially well equipped to run the LNG-model in which a substantial mathematical problem is part of a larger simulation model. The HPC further enables the complete exploration of the scenario space. Such a parameter sweep reduces the risk of noise in the simulation results because of it compares the complete range of parameter settings over multiple runs.

The events that take place after the model initialization (Figure 54) show that each of the conceptual LNG-model components is called upon during the simulation run. It can also be seen that the LNG-model is built around its main component: the LNGAgent. The environment in which the LNGAgent is to make its decisions is determined by the ruling LNGScenario which is responsible to set the starting conditions of the LNG-model. First of are the parameter settings for the Diamond model and the LNGProject specifications. The LNGScenario also contains information that is directly linked with the LNGAgent in the form of the forecasted LNG demand and the agents’ character. This is introduced to guarantee the uniqueness of each individual LNGAgent and plays an important role during the strategic and managerial decision making process. Once the LNGScenario has provided the other model components with the required information it is time to proceed with the actions of the LNGAgent. The LNGAgent constantly checks its running LNGProjects and LNGContracts against the ruling market conditions to identify potential improvements. The decisions that it makes are all evaluated by the Diamond model which returns the market value of other optional LNGProject arrangements.

It should be noted that these actions are repeated for each LNGAgent on the LNG market for each LNGProject that it owns and operates. This explains the need to run the LNG-model on the HPC as the number of interactions increases exponentially with the growth of the market. Finally, the simulation results need to be processed. Because of the large amount of data that is produced during the model run a database is required to store the results in an orderly fashion. Once the database is in place, it can be accessed, visualized, and analyzed through MATLAB. Of course it is also possible to use other statistical software packages such as SPSS or R if this is preferred.

With the conceptual LNG-model and the software stack that facilitates the simulation of the LNG-model in place is it time to proceed with the discussion of the adjusted Diamond model of contracting.
6. The Diamond Model & Adjustments

The use of the adjusted stylized model of contracting that is based on the ideas of Diamond (1984), Diamond and Maskin (1979; 1980), and their adoption by Brito and Hartley (2007) is explicated here. First the adopted model from Brito and Hartley (2007) of contracting is presented (§6.2.1) and subsequently compared with the adjusted model that is used by the LNG Agents to make their decisions (§6.2.2). Next, is a discussion of the parameters settings and the desired results (§6.2.3). This section concludes with an overview of the equations that are used by the LNG Agent to make strategic and managerial decisions (§6.2.4).

6.2.1 Decision Making of the LNG Agent and the Adopted Diamond Model

If the LNG Agent want to initiate a new LNG Project it is faced with the initial investment decision in which it can determine the timing of investment. As such, the possibilities include: canceling the investment, search for a suitable partner before investing in the LNG Project, or investing in the LNG Project before searching for a suitable partner. In accordance with Brito and Hartley (2007), this investigation considers a shift in the timing of investment to be the most important indicator for a transition in the LNG market. While the traditional LNG market required firms to have a long-term SPA in place before investing in LNG infrastructure, the alternate or global LNG market envisions firms to invest in LNG infrastructure before such an agreement is formed. As such, the investment is made without having a complete coverage of the anticipated output in place and a substantial part of the LNG trade are made on the spot market LNG.

Closely related to the timing of investment on a strategic level is the contract negotiation process on the managerial level of the LNG Agent. If the contract negotiation process is easy and straightforward, the LNG Agent might favor the investment before searching strategy because this enables it to start making a profit sooner. If on the other hand the contract negotiations are a timely and expensive process, the risks of investing in a LNG Project prior to a partnership formation might prove too high as of consequence of which the LNG Agent searches for a partner before making the required LNG Project investment. This study proposes to incorporate the stylized model for contracting that it adopts from Brito and Hartley (2007) and is based on the ideas of Diamond (1984), Diamond and Maskin (1979; Diamond 1980).
This investigation acknowledges that a transition of the LNG market is hard to realize through changes in the exogenous market drivers alone (§5.3.5) and argues that expectations about the future development shape the investment decision as well. Brito and Hartley (2007) note that “while exogenous changes in costs or demand are critical to promoting a change in market structure, there is also a substantial endogenous component. Expectations about the evolution of the market influence investments and trading decisions and can make the change in market structure much faster and more abrupt”. The stylized model of Diamond (1979) demonstrates that market structure can change faster and more abrupt than would normally be expected due to the existence of multiple equilibriums and the amplification of the impact of exogenous changes by the endogenous ones. Integrating the stylized model of contracting thus allows this investigation to analyze the role of both exogenous market drivers and endogenous expectations on the development of the LNG market through the strategic and managerial decisions of the LNG Agent.

The stylized Diamond model views the search for potential contracting partners as a costly stochastic search process in which the negotiations are costless and instantaneous. For simplicity there are two possible outcomes of the contract negotiation process: a good partnership or a poor partnership in which the return of investment of a good partnership exceeds that of a poor one. This implies that a LNG Agent that owns a LNG Project finds itself in one of three states: without a partner, with a partner in a good match, or with a partner in a poor match. Once the LNG Agent and LNG Project have entered a partnership it is possible to continue the search for a better match or be content with the current situation and abandon the search process. If the LNG Agent opts to continue its search and finds another partnership it is forced to breach the old contract and compensate the former partner for its loss. Thus it is only profitable to end an existing partnership when the new one is worth more then the old one plus the required compensation. As such, the formal model of Brito and Hartley (2007) allows LNG Projects to be in one of six states (Table 14).

<table>
<thead>
<tr>
<th>LNG Project State</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>LNG Agents needs to decide if it wants to initiate a new LNG Project</td>
</tr>
<tr>
<td>1</td>
<td>LNG Agent searches for a partner without investing in a LNG Project</td>
</tr>
<tr>
<td>2</td>
<td>LNG Agent searches without a partner after investing in a LNG Project</td>
</tr>
<tr>
<td>3</td>
<td>LNG Agent has a LNG Project in a poor match and continuous to search</td>
</tr>
<tr>
<td>4</td>
<td>LNG Agent has a LNG Project in a poor match but is not searching</td>
</tr>
<tr>
<td>5</td>
<td>LNG Agent has a LNG Project in a good match</td>
</tr>
</tbody>
</table>

Table 14: Possible LNG Project States.

While the contract negotiations are free and instantaneous, the partnership search process is not. In order to find a complimentary LNG project each LNG agent needs to search at a certain costs per unit of time. During the search process the chance that any two searchers (of opposite type) meet is hold constant\(^ {17} \). The outcome of the contract negotiation process is determined by chance with the probability of a good match \( x \) and that of a poor match \((1-x)\). Finally there is the meeting technology which states that the probability of meeting any given LNG agent is independent of the number of other LNG agents around. In this case, the LNG agents’ probability of meeting someone rises linearly with the number of LNG agents. This technique, which is a reasonable model of meeting for an economy with a low density of potential partners, is referred to as the quadratic case (Brito 2007).

The motivation for LNGAgents to make an investment in an LNGProject before forming a partnership is that it creates a situation in which it is possible to arrange trades at short notice with any other LNG agent that has already invested. This includes LNG Agents that are in a poor partnership and LNG Agents that severed a previous contract. If however the LNG Agent opts to search for a partner before it invests in the LNG Project it is restricted to finding a partner in the separate long-term bilateral contract market. The logic behind this assumption is that LNG Agents that own existing LNG Projects are not interested in partnership if this causes there LNG Project to be idle for a long period of time. There is however a penalty on investing without a partnership which is caused by the fact that the

\(^{17}\) Note that this meeting probability needs to be small enough so that the probability of simultaneous meeting is zero, so that the possibility that both find better matches can be ignored Brito, D. L., Hartley, P.R. (2007). "Expectations and the Evolving World Gas Market." The Energy Journal 28(1).
required LNG Project investment needs to be financed without the benefit of constant revenue from the start of the LNG Projects operations.

After the initial investment decision the LNG Agent has a number of options at its disposal to change the state of the LNG Project. These are illustrated in Figure 55. If the LNGAgent opts to delay its investment in a LNG Project and search for a partner first, the LNG Project turns to state 1. State 1 LNG Projects are only allowed to partner other state 1 LNG Projects. Alternatively, if the LNG Agent decides to invest in a LNG Project first and search for a partner afterwards, the LNG Project turns to state 2. The initial investment decision of the LNG Agent is illustrated by the blue arrows of Figure 55. This earns the LNG Agent access to a potentially more liquid contract market where it can form partnerships with both state 2 and state 3 LNG Projects. Once a partnership has been formed, the transition of state depends on the quality of the match and might result in a LNG Project in state 3, 4, or 5. If the partnership turns out to be a poor one and the LNG Agent continuous to search for an improved one, the LNG Project turns to state 3. LNG Projects in state 3 can partner LNG Projects of both state 2 and 3. Regardless of the match, the new partnership becomes a success and turns both LNG Projects to state 5. The assumption here is that LNG Agents that own LNG Projects in state 3 are not willing to breach an existing partnership without the guarantee that this results in an improvement of their position. The former partner, who needs to be compensated for the breach of contract, will now own a LNG Project in state 2. Both LNG Projects in a good match (state 5) and a poor match (state 4) are no longer available for contract negotiations. Force majeure can cause a breach of contracts and transit LNG Projects in state 4 or 5 to state 2. The contract negotiations are illustrated by the green arrows in Figure 55, while the related change in state is illustrated by the black arrows.

![Figure 55: Possible Actions of the LNG Agent in relation with the LNG Project State.](image)

With the integration of the strategic and managerial decisions with the stylized model of contracting in place it is time to look at the required adjustments for the LNG-model implementation.

6.2.2 Required Diamond Model Adjustments

The adopted model of contracting failed to meet one important requirement of this study: the ability to capture the emergent behavior of the LNG market in a way that respects the bottom-up modeling perspective that is advocated by ABM and does justice to the social-technical interactions of the LNG-trade. The required adjustments to the adopted model of contracting are compared to the original model settings in Table 15.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Original Model of Contracting</th>
<th>Adjusted Model of Contracting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social building block</td>
<td>Firm</td>
<td>LNGAgent</td>
</tr>
<tr>
<td>Technical building block</td>
<td>LNG value-chain</td>
<td>LNGProjects: liquefaction plant</td>
</tr>
<tr>
<td>Contract</td>
<td>0,1 contract per value-chain</td>
<td>0,1,2 contract(s) per value-chain</td>
</tr>
<tr>
<td>Possible states</td>
<td>Six (0.5)</td>
<td>Twenty-three (3*(0.6))</td>
</tr>
<tr>
<td>States per technical building</td>
<td>One</td>
<td>Three</td>
</tr>
</tbody>
</table>
block | Market | Probability of success | Static: Predetermined | Dynamic: Emergent
--- | --- | --- | --- | ---
ROI of the LNG spot market | | ROI | Fixed | Emergent
Identity | All firms are equal | Emergent
Trade strategy | Predetermined

Table 15: Diamond Model Adjustments.

The first distinction between both models of contracting is the social building block. While the original model of contracting or Brito (2007) does not differentiate between buyers and sellers, the adjusted model does. Not only does it distinguish between buyers and sellers but it also allows the LNGAgent to adopt multiple roles if its LNGProject portfolio allows it to. Another difference concerns the technical building block of the model which is limited to complete LNG value-chains in the original. This contrasts with the socio-technical perspective that is advocated by this study and shows that the technical subsystem consists of three major components: liquefaction, shipping, and regasification (§2.2). Without the possibility to distinguish between these components of the LNG value-chain it is hard simulate the impact of some of the key market drivers and inhibitors. Most noticeably the impact of an asymmetrical capacity development throughout the LNG value-chain. Note that this asymmetrical development can be caused by a variety of reasons which include but are not limited to differences in the required capital investments, introduction of innovative technologies, and differences in the permitting process. By introducing the possibility for LNGAgents to invest in liquefaction, shipping, and/or regasification separately it becomes possible to resemble the LNG market and its complexities more realistically. This in turn, generates a more thorough understanding of the interdependencies between the key market drivers and the transition of the LNG market.

As there are only complete value-chains in the original model, only one contract between the buyer and seller is needed to start the exchanges of goods and services. This becomes more complicated when a complete value-chain consists of three different LNG Projects that need to be in place before the LNG-trade can start. Instead of one contract the LNG Agent needs two contracts to complete the LNG value-chain. Adding to the complexity is the fact that a complete value-chain can be initialized by each of the three LNG Project types. As such, there are three possible contracts for a value-chain with two LNG Projects, and three for a value-chain with three LNG projects. Thus, the number of contracts rises from two in the original model to nine in the adjusted model. In order to facilitate the increased complexity of the LNG value-chain a sixth state is added to the adopted model. This is introduced for LNG Projects that are part of a complete LNG value-chain but only have one LNG Contract. The added complexity makes state management an important element of the adjusted model. While the original model of contracting assigns a state to each firm, the adjusted model assigns three states to each LNG Project. This allows the LNGProject to check its state in relation to the other LNGProject types of the LNG value-chain. Figure 56 illustrates the state management for a liquefaction plant. The liquefaction plant is never in need of another liquefaction plant, while it can search for or have a partnership with both the LNG tanker and regasification plant.

Another difference between the adopted and adjusted model concerns the LNG market seize. While the adopted model is solved in a static market (e.g. a constant number of market participants), the adjusted model is solved in a dynamic market in which the number of market participants and
LNGProjects is allowed to change over time. The result of this assumption is that LNGAgents need to make their strategic and managerial decisions in a changing environment. The LNG-model also expects that the development of the LNG market will influence the probability of success for a random match between two complimentary LNGProjects. This means that the probability of success is not predetermined, as is the case in the original model, but a result of the market itself. Recall that the quadratic search technology prevents the LNG-model from changing the probability of meeting during the model simulation. The LNG-model therefore assumes that the market growth causes the probability of a good match to change instead. The justification for this assumption is adopted from (Brito 2007) and is based on the premises that the quality of a match primarily reflects the differences in transportation costs but is implemented in a different way. The reason that the probability of success for a random match increases as the market grows is to be found in the assumption that the LNGAgents are uniformly distributed around the world. This ensures that any market expansion reduces the transportation costs evenly for all the market participants. “The radius of the potential area about a particular supplier or demander where a match would be low cost would be inversely proportional to the transport costs.” Thus, the probability of a low cost match (which will be the ratio of two areas) will tend to rise with the inverse square of the reduction in transport cost” (Brito 2007). For the LNG-model this means that the introduction of new LNGProjects enhances the probability of a good match.

While LNGAgents in the traditional market are expected to a trade strategy in which they search for a suitable partnership before making any investment (state 1), a modest part of the transactions is already executed on an alternative basis: the LNG spot market (§4.1). The existence of the LNG spot market is an important enabler of the perceived market transition because it reduces the risks that are involved for alternative trade strategies. This means that the spot market is able to lower the costs of searching for a suitable partnership once the LNGProject is already in place. Put differently, it reduces the risks of commencing a new LNGProject without having secured the complete coverage of its output. This is favorable for LNGAgents that want to pursue a different trade strategy: invest in an LNGProject before searching for a partnership (state 2) and LNGProjects that are not yet part of a complete LNG value-chain. Instead of a ROI of zero, both LNGProjects can now turn to the LNG spot market for a more reasonable ROI. However, it does not suffice to include a spot market for LNG with a fixed ROI. Instead the LNG-model will make the ROI of the spot market dependent on its liquidity. The LNG-model therefore adjusts the adopted model of contracting with an equation that relates the surplus per unit of time that is earned from the spot trade with the relative importance of the LNG spot market in the global LNG market. The LNG-model determines the liquidity of the LNG spot market by comparing the ratio of traded volumes and delivered volumes (§3.1.4).

The LNG-model also acknowledges the fact that there are diverging strategies and interests among the LNGAgents. Asian Pacific customers for instance, are likely to be more risk averse then their Atlantic counterparts who might prove to be more willing to take risks (§3.2.2, §3.3.2, §3.4.1). Difference in the LNGAgents character are created by the introduction of a risk-factor that is used to decide when the ROI of a particular strategic (investment decision) or managerial (contract negotiations) decision justifies the decision outcome. The logic behind the introduction of the risk-factor is that risk adverse LNGAgents are satisfied with a lower ROI than risk prone LNGAgents. Accordingly the risk-factor is determined by amongst other things, the availability of LNG alternatives and the LNGAgents credit level. Related to the variation in LNGAgents is a variation in trade preferences. While the adopted model is solved in a stationary environment where the proportions of firms is constant, it is also solved in four predetermined market structures or regimes:

- Regime 1, LNG agents search for a partner first before they invest in the LNG project and continue to search if this partnership turns out to be a poor match.
- Regime 2, LNG agents search for a partner first before they invest in the LNG project but are content to stay in a partnership that turns out to be a poor match.

18 Let the cost of moving LNG between two locations that are a distance $d$ apart be $c=ad$ and suppose that the rents are given by $u=u_0 – ad$. If we define a good match to be one that yields rent greater than or equal to $u_0$, the maximum distance that yields a good match is $(u – u_0)/a$. Thus the probability of a good match is given by the ratio of the area that would yield a good match to the total area yielding positive surplus (which is the only place a firm would look for a potential partner). For a constant $(u_0-u)$, this ratio of areas would vary with $(1/a)^2$. 

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• Regime 3, LNG agents make the investment in the LNG project before they have formed a partnership and will continue to search if this partnership turns out to be a poor match.
• Regime 4, LNG agents make the investment in the LNG project before they have formed a partnership and are content to stay in a partnership that turns out to be a poor match.

Note that this categorization implies that firms that are content after a poor match (state 4) are non-existent in the stationary market outcome of regime 1 and 3, and likewise that firms that search for a suitable partnership before investing (state 1) are non-existent in regime 3 and 4. Furthermore there are no firms with a partnership in place that continue to search (state 3) in regime 2 and 4, and finally that there are no firms that invest before they have a partnership in place in regime 1 and 2. This predetermined exclusion of certain trade strategies is not applicable in a model that seeks to uncover (as opposed to predetermine) the emergent behavior of the LNG market. It is more valuable to assess the perceived market transition in a LNG market that is free of such artificial constraints and one that allows the LNGAgent, as the owner of the LNGProject, to freely select its preferred trade strategy. The LNG-model therefore allows different trade strategies to coexist.

With the differences between the adopted and adjusted model of contacting clarified it is time to assess how these differences change the expected values and search times of the LNGProjects.

### 6.2.3 LNG-Model Parameter Settings & Desired Results

The model variables or parameters that impact the strategic and managerial decisions of the LNG Agent with regards to the transition of their LNG Projects are discussed here. For ease of later reference, Table 16 provides an overview of the model variables or parameters and their definitions. These variables are adopted from Brito (2007) and adjusted to the specific needs of the LNG-model.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$i$</td>
<td>The state of the LNGProject, $i = 1, 2, 3, 4, 5, 6$</td>
</tr>
<tr>
<td>$i = 1$</td>
<td>The LNGProject is not yet invested in and need a partner first</td>
</tr>
<tr>
<td>$i = 2$</td>
<td>The LNGProject is invested in but has no partner yet</td>
</tr>
<tr>
<td>$i = 3$</td>
<td>The LNGProject is in a poor match and searching</td>
</tr>
<tr>
<td>$i = 4$</td>
<td>The LNGProject is in a poor match and is not searching</td>
</tr>
<tr>
<td>$i = 5$</td>
<td>The LNGProject is in a good match</td>
</tr>
<tr>
<td>$i = 6$</td>
<td>The LNGProject is part of a complete value-chain, but only has one contract</td>
</tr>
<tr>
<td>$X_i$</td>
<td>Number of LNGProjects of state $i$</td>
</tr>
<tr>
<td>$V_i$</td>
<td>Expected value of a LNGProject in state $i$</td>
</tr>
<tr>
<td>$T_i$</td>
<td>Expected time that an LNGAgent searches before forming a partnership for LNGProject in state $i$</td>
</tr>
<tr>
<td>$K$</td>
<td>Present value of the LNGProject investment cost</td>
</tr>
<tr>
<td>Type</td>
<td>The type of the LNGProject</td>
</tr>
<tr>
<td>Type A</td>
<td>The LNGProject is a liquefaction plant</td>
</tr>
<tr>
<td>Type B</td>
<td>The LNGProject is a LNG tanker</td>
</tr>
<tr>
<td>Type C</td>
<td>The LNGProject is a regasification plant</td>
</tr>
<tr>
<td>$c$</td>
<td>Per period explicit cost of searching for a partnership</td>
</tr>
<tr>
<td>$r$</td>
<td>Real interest rate per unit of time</td>
</tr>
<tr>
<td>$u_1$</td>
<td>Per LNGProject surplus per unit of time for LNGProjects in a good match</td>
</tr>
<tr>
<td>$u_2$</td>
<td>Per LNGProject surplus per unit of time for LNGProjects in a poor match</td>
</tr>
<tr>
<td>$u_3$</td>
<td>Per LNGProject surplus per unit of time for LNGProject that are trading in the spot market</td>
</tr>
<tr>
<td>$p$</td>
<td>Probability that a random match will be good</td>
</tr>
<tr>
<td>$a$</td>
<td>Probability of meeting a specific potential partner per period</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Per period rate of partnership dissolution for exogenous reasons</td>
</tr>
<tr>
<td>$x_0$</td>
<td>Number of LNGProjects to the market per period</td>
</tr>
</tbody>
</table>

Table 16: Model Parameters (Brito 2007).

The number of LNGProjects in each state is expressed through the variable $X_i$ while $V_i$ refers to the expected value of each state and $T_i$ to the expected time that an LNGProject owner (e.g. the LNGAgent) must search before forming a partnership. Once a partnership is formed the probability of it being a good match is $p$ while the probability of a poor match is $(1-p)$. Whilst searching for a partner the LNG Agent incurs an explicit cost $c$ per unit of time and since no revenues are incurred
during this search process the costs of postponing a partnership are dependent on the interest rate $r$ and the required initial capital investment $K$. While the quality of a match is most accurately represented by a continuum, this study assumes that there are only two types of matches good ones and poor ones. A good match obviously returns a higher surplus, $2u_1$, to both partner per unit of time than a poor match, $2u_2$, which is expressed by the fact that $u_1 > u_2$. The surplus of such a partnership is evenly divided by both partners and is allowed to accrue over time. As is already discussed in (§6.2.1) the model assumes that the probability of meeting per time unit $a$, or potentially matching, a specific designated partner is independent of the number of other potential partners. Finally, there is the possibility that a partnership is dissolved through exogenous reasons (force majeure) which causes both partners to exit the market. This rate of dissolution per unit of time is expressed in $\phi$.

Solving the stylized model of contracting for a particular parameter setting provides insights into the optimal market structure. This is obtained through a comparison between the expected value of LNGProjects in state 1 (search before investing) and state 2 (invest before searching). The outcome of this comparison shows which of the two strategies prevails, and accordingly if the Traditional LNG market structure remains dominant or its Global oriented counterpart. After the optimal market structure has been identified it is time to assess whether or not the optimal market structure is also the equilibrium outcome of the model. This depends on the relative value of LNGProjects that are in state 4 (content with a poor match) and those of state 3 (continue to search in a poor match). If the expected value of state 4 firms exceeds that of state 3 firms this means that the expected value of staying in a poor match exceeds that of being in a poor match whilst continuing to search and thus that the optimal market structure is also the equilibrium outcome. If however the expected value of state 3 firms exceeds that of state 4 firms this means that the optimal market structure is not the equilibrium outcome.

6.2.4 The Adjusted Stylized Diamond Model of Contracting

In order to exemplify the differences between the adopted and adjusted stylized model of contracting, this section compares and discusses the respective mathematical equations of both. Please note that an overview of all the equations and an explanation can be found in appendix VI.

For LNG Agents that are content with LNG Projects in a poor match (state 4) and those that are in a good match (state 5) no further search occurs. The present value of these states are therefore equal to the surplus of that particular state $t$ periods in the future, multiplied by the probability that the partnership survives this period and integrated over all possible survival intervals. This is also true for the adjusted model of contracting, only the number of possibilities for state 4 and 5 LNGProjects exceeds that of the original. As each LNGProject type can have one or two LNGContracts in place, the number of state 4 and state 5 LNGProjects now amounts to eighteen instead of the original two. LNG Agents that continue to search for their LNG Project in a poor match (state 3) will receive net benefits of the existing partnership during the time that it takes to find a partner $T_3$. From this time onwards however it would receive the net benefits of a good partnership that is formed with another complementary LNGProject with either state 2 or state 3. The probability that the new partnership is with a state 2 or state 3 LNGProject depends on both the number of LNGProjects in state 2 and state 3. While there is only one type of state 3 firm in the original model, there are fifteen possible

\[\text{Total number of possibilities for state 2 LNGProjects thus equals 18.}\]

\[\text{Calculation of the number of possibilities for value-chain seize 2: 3 Types of LNGProjects } \times \text{2 possible states (4 or 5)} \times \text{1 contract } = \text{6 possibilities}\]

\[\text{Calculation of the number of possibilities for value-chain seize 3: 3 Types of LNGProjects } \times \text{2 possible states (4 or 5)} \times \text{2 contracts } = \text{12 possibilities}\]

\[\text{Calculation of the number of possibilities for a state 3 LNGProject } = \text{12 + the LNGProject arrangement in which both partnerships are of state 3 = 15 possibilities.}\]

19 “The equilibrium need not to be Pareto optimal, however, since the search process exhibits an externality. A decision to stop searching decreases the number of potential partners for other firms, and increases the time it takes them to make a match. The gains to firms forming a partnership might be more than offset by the losses borne by others.” Brito, D. L., Hartley, P.R. (2007). “Expectations and the Evolving World Gas Market.” The Energy Journal 28(1).

20 Calculation of the number of possibilities for value-chain seize 2: 3 Types of LNGProjects * 2 possible states (4 or 5) * 1 contract = 6 possibilities

Calculation of the number of possibilities for value-chain seize 3: 3 Types of LNGProjects * 2 possible states (4 or 5) * 2 contracts = 12 possibilities

Total number of possibilities for state 2 LNGProjects thus equals 18.

21 Calculation of the number of possibilities: 3 Types of LNGProjects * 1 possible states (3) * 2 contracts * 2 possibilities for a state 3 LNGProject = 12 + the LNGProject arrangement in which both partnerships are of state 3 = 15 possibilities.
LNGProject arrangements that include state 3. The search time for state 3 LNGProjects depends on the total number of projects that are searching and the probability that a given LNGProject meets another complementary LNGProject. Since the only acceptable match for a LNGProject of state 3 is a good one the probability of making a good match is also included in the calculation of $T_3$. As there are fifteen possible LNGProject arrangements that include state 3, the same holds for $T_3$.

LNGProjects in state 2 are a special case in the adopted Diamond model because the equation depends on whether or not it is optimal to continue to search after a poor match or not. The expected search time $T_2$ is the same in both instances and depends on the probability of meeting a complimentary partner $a$ and the probability of success $p$ with another LNGProject in state 2. Because the calculation of LNGProjects in state 2 is more complicated then that of the other states it is discussed here. When search is not optimal after making a poor match the expected value for LNGProjects in state 2 is determined by the probability $p$ on success (and the probability $p-1$ on failure) and the expected value of the newly created state 5 (and state 4) partnership. The sum of both needs to be multiplied by the probability that the partnership survives period $T_2$. Finally, the costs of searching $c$ and interest payments $r$ need to be subtracted from the expected payoffs and are partially offset by the ROI from the spot trade $u_3$ (Figure 57). Note that in accordance with Brito (2007) $u_3$ is not allowed to let $V_2>V_3$ as this would fundamentally change the set of equations. “It also may be realistic to assume. In particular, it may be much more risky to rely upon the spot market for all of one’s customers or suppliers. The certainty equivalent revenue associated with spot market purchases may therefore be less than the revenue associated with contracted cash flows even if the two revenues streams have the same expected value” (Brito 2007)

$$v_2 = e^{-rT_2} \times \frac{pu_1}{r+\delta} + \frac{(1-p)u_2}{r+\delta} - (c - u_3) \times \frac{1-e^{-rT_2}}{r}$$

Figure 57: Equation for LNGProjects in State 2 when Search is Not Optimal.

If however search is optimal after making a poor match the expected value for LNGProjects in state 2 becomes more complicated (Figure 58). In addition to meeting another LNGProject in state 2 it is now also possible to come across a LNGProject in state 3. The expected value of state 2 is therefore dependent on the probability on success and failure for two LNGProjects in state 2 with the related values for the new partnership $V_3$ or $V_5$. LNGProjects in state 2 however have an additional potential partner in LNGProjects in state 3. Since the only acceptable match with such an LNGProject is a good one the probability on success is dependent on the number of state 2 and state 3 LNGProjects. Finally, the costs of searching $c$ and interest payments $r$ need to be subtracted from the expected payoffs. Thus the expected value for LNGProjects in state 2 becomes:

$$v_2 \times (e^{-rT_2} - \frac{px_3}{x_2 + x_3 - 1}) + v_3 \times \frac{p - x_2 + 1}{x_2 + x_3 - 1} = \frac{(c - u_3) \times (1 - e^{-rT_2})}{r} + \frac{pu_1}{r+\delta}$$

Figure 58: Equation for LNGProjects in State 2 when Search is Optimal.

The introduction of additional LNGProject types to the LNG-model proves to have quite complex consequences for the calculation of the expected values for LNGProjects of state 2 and 3 in a market where it is optimal to continue to search after a poor match. Instead of solving the Diamond model with two equations, it now needs to be solved for each LNGProject type of state 2. Added to this is the fact that LNGProjects in state 2 are now in a position to meet a larger number of LNGProjects of state 3. Compared with the optimization problem of the original model that consists of two equations, the adjusted model is faced with an optimization problem of twenty-one equations. In addition to this increased complexity the LNG-model needs to calculate the expected values for LNGProjects in state 2 and state 3 for a market where continuing to search is optimal for some LNGProjects and not optimal for others. For a complete overview for the mathematics of the adjusted model of contracting and the implementation in Maple 12, the reader is referred to appendix VI.

Finally there are the LNGProjects in state 1, the owners of which opt to search for a partner before any investments is made in the LNGProject. The search for a corresponding LNGProject is limited to

Total number of possibilities for state 3 LNGProjects thus equals 15.
other complementary LNGProjects of state 1 and \( T_T \) is thus dependent on the number of LNGProjects in state 1 and the probability of meeting such a LNGProject \( a \). The match between two LNGProjects in state 1 either results in a good partnership, in which case the value of the new project arrangement equals the expected value of the state 5 partnership minus the required investment \( K \), or in a poor partnership. When this is true, the value of the new partnership depends on whether or not it is optimal to search or not. The surplus from a poor match thus becomes the highest expected value of a state 3 or 4 partnership minus the required investment \( K \).

With the adjusted model of contracting in place it is time to proceed with the actions of the LNGAgent.

### 6.3 The LNG Agent

The LNG Agent is the central component of the LNG-model and inhibits (to varying degrees) all of the agent properties that are listed by Schieritz and Milling (2007) in Table 12 (§5.1.2). The LNG Agent allows this study to assess the development of the LNG market, or in keeping with the metaphor of Schieritz and Milling (2007), the LNG Agent represents the tree that is used to model the forest which in this study represents the LNG market. The sequence of actions that are executed by the LNGAgent are discussed first (§6.3.1) before proceeding with a more detailed overview of the strategic (§6.3.2), managerial (§6.3.3), and operational (§6.3.4) decisions.

#### 6.3.1 Sequence of LNG Agents Actions

The focus of this LNG-model are the strategic and managerial decisions of the LNG Agent (§5.3.1, §6.2.1). Accordingly these two decisions are at the center of attention of the LNG-model. The investment decision and trade decisions are made on a strategic level, while the partnership search process and contract negotiations are made on a managerial level. The operational decisions of the LNG Agent are limited to the control of the LNG Project. The actions of the LNG Agent and their interdependency with the LNG Project, LNG Scenario, LNG Contract, and Diamond model are illustrated in Figure 59.
The first decision of the LNGAgent is whether or not to invest in new LNGProject or not. This decision is based on both the LNG demand and supply balance and the character of the LNGAgent. The initial investment decision results in the selection of the LNGProject (§5.3.5). The LNG-model is capable of distinguishing between investments in liquefaction, shipping, and regasification capacity (LNG Project type A, B, and C). Once the LNGProject type is decided upon it is time to determine the initial trade strategy for the new LNGProject. This is referred to as the trade decision of the LNGAgent, and it is here that the timing of investment is established. The LNG Project state after the trade decision is used on a managerial level to decide if the LNG Projects owner continues to search process for an improved partnership. Pending on the current state of the LNGProject and the running contracts of the LNG Agent it might be necessary to find a complimentary LNGProject to ensure that the LNG value-chain is complete. Alternatively, the LNGAgent might find that the current performance of the LNG Project is below expectations and that it might be interesting to look at alternative LNG Project partners. Once a potential partner has been identified it is time to enter the contract negotiations. This process involves the consideration, selection, and activation of new partnership arrangements and the signing of a new, and possible breaching of the old, LNG Contract. With the revised partnership in place, the LNG Agent needs to operate the LNG Project and generate the LNG flows of that are set in the LNG Contract and make the corresponding payments. The resulting credit level of the LNGAgent and the changed market conditions are subsequently used as the input for a new sequence of LNGAgents’ actions.

With the sequence of actions discussed it is time to look at the strategic investment and trade decisions in more detail.

6.3.2 Strategic Investment & Trade Decision

The first action of the LNG Agent concerns the investment decision which is based on the current demand and supply balance of LNG infrastructure capacity. The LNG Agent that is allowed to make an
investment decision is randomly selected from the LNG Agents that are active on the market. This randomness is introduced to ensure that there is no preferential treatment among the LNG Agents, and hence guarantees a unbiased investment climate. The same holds for the type of LNG Project that is evaluated by the LNG Agent and the creation of LNG Agents themselves. If the LNG Agent decides that it want to initiate a new LNG Project, it evaluates the LNG Project through the Diamond model that generates the expected ROI of not initiating the LNG Project (state 0) or initiating the LNG Project in state 1 or state 2 (Table 14). As this investigation assumes that LNG Agents behave rationally, the trade strategy that provides the highest ROI is selected. The LNG Project is assigned the correct state before the LNG Agent turns to its managerial decisions.

6.3.3. Managerial Contract Negotiations & Partnership Search Process

The managerial decisions of the LNG Agent involve the partnership search process and the contract negotiations for LNG Projects in state 1, 2, and 3. The LNG Agent can earn a ROI from its LNG Project if it becomes part of a complete LNG value-chain or by participating on the LNG spot market where LNG Projects of an incomplete value-chain trade with one another. Both options require the LNG Agent to search the market for potential partners.

If the LNG Agent owns a LNG Project that is currently without a partner or in a unsatisfactory partnership, it looks for partners on the LNG market by sending out a request with its LNG Project details. Information about the LNG Project type and its current state are used by the LNG Agents that receive this request to evaluate the offer in the Diamond model and determine the ROI of the newly proposed partnership. The input for this calculation consists of the LNG Project details of the initiator and responding LNG Agent. The current ROI of the initiators LNG Project is unknown to the responding LNG Agent that estimates it based on the LNG Project type and state. This information is added to the knowledge of the responding LNG Agent about its own LNG Project, including the current ROI, and allows it to project the value of the new, to be formed, partnership. It is conceivable that the responding LNG Project is already tied to an existing contract. If this proves to be the case it needs to determine the compensation value of the, to be breached, contract with the former partner. The responding LNG Agent now has the required information in place to decide if it wants to return a positive response to the request of the searching LNG Agent. If the ROI of the to-be formed partnership exceeds the existing one with a certain margin the response will be positive and the responding LNG Agent will send the LNG Project type and state back to the initiating LNG Agent.

As the request is not directed to any particular LNG Agent, it is likely that the initiating LNG Agent receives multiple responses. It evaluates this in the same way as the responding LNG Agents, through the Diamond model. The only difference being the information asymmetry between the two about their own LNG Projects. The response with the highest ROI is selected and if it exceeds the current value with a certain margin, the new partnership needs to be activated and the old ones breached.

6.3.4 Operational Payments & LNG Project Operations

The contract activation consists of two steps, the first is to determine the actual market value of the newly formed partnership. Note that unlike the estimates of the ROI for the new to-be formed partnership by both the initiating and responding LNG Agent that was based on incomplete information, the actual value of the new partnership is determined on the LNG market. The Diamond model is again used to calculate the ROI of the new partnership, only this time with complete information about the participating LNG Projects.

The second step is to determine the actual compensation fee of the contracts that are breached during the contract activation. This requires the LNG Agent to compare the ROI of the old to-be breached partnership with that of the remaining partnership without the LNG Project that causes the breach. The difference between both LNG Project arrangements equals the compensation fee that needs to be paid to the former partners.

With the new partnerships in place it is time to bring the LNG Project arrangement into practice. It is assumed that the exchange of goods and services that are specified in the LNG Contract are followed by the LNG Project. For now these include the LNG and money flows that are generated. The contract activation changes the market conditions in which the next LNG Agent needs to make its decisions.
This is a fundamental characteristic of the LNG-model as allows this investigation to generate knowledge and insights about the development trajectory and transition of the LNG market.

6.4 The LNG Project

The LNG Project characteristics include its type, status, state, and ownership (§5.3.3). The LNG-model incorporates three types of LNG Projects, liquefaction plants, LNG tankers, and regasification terminals which take 12 months to be constructed. The LNG-model uses normalized capital costs and returns for the performance of the LNG Projects and there are no differences between the operational capacities of the LNG Projects. The LNG Project details are provided for in Table 17.

<table>
<thead>
<tr>
<th>LNG Project</th>
<th>Liquefaction Plant</th>
<th>LNG Tanker</th>
<th>Regasification Terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment costs, $K$</td>
<td>1.09 (55%)</td>
<td>0.54 (27%)</td>
<td>0.36 (18%)</td>
</tr>
<tr>
<td>Capacity</td>
<td>6.90 [BCM] (42%)</td>
<td>1.40 [BCM]</td>
<td>10 [BCM] (57%)</td>
</tr>
<tr>
<td>Lifetime</td>
<td>20 years</td>
<td>20 years</td>
<td>20 years</td>
</tr>
<tr>
<td>Netback good match, $u_1$</td>
<td>0.55 (50% * $K$)</td>
<td>0.27 (50% * $K$)</td>
<td>0.18 (50% * $K$)</td>
</tr>
<tr>
<td>Netback poor match, $u_2$</td>
<td>0.16 (15% * $K$)</td>
<td>0.08 (15% * $K$)</td>
<td>0.05 (15% * $K$)</td>
</tr>
</tbody>
</table>

Table 17: Normalized Starting Assumptions.

Please note that the values of each of the LNG Projects rest on the following assumptions:

- The investment costs $K$ are derived from a variety of sources that include (Platt 2005; EIA 2006; PeruPetro 2009), averaged and multiplied by the value of the normalized LNG project of Brito and Hartley (2007).
- As the capacity of the liquefaction plants and regasification terminals refer to the annual output capacity in million tons per year the same unit of measure needs to be acquired for the LNG tankers. In order to do so the average duration of a voyage was calculated which showed that on average 17.5 days were required to make the journey from the liquefaction plant to the regasification terminal. As the LNG tanker returns makes the return journey empty, the duration of a return trip is 2*17.5 = 35 days. This implies that 365/35 = 10.42 voyages a year can be made by a LNG tanker, and hence 10.42*0.0085% = 8.9% or roughly 1/5 (1.15/5.52) of the output of a liquefaction plant can be accounted for by one LNG tanker.
- Since the scenario analysis of chapter 4 expresses the annual increase of global LNG infrastructure in [BCM/year] the same unit of measure needs to be obtained for the LNG projects of Table 17. In order to convert [million tons/year] to [BCM/year] this needs to be multiplied by 1.38 according to the BP (2007).
- The default relation between the investment costs $K$ and the netback of both a good match and a poor match are derived from Brito and Hartley.
- Technological innovation results in the introduction of floating regasification and liquefaction during the simulation run. For detailed discussion of these technologies the reader is referred to (§2.2.2). The main differences between these innovative technologies for the LNG-model is their construction time. The main difference between floating regasification and liquefaction and their onshore counterparts is the construction time.

6.5 The LNG Scenario

The LNG-model is developed to assess the impact of the key market drivers and inhibitors (§3.5) on the strategic and managerial decisions of the LNG Agent and the emanating LNG market development. The imminent key market drivers and inhibitors of the LNG spot market are incorporated in the LNG-model through the LNG Scenario. First, the integration of the market drivers and the parameters of the LNG-model is discussed (§6.4.1), after which an overview of the scenario space is provided for (§6.4.2).
6. LNG Spot Market Simulation

6.5.1 Integration of the Key Market Drivers in the LNG-Model Scenario

The categorization of economic, technical, and institutional drivers and inhibitors that was introduced in (§3.5) is continued here to integrate the key market drivers with the model parameters (Table 16, §6.2.3).

Economic Scenario Affected Parameters

The LNG demand in the LNG-model follows the demand estimates of the scenario analysis (§4.2). Considering the assumption that the global demand for LNG is set to increase (§3.3.3), and the LNG-model is demand driven this implies that the global LNG infrastructure capacity or the number of LNG Projects will increase. The scenario-logic (§4.2.1) shows that the LNG demand can be modest, neutral, and surging. The capital costs of the LNG Projects are closely related to the risks of initiating a new project. Economies of scale play an important part in the falling capital costs and are resembled in the LNG-model by parameter $K$. Finally, there is the ROI for the different trade arrangements: a good partnership $u_1$, a poor partnership $u_2$, and the surplus from trading through the spot market $u_3$. It will be interesting to assess the impact of varying ROI rates on the strategic and managerial decisions. Note that although the surplus of the spot market is a product of the LNG-model itself, a starting value is required to model the surplus that LNGProjects receive from the existing spot market.

Technical Scenario Affected Parameters

In addition to varying the capacities of the LNG Projects, the technical scenario space also includes another axis of the scenario logic: the speed of technological innovations. This implies that the availability of innovative technologies to the LNG Agents is determined exogenously. This contrasts with the benefit of economies of scale that are determined by the adoption rate of LNG Agents themselves. LNG infrastructure is subject to continuous technological progress and innovation. The LNG-model allows floating regasification and liquefaction to become available to the LNG Agents (§2.2) and varies the moment at which the LNG Agents are allowed to invest in them. While floating regasification can be used to shorten the construction time by circumventing permitting issues and increase the flexibility of the LNG buyer, floating liquefaction is mainly used to gain access to remote natural gas reserves and to protect the liquefaction process from mainland disturbances. The LNG-model varies the capital costs of these investments, the construction time, and capacity.

Institutional Scenario Affected Parameters

The duration of the long-term SPA is believed to impact the trade decision of the LNG Agent as it impairs the trade flexibility of the LNG Agents and affects the costs of a breached contract. Changes in the contract duration of the partnership between different LNG Agents are reflected in the LNG-model through different values of $\varphi$. This allows the LNG-model to assess the impact of a shortening SPA contract length on its strategic and managerial decisions. Secondly, it is conceivable to assume different meeting probabilities for LNG Projects that are already in a partnership and those that are without. The probability of meeting in the LNG-model is therefore dependent on the current LNGProject state (for example an existing partnership between a liquefaction and regasification plant has a higher probability of meeting a LNG tanker then a regasification plant on its own).

Table 18 summarizes the key economic, technical, and institutional drivers that are included in the LNG-model and the parameters that are varied to simulate these changes.

<table>
<thead>
<tr>
<th>Market Drivers</th>
<th>Affected Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic drivers and inhibitors</td>
<td></td>
</tr>
<tr>
<td>LNG Demand</td>
<td>Number of LNG Projects</td>
</tr>
<tr>
<td>Capital costs</td>
<td>$K$</td>
</tr>
<tr>
<td>ROI</td>
<td>$u_1$, $u_2$, $u_3$</td>
</tr>
<tr>
<td>Technical drivers and inhibitors</td>
<td></td>
</tr>
<tr>
<td>Innovative technologies</td>
<td>Availability of floating regasification and liquefaction</td>
</tr>
<tr>
<td>Institutional drivers and inhibitors</td>
<td></td>
</tr>
<tr>
<td>Contract duration</td>
<td>$\varphi$</td>
</tr>
<tr>
<td>Probability of meeting</td>
<td>$a$</td>
</tr>
</tbody>
</table>

Table 18: ‘Translation’ of Key Drivers to Model Parameters.
With each of the marker drivers assigned to a specific parameter it is time to explore the scenario space of the LNG-model.

### 6.5.2 LNG Scenario Parameter Settings

The scenario space for the LNG-model consists of the following parameter settings. As this investigation is looking to assess the impact of the imminent key market drivers on the strategic and managerial decisions of the LNG Agent, it has opted to position the parameter settings in favor of the long-term SPA trade or of its alternative the short-term MSA trade.

#### Economic Scenario Parameters Settings

If the LNG demand increase is neutral this corresponds to a demand increase of 6.4 percent per year (§4.2.2) over the course of the simulation. The modest LNG demand relates to a 10% decrease of the relative growth rate of the nil-scenario, whereas a surging LNG demand relates to a 20% increase of this growth rate. This results in a 5.7 percent per year increase of the LNG demand in the modest setting and a 7.7 percent per year increase when the LNG demand is surging. The capital costs of the LNG Projects are sensitive to economy of scale effects and the expansion of the global LNG infrastructure or not. If the LNG-model assumes that LNG Agents do not benefit from economy of scale effects, the capital investment $K$ is independent of the number of LNG Projects around, and hence remains constant over time. If however economy of scale effects are included in the LNG-model, the capital costs are related to the number of LNG Projects around. The equation for the capital costs in the LNG-model allows $K$ of a certain LNG Project type to decrease with 25% of the initial value when there are a hundred LNGProjects of this type available on the market. These effects correspond to the economy of scale effects of the LNG infrastructure in §2.2.1. The final economic parameter concerns the ROI of the LNG Project in relation to the selected trade strategy. Brito and Hartley (2007) assume that a good ROI of a LNG Project equals 50 percent of the present (u1) value of the infrastructure investment $K$, while a poor match equals 15 percent (u2), and the spot market 5 percent (u3). These ROI are adjusted by 10 percent in favor of the long-term trade (u1 and u2), or in favor of the short-term trade (u3).

#### Technical Scenario Parameters Settings

Technological innovation is incorporated in the LNG-model through the introduction of floating liquefaction and regasification (§2.2.2). The first possibility is that both technologies become available as investment opportunities after 5 years after the start of the simulation. Alternatively it takes 20 years before these technologies become available for the LNG Agents.

#### Institutional Scenario Parameters Settings

The default contract duration of a long-term contracts is set to 10 and 20 years respectively. As a shorter contract duration lower the costs of a contract breach, it is expected that a default contract duration of 10 years creates a more dynamic LNG trade than its counterpart of 20 years. Secondly the default probability of meeting from Brito and Hartley (2007) is compared with a meeting probability that is dependent on the current LNG Project state as LNG Projects that are part of an existing LNG value-chain form a better match than single LNG Projects.

An overview of the different parameter settings is provided for in Table 19.

<table>
<thead>
<tr>
<th>Market Drivers</th>
<th>SPA Favored Parameter Settings</th>
<th>MSA Favored Parameter Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Economic drivers and inhibitors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LNG Demand</td>
<td>+ 5.7 [%/year]</td>
<td>+ 7.7 [%/year]</td>
</tr>
<tr>
<td>Capital costs</td>
<td>Endogenous modifier off</td>
<td>Endogenous modifier on</td>
</tr>
<tr>
<td>ROI</td>
<td>$u_1 = 0.55, u_2 = 0.175, u_3 = 0.0225$</td>
<td>$u_1 = 0.45, u_2 = 0.135, u_3 = 0.0275$</td>
</tr>
<tr>
<td><strong>Technical drivers and inhibitors</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

-111-
Availability of Innovative technologies
20 years 5 years

Institutional drivers and inhibitors

<table>
<thead>
<tr>
<th>Parameter</th>
<th>20 years</th>
<th>10 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contract duration</td>
<td>Value-chain 1, a = 0.002</td>
<td>Value-chain 1, a = 0.002</td>
</tr>
<tr>
<td>Probability of meeting</td>
<td>Value-chain 2, a = 0.002</td>
<td>Value-chain 2, a = 0.006</td>
</tr>
<tr>
<td></td>
<td>Value-chain 3, a = 0.002</td>
<td>Value-chain 3, a = 0.006</td>
</tr>
</tbody>
</table>

Table 19: Overview of the LNG-model Parameter Settings.

The LNG-model is now ready to for the simulation run, the results of which are discussed in the next chapter.

6.6 Preliminary Conclusions of the LNG-model Development

The conceptual Agent-Based LNG Model of chapter 5 is integrated with the existing Agent-based modeling knowledge base of the Energy & Industry Group at the Technology, Policy and Management faculty of Delft University of Technology. In order to expand the mathematical capabilities of the model, the mathematical software package Maple 12 was added to the existing software tools for ABM.

This investigation acknowledges that a transition of the LNG market is hard to realize through changes in the exogenous market drivers alone (§5.3.5) and argues that expectations about the future development shape the investment decision as well. In order to enable LNG Agents to make strategic and managerial decisions regarding the trade of LNG and assess the impact of key imminent market drivers and expectations on these decisions, a stylized model of contracting which is based on the ideas of Diamond (1984), Diamond and Maskin (1979; 1980), and their adoption by Brito and Hartley (2007) was implemented. The possible shift in the timing of investment that emanates from these decisions is considered to be the most important indicator for a transition in the LNG market and is decided upon during the strategic trade decision of the LNG Agent.

As the stylized model of contracting from Brito and Hartley (2007) proved unable to satisfy the research objectives of this investigation, it was adjusted accordingly. The main issues with the adopted model of contracting was that its rather restricted and static assumptions did not meet those of the bottom-up ABM paradigm. With the adjusted model of contacting in place, the center of attention turned to the operationalization of the LNG Agent, LNG Project, and LNG Scenario. The LNG Agent is the central component of the LNG-model and it is here that the strategic, managerial, and operational decisions are made. The interaction between the LNG Agent and the other components of the LNG-model, especially the adjusted Diamond model, shows that the decisions of the LNG Agent and the ruling market conditions of the LNG market are interrelated.

The final step before the actual simulation run is to relate the previously identified key market drivers and inhibitors with the relevant modeling parameters. The scenario space thus created is able to assess the impact of a changing LNG demand, economies of scale, ROI of different trading models, introduction of floating liquefaction and regasification, different contract durations, and a different probability of meeting (§6.5). The simulation results of the 64 unique scenario settings are presented in the next chapter.
7. Simulation Results; Signaling the Arrival of the LNG Spot Market
7. Simulation Results and the LNG Spot Market

The purpose of this chapter is to show how the LNG-model enables this research to explore the impact of the key imminent market drivers and inhibitors on the strategic and managerial decision making of the LNG Agents and the emanating market structure of the LNG market. The simulation length of the reported runs is 25 years and all 64 LNG Scenarios are run 5 times to minimize the noise of the simulation. Before the actual presentation results, the desired modeling results and running practicalities are discussed (§7.1). Next, the accumulative simulation results of the parameter space are presented (§7.2), after which specific LNG Scenario settings are explored (§7.3). Finally, an answer is formulated to the fifth sub-question of this investigation (§7.4).

7.1 Simulation Practicalities

This section starts of with a discussion of the desired modeling results (§7.1.1). As there are numerous way of presenting the simulation results the selected presentation technique of the modeling results is presented next (§7.1.2).

7.1.1 Desired Modeling Results

This study has consistently argued (§3.5, §5.3.1) that insights in the strategic and managerial decisions of the LNG Agent are key to understanding the degree and conditions under which a spot market for LNG materializes. The timing of investment is considered to be the most important indicator for a transition in the LNG market (§6.2.1) as it determines how new LNG Projects are initiated. While the traditional LNG market required firms to have a long-term SPA in place before investing in LNG infrastructure, the alternate or global LNG market envisions firms to invest in LNG infrastructure before such an agreement is formed. This implies that investments are made without having a complete coverage of the anticipated output in place, and hence that a substantial part of the LNG trade needs to be conducted on a short-term MSA basis. Table 14 provides an overview of the different trade strategies that each LNG Agent has at its disposal (a more detailed discussion of which can be found in §6.2.1). The expected value or ROI of a LNG Project in a certain state provides the LNG Agent with the information that is used to make its decisions.

When a LNG Agents considers investing in a new LNG Project it has three options at its disposal. If the ROI of the LNG Project does not exceed the required threshold of the LNG Agent the investment is cancelled. Note that the risk attitude of the LNG Agents and the related minimum ROI differ, thereby guaranteeing the uniqueness of each LNG Agent. When the ROI exceeds the minimum ROI requirement of the LNG Agent it can initiate the LNG Project in two ways. The first is to search for a partnering LNG Project first and invest in the LNG Project once the partnership with its owner is in place. The second to invest in the LNG Project before the formation of a partnership (§6.2.1). In the LNG-model this strategic decision is made by comparing the ROI of each of the respective trade strategies and selecting the highest value. If the LNG Agent has opted to initiate its LNG Project in state 1, it can find partnering LNG Projects in the bilateral long-term contract market. The resulting partnership can turn out to be a good and a poor match with complimentary LNG Projects that are also initiated in state 1. Alternatively, the LNG Agent can decide to initiate the LNG Project in state 2, and find a partner in the short-term spot market with LNG Projects of the same state or LNG Projects that are part of an existing LNG value-chain but on the look out for a different partner. The resulting partnership can again be either good or poor (Figure 55, §6.2.1).

LNG Project State | Definition
------------------|--------------------------------------------------
0 | LNG Agents needs to decide if it wants to initiate a new LNG Project
1 | LNG Agent searches for a partner without investing in a LNG Project
2 | LNG Agent searches without a partner after investing in a LNG Project
3 | LNG Agent has a LNG Project in a poor match and continuous to search
4 | LNG Agent has a LNG Project in a poor match but is not searching
5 | LNG Agent has a LNG Project in a good match

Table 14: Possible LNG Project States.
7. Simulation Results; Signaling the Arrival of the LNG Spot Market

Once a partnership is good it can only be dissolved by force majeure and the LNG Project turns to state 5. If however, the partnership is a poor one the LNG Agent faces the decision to continue to search for a different partnership (state 3) at a certain costs per time, or be content with the poor partnership (state 4) and receive the corresponding ROI. Whether or not the LNG Agents continues to search in a poor match has important implications for the number of potential partners in the short-term spot market and thus to the attractiveness of initiating LNG Projects in state 2. This explains why the LNG-model also looks at the contract negotiation process on the managerial level as it allows for the identification of the moment in which LNG Agents decide to breach existing contracts in favor of new ones through the short-term spot market. The importance of the contract negotiations become apparent in the trade decision of the LNG Agent. If the contract negotiation process is relatively easy and inexpensive this reduces the risks of initiating LNG Projects without a partner (i.e. state 2), while timely and expensive contract negotiations make it more attractive to delay the investment of a new LNG Project until after the formation of a partnership (i.e. state 1) (§6.2.3).

With the desired results in place, it is time to look at how the results of the LNG-model simulation can best be assessed and presented.

7.1.2 Presentation of the Simulation Results

This investigation opts to present the simulation results in a boxplot as this presentation technique allows for a quick examination of the simulation results and is “a convenient way of graphically depicting groups of numerical data through their five-number summary” (Wikipedia 2009)). Figure 60 shows how the sample minimum, maximum, median, and the lower and the upper quartile are related in a boxplot. The median or middle value is at the center of the boxplot (i.e. the black line) and represents the observation that separate the highest value from the lowest (i.e. the middle value). The area directly surrounding the median represents the lower and upper quartile of the data. The interquartile range is subsequently used to measure the minimum and maximum of the boxplot which are the 1st and 3rd quartile added to one-and-a-half the interquartile range. As such, the boxplot shows 99.7 percent of the data observations. Any observations that are not included in these boundaries are considered to be outliers.

The boxplot consists of a series of data point that are connected to each other. This is illustrated in Figure 61 and shows how the boxplots of the LNG-model simulations are constructed from the different data points of the simulation.
With the presentation technique in place, it is time to commence with the presentation of the simulation results.

### 7.2 Averaged Simulation Results of the Parameter Space

The accumulative simulation results of the LNG models complete parameter space are provided for here. As such, the presented graphs are based on the aggregate data of the simulation (i.e. 320 runs).

Before this investigation turns focus to the timing of investment, it checks whether or not certain prerequisites to the proper functioning of the LNG-model are in place. The first check concerns the introduction of new LNG Projects. As the LNG-model settings assumed equal capacities and capital costs for each type of LNG Project, the number of liquefaction plants, LNG tankers, and regasification terminals should be balanced. Figure 62 illustrates that this is indeed the case as the number of LNG Project of each type (liquefaction plants, LNG tankers, regasification terminals) increase relatively uniform over time. The second check concerns the credit level of the LNG Agent and whether or not this changes over time. Figure 63 illustrates the average capital level of the LNG Agent and shows a steady decline which indicates that the current ROI is not sufficient to recuperate the initial investment. It does however indicate that payments are made and received. The final check concerns the difference in ROI between a good and poor partnership. The green graph represents the ROI of a good partnership which according to the assumptions of the stylized level of contracting (§6.2) must surpass that of a poor partnership which is the maximum of the LNG Project in state 3 (black graph) and state 4 (white graph). During the strategic trade decision of the LNG Agent it compares initiating a new LNG Project in state 1 (blue graph Figure 64) and state 2 (yellow graph Figure 64). The overall market value of both strategies change over time and it can be seen that there is a downward trend for initiating LNG Projects in state 1, and an upward trend for initiating LNG Projects in state 2.

In the initial years the expected value of state 1 LNG Projects ranges from 1.9 to 3.3 (Figure 65), while the expected value of state 2 LNG Projects is substantially lower with a ROI of 1.25 to 1.8 (Figure 66). This corresponds with the expectations as the ROI of a more conservative strategy in a LNG market with a limited number of trading partners seems to be more favorable than the alternative more risk full pursuit of initiating LNG Project with uncovered output. However, as the demand for LNG increases and the global LNG infrastructure expands, the values of state 1 and state 2 start to converge. This is illustrated by the slow decline of the blue graph that represents state 1, and the consistent increase of the yellow graph of state 2. This is an interesting development as it implies that the optimal trade strategy for new LNGProjects might eventually switch from state 1 to state 2. The overlap between the 1	extsuperscript{st} and 3	extsuperscript{rd} quartile (§7.1.2) of both strategies start to occur after 5 years, while the median of both strategies is approximately equal after 25 years. While the initial overlap indicates that the average value of state 2 LNG Projects during the simulation occasionally surpasses that of state 1 LNG Projects, the proximity of the median at the end of the simulation implies that the clear preference for state 1 strategies is no longer present.
Whether or not the optimal trade strategy (e.g. initiating new LNG Projects in state 1 or state 2) also leads to an equilibrium market structure or not depends on the managerial decisions of the LNG Agents. After the LNG Agent has made a poor match it can opt to continue to search for a better partnership (state 3) or be content with the current match (state 4). This decision is based on which of the two LNG Project states generates the highest ROI to its owner. If the averaged expected value of LNG Projects in state 4 exceeds those of state 3, this implies that the majority of LNG Agents will continue to search for an improved partnership, and accordingly that the market will not reach the equilibrium status. At the start of the simulation, LNG value-chains that find themselves in a poor match and continue to search (i.e. state 3, cyan graph, Figure 67) have a lower ROI than those that have stopped searching (i.e. state 4, red graph, Figure 67). It does not take long however before the median of the state 3 strategy surpasses that of slow but steadily declining state 4. This implies that on average, it is more profitable to continue to search after a poor match than it is to stop searching.

As such, LNG Agents are expected to be less reluctant to breach a existing partnerships in favor of a new one than during the start of the simulation. Once a contract has been breached, the breached partner(s) are temporarily out of a complete value-chain and might decide to turn to the spot market to earn a ROI. This makes a LNG market in which searching is favored above non-searching more susceptible to a shift of the timing of investment.

In addition to determining whether or not the LNG market has already reached its market equilibrium, the relative values of state 3 and state 4 LNG Projects determines the equations that are used to calculate the ROI of state 2 LNG Projects (§6.2.4). As the LNG-model allows LNG Agents to freely select their optimal trade strategies it is possible for state 3 and state 4 LNG Projects to coexist in the market place (§6.2.2). This enables this investigation to simultaneously monitor the development of newly initiated LNG Projects in a market where search is optimal and suboptimal and compare averaged values of state 2 LNG Projects. Initially, the value of state 2 LNG Projects in a non-searching market (red graph) surpasses those of a searching market (green graph). However as the market expands, the situation turns and the value of state 2 LNG Projects of a searching market surpass similar LNG Projects in a non-searching market. The importance of this observation becomes apparent when the trend of both graphs are compared. Figure 68 illustrates that the value of state 2 strategies in a searching market increases more rapidly than its non-searching counterpart and thus is a more serious alternative to the commissioning of LNG Projects in state 1.
Figure 63: Averaged Capital Development of the LNG Agents

Figure 64: Expected Value Development of LNG Projects in State 3, 4, and 5.

Figure 65: Expected Value Development of LNG Projects in State 1.
7. Simulation Results; Signaling the Arrival of the LNG Spot Market

Figure 66: Expected Value Development of LNGProjects in State 2.

Figure 67: Expected Value Development of LNGProjects in State 3, and 4.

Figure 68: Expected Value Development of LNGProjects in State 2 in a Searching and Non-Searching Market.
### 7.3 Exploring the LNG Scenarios

Before the individual market drivers of the LNG Scenario (§6.5) are analyzed, this investigation will explore the scenario extremes first. The comparison between the parameter settings of the ‘SPA-favored’ simulations with the ‘MSA-favored’ shows whether or not the scenario space creates significant difference with regards to the timing of investment. The simulation results of the SPA-favored settings (Figure 69) show that LNG Projects that are initiated in state 1 during the start of the simulation offer a better ROI (i.e. median of around 3.3) than LNG Projects of state 2 (i.e. median of around 2.2). Despite a clear converging trend between both graphs there is no overlap between both trade strategies during the simulation. While the initial trade decision in the MSA-favored simulation (Figure 70) also favors the introduction of LNG Projects in state 1 (i.e. median of 1.55) at the expense of state 2 (i.e. median of 1.22), the two strategies converge much faster. The graphs show that the value of the LNG Projects in state 1 and state 2 start to overlap after 10 years. A remarkable difference between the two scenario extremes is to be found in the initial values of new LNG Projects. In the SPA-favored simulation this is almost twice as high as the MSA-favored simulation. Although it is too early to tell which of the imminent key market drivers and inhibitors has the largest impact on the strategic and managerial decisions of the LNG Agents, it is clear that the combined settings of the scenario extremes have a considerable impact.

![Figure 69: Impact of the SPA-favored Extremes on the Expected Value of LNG Projects in State 1 and 2.](image)

![Figure 70: Impact of the MSA-favored Extremes on the Expected Value of LNG Projects in State 1 and 2.](image)
With the ascertainment in place that the LNG Scenario space is able to capture different development trends for the trade strategy of the LNG Agent (i.e. initiating LNG Projects in state 1 versus state 2), it is time to proceed to the impact of the imminent key market drivers and inhibitors on the strategic and managerial decision making.

Whether the yearly LNG demand increase equals 5.7 percent or 7.7 percent does not seem to have a significant impact on the ROI of state 1 and state 2 LNG Projects, and thus on the strategical decisions of the LNG Agent. Both scenario settings create a situation where LNG Projects in state 1 create a higher ROI than those in state 2. The differences between Figure 71 and Figure 72 include the initial rise of the value for state 2 LNG Projects in the market where the LNG demand is modest and the more steep decline afterwards (blue graph Figure 71). The value of state 1 LNG Projects (yellow graphs) develops the same.

The inclusion or exclusion of economies of scale effects in the LNG-model shows clear differences between the ROI of state 1 and state 2 LNG Projects (Figure 73 & Figure 74). Without economies of scale it is clear that initiating LNG Projects in state 1 creates higher ROI than initiating the same project in state 2. The attractiveness of this option however declines over time whereas that of initiating a LNG Project in state 2 increases. This contrasts with the simulation results where economies of scale are taken into consideration. Although the initial difference between the value of state 1 and state 2 LNG Projects remains the same, the value of state 1 LNG Projects declines more rapidly, while the increase of state 2 LNG Projects is more modest. Introducing a different ROI for good, poor and spot market partnerships create substantial differences in the value development of state 1 and state 2 LNG Projects (Figure 75 & Figure 76). If the ROI favors LNG Projects that are part of a LNG value-chain the value of state 1 and state 2 LNG Projects are steadily declining. If on the other hand the ROI favors the ROI of the spot market the value of state 1 LNG Projects steadily declines, albeit with incidental peaks whereas that of state 2 steadily increases.

With regards to the introduction of innovative technologies (i.e. floating liquefaction and regasification) after 5 years or 20 years there are no remarkable differences between the two settings. The declining value curve of LNG Projects in state 1 are converging with those of state 2. Note that these trends are not caused by the adoption of technologies as both are currently neglected by the LNG Agents of the LNG Agents in favor of the conventional LNG Projects (appendix V).

Changing the default contract duration from 20 years to 10 years does not seem to influence the value of newly initiated LNG Projects in the LNG-model. Both parameter settings show the same declining value curve of initiating LNG Projects in state 1 that converge with a steadily increasing value of state 2 LNG Projects (appendix V). Changes in the probability of meeting between LNG Projects that are part of an existing LNG value-chain and those that are modest show that the value of state 1 LNG Projects with a favorable meeting probability for LNG Projects in a value-chain start higher. Both scenario settings however show a converging trend between a gradually declining value of state 1 LNG Projects and rising value of state 2 LNG Projects (appendix V).
7. Simulation Results; Signaling the Arrival of the LNG Spot Market

Figure 71: Impact of a Modest LNG Demand on the Expected Value of LNG Projects in State 1 and 2.

Figure 72: Impact of a Surging LNG Demand on the Expected Value of LNG Projects in State 1 and 2.

Figure 73: Impact of the Exclusion of Economy of Scale on the Expected Value of LNG Projects in State 1 and 2.
7. Simulation Results; Signaling the Arrival of the LNG Spot Market

Figure 74: Impact of the Inclusion of Economy of Scale on the Expected Value of LNG Projects in State 1 and 2.

Figure 75: Impact of a SPA Favored ROI on the Expected Value of LNG Projects in State 1 and 2.

Figure 76: Impact of a MSA Favored ROI on the Expected Value of LNG Projects in State 1 and 2.
7.4 Conclusions from the Agent-Based LNG-Modeling Exercise

With the simulation results of the LNG-model in place it becomes possible to answer the fifth and last sub-question of this research:

- Under which conditions does a spot market for LNG arise from the social and technical interactions of the market if agent-based modeling is used to assess the impact of its key market drivers?

The LNG-model simulation runs produced a large amount of data, the results of which are presented in boxplots. The averaged simulation results indicated that the LNG Agents of invest in new LNG Projects as the demand for LNG increases. The number of liquefaction plants, LNG tankers, and regasification terminals increase and with it the number of potential partnerships of the LNG market. After the LNG Projects are constructed and operational, LNG Agents start to make payments and the capital level starts to change accordingly. The changing capital levels of the LNG Agents illustrate that payments are indeed made and received during the simulation. A final consistency check with the assumptions of the stylized model of contracting confirm that a good partnership earns a higher ROI than that of a poor partnership (i.e. whether the owner is searching or not).

Turning focus to the timing of investment of the LNG Agents and the strategic trade decision between investing in new LNG Projects once a partnership is in place (state 1) and before a partnership has been formed (state 2). The averaged simulation results indicate that the value of initiating a LNG Project in state 1 initially surpasses that of its alternative state 2. This corresponds with the expectations as the ROI of a more conservative strategy in a LNG market with a limited number of trading partners seems to be more favorable than the alternative more risk full pursuit of initiating LNG Project with uncovered output. However, as the demand for LNG increases and the global LNG infrastructure expands, the values of initiating new LNG Projects in state 1 and state 2 start to converge. This is an interesting development as it implies that the optimal trade strategy for new LNGProjects might eventually switch from state 1 to state 2. The overlap between the 1st and 3rd quartile of both strategies start to occur after 5 years, while the median of both strategies is approximately equal after 25 years. While the initial overlap indicates that the average value of state 2 LNG Projects during the simulation occasionally surpasses that of state 1 LNG Projects, the proximity of the median at the end of the simulation implies that the clear preference for state 1 strategies is no longer present.

The optimal trade strategy however, does not yet result in an equilibrium market structure as it is more beneficial to continue to search in a poor partnership (state 3) than it is to be content with the situation (state 4). At the start of the simulation it is more interesting to stop searching and receive the ROI of a poor match without having to funds the search process. The situation changes however when the value of LNG Projects in state 3 surpasses that of state 4. This implies that LNG Agents will be more inclined to continue to search, and in doing so increase the number of potential partners for LNG Projects of state 2, and hence make the market more susceptible to change.

The exploration of the scenario extremes in which a comparison between the parameter settings of a 'SPA-favored' and 'MSA-favored' LNG market show that the value of state 1 LNG Projects initially surpasses that of state 2 and show a converging trend. An important difference between the two settings however concerns the speed of convergence. While there is no overlap between the value state 1 and state 2 LNG Projects in the SPA-favored scenario, there is considerable overlap between the two in the MSA-favored scenario. This implies that LNG Agents are no longer bound to initiating LNG Projects in state 1.

In terms of the individual contribution of the key market drivers and inhibitors on the timing of investment, the results are less clear. With regards to the introduction of innovative technologies (i.e. floating liquefaction and regasification) after 5 years or 20 years, and a change in the default contract duration from 20 to 10 years there are no differences between the state 1 and state 2 development trends. A general trend however is that all of the individual scenario settings demonstrate a converging trend between a initially higher value of state 1 LNG Projects and a steadily increasing value of state 2 LNG Projects. Some remarkable differences include the more stronger decline of state
7. Simulation Results; Signaling the Arrival of the LNG Spot Market

1 LNG Projects if economies of scale effects are included, and the increase of state 2 LNG Projects if the ROI favors the short-term spot market (as opposed to a decrease of the state 2 when the ROI favors the SPA trade).
8. Conclusions & Recommendations

The enclosing chapter of the main part of the paper contains the conclusions and final recommendations of the executed thesis project. First, the conclusions of this thesis will be stated by answering the Overall Research Question (§8.1). The recommendations that follow will discuss the areas for future research and the related continuation of this research (§8.2). Finally, a reflection on the graduation process is provided for (§8.3).

8.1 Conclusions

The aim of this research was to execute an explorative investigation into the degree and conditions that shape the transition towards a spot market for LNG through a quantitative agent-based model. The Overall Thesis Question that was formulated to this end was:

- To what degree and under which conditions will a spot market for Liquefied Natural Gas materialize?

As such, this investigation used a LNG case study to get to grips with the complexities of the LNG trade and used the acquired insights as the input for the development of a explorative agent-based simulation model.

This study has consistently argued that a shift in the timing of investment for the realization of new LNG infrastructure are a prelude to the departure from the ‘Traditional’ LNG market, which is governed by long-term project specific Sales and Purchase Agreements, towards a ‘Global’ LNG market that actively pursu its more flexible spot trading models and is governed by Master Sales Agreements. The key market drivers and inhibitors that are evaluated by the LNG-model and their settings are summarized in Table 20. In addition to these exogenous market drivers, the LNG market development is also shaped by the future expectations of its participants.

The decisions of the market participants in the LNG-model are thus shaped by both the exogenous market drivers and endogenous expectations. A shift in the timing of investment is resembled by the LNG-model as the difference between investing in LNG infrastructure after the realization of a successful partnership or prior to the partnership search process. The averaged simulation results (i.e. those of the complete scenario space) indicated that the initial superiority of the searching for a partner before investing in LNG infrastructure strategy is diminishing in favor of its alternative investing before searching. This corresponds with the expectations as the expected ROI of a more conservative strategy in a LNG market with a limited number of trading partners seems to be more favorable than the alternative more risk full pursuit of initiating LNG infrastructure with uncovered output. However, as the demand for LNG increases and the global LNG infrastructure expands, it reduces the difference between the two trade strategies until they overlap. This is an important observation as it implies that certain liquefaction, regasification, or LNG tankers are invested in despite the fact that there is uncommitted output.

<table>
<thead>
<tr>
<th>Market Driver</th>
<th>‘SPA-favored’ Settings</th>
<th>‘MSA-favored’ Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growing LNG demand</td>
<td>+ 5.7% per year</td>
<td>+ 7.7% per year</td>
</tr>
<tr>
<td>Capital cost reduction</td>
<td>Not present</td>
<td>0.25 % per new LNG project of type</td>
</tr>
<tr>
<td>Return on Investment</td>
<td>Favoring LNG Projects that are active on the bilateral market, + 10% as opposed to -10% for the spot market</td>
<td>Favoring LNG Projects that are active on the spot market, + 10% as opposed to -10% for the bilateral market, After 20 years After 5 years</td>
</tr>
<tr>
<td>Introduction of floating liquefaction and regasification</td>
<td>After 20 years</td>
<td>After 5 years</td>
</tr>
</tbody>
</table>
8. Conclusions & Recommendations

The simulation also indicated that it is more beneficial for owners of LNG infrastructure in a poor match to keep on searching and pay the costs, as opposed to not searching and receiving the ROI of a poor match. This implies that the simulation has not yet reached its market equilibrium, and more importantly that more LNG infrastructure becomes available on the spot market for LNG. The impact of this development will transpire to the strategic decisions of the market participants, and as it favors the trade strategy in which LNG infrastructure investments are made prior to the partnership formation, make the LNG market more susceptible to a possible transition. The exploration of the scenario extremes in which a comparison between the parameter settings of a 'SPA-favored' and 'MSA-favored' LNG market is made indicates that the market participants are sensitive to the market drivers and inhibitors of the LNG-model. A general trend of the individually assessed market drivers is that the value of searching before investing declines, and converges with a steadily increasing value of investing before searching.

It is important to note that despite the fact that the combined impact of the market drivers is seemingly strong enough to initiate the start of a market transition, this is not yet the case for the individual market drivers. This complicates the assessment of the individual market drivers and their impact on the development of the spot market for LNG. It is the belief of this study that this is caused by the conservative variations of the market drivers in the current simulation. Once the researcher comes to grips with the LNG-model behavior and properly adjusts these settings a rerun of the simulation should provide this research with a improved understanding of the relative importance of each of the key market drivers.

8.2 Recommendations

Based on the findings of this report, the researcher was able to formulate a number of general recommendations which should improve the usability of the agent-based LNG-model (§8.2.1). It could also identify a number of areas that warrant future research and should resolve some of the reliability and usability issues of this investigation (§8.2.2).

8.2.1. General Recommendations

Starting with agent-based modeling and getting to know the agent-based knowledge base proved to be a daunting exercise. This makes it important to start the agent-based modeling exercise as early in the research process as possible as it shows the modeler the strengths and weaknesses of this modeling technique. This in turn prevents the development of unrealistic expectations with regards to the capabilities of the model. Important to remember in this respect is that the modeling exercise is a continuous process and not a one-off exercise. Starting with a simple model and gradually expanding it with new insights about the system proves to be far more efficient than trying to create final model in the first attempt. Especially, as the model development process creates new insights about the system as it forces the researcher to look at the system from a different perspective.

With regards to the implementation of Maple 12 calculations it is recommended to use the Open Maple Java applet as this interface allows for a much faster processing of the calculations. For the debugging of Maple 12 calculations themselves it is very useful to generate a text document as this allows for a quick and accurate check of the variables. The calculation in Maple 12 itself works far more efficient if the output of the file is removed. The time gain of this procedure with
8. Conclusions & Recommendations

Large and complicated calculations is substantial. To remove the output of the Maple file, select Edit, Remove Output, From Worksheet, and start the calculation. The additional benefit from this method is that temporary results that might disturb the calculation are removed. Another important lesson is that Maple 12 runs through the equations in order, and hence that the order of the equations needs to be correct to solve the mathematical problem at hand.

Finally, this investigation would like to recommend the modeler to start presenting mid-term results to expert panels to validate the assumptions and results as soon as possible. Although it proves hard to determine when the model is ready to be exposed to the outside world, this is considered to be an important check for the research.

8.2.2 Suggested Model Improvements

There are a number of model extensions that this investigation would like to propose to improve the reliability and usability of the LNG-model. It would be interesting to simulate the strategic and managerial decisions of the LNG Agent more realistically. Important improvements include the introduction of a feedback mechanism between the current performance of the LNG Agent and its ability to engage in new investments. Another possibility is to adjust the bargaining position of the LNG Agent by introducing portfolio advantages. This could also lead to more specialized LNG Agents which would correspond more closely to the real LNG trade in which there are specialized shipping companies and LNG producers.

The current LNG-model operates with a minimal representation of the operational side of the LNG market (e.g. the LNG trade follows the exchange of goods and services that are specified in the contracts). This is not necessarily the most accurate representation of the reality as operational issues might create unforeseen circumstances. The shipping market proves to play an important part in the LNG trade, accounting for around 30 percent of the costs in a complete LNG value-chain, and constitutes the only moveable component of the LNG-trade. This justifies an expansion of the LNG-model as a more accurate representation of the shipping market will allow the model to accommodate cargo swaps, reroute shipments, and delayed deliveries. During the modeling exercise however, it turned out that the agent-based knowledge base did not yet offer the possibility to simulate the transportation and loading and unloading procedure of LNG tankers.

Another interesting model expansion would be the introduction of different regional areas in which LNG is produced and consumed. This would allow the LNG-model to address a number of interesting issues, such as: regional demand variations, regional price differentials, and different transportation distances. It would also make it more interesting to look at the impact of innovative technologies such as the storage and trading hub for LNG, floating liquefaction, and floating regasification on the decisions of the LNGAgent. Offering LNG Agents the possibility to extend the use of their expired LNG Project, albeit under different operating conditions, is another interesting expansion that could be used to make the LNG trade more versatile.

In terms of the model optimization itself, this research expects that improvements on the use of Maple 12 by the LNG-model have the potential to reduce the processing requirements of the simulation. Although the mathematical optimization problem is solved in tenths of a second, the calculation is called upon every time that the LNG Agent needs to make a investment decision, or is involved in contract negotiations. As the number of LNG Agents and LNG Projects increases, the number of potential interactions grows exponentially.
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8.3 Reflection

Enclosing this chapter, the researcher would like to reflect on the implications of this research in relation to current insights. First it will reflect on the ability of this investigation to satisfy the research objectives (§8.3.1). Next, it will discuss the modeling process and the lessons learned (§8.3.2). Subsequently, a personal reflection is added in which the researcher shares its personal views on the conducted thesis project (§8.3.3).

8.3.1 Reflection on the Research Objectives

In addition to answering the Overall Thesis Question, this research was conducted with the following two research objectives in mind:

- To understand the impact of imminent key market drivers and inhibitors on the development of the spot market for LNG by relating these with the trade decisions of its participants.

- To execute an explorative investigation that supplements the existing base of literature on the development of a spot market for LNG with a more quantitative analysis that makes use of agent-based modeling to assess the perceived transition of the LNG market while using a bottom-up perspective.

At the start of this investigation the complicated world of oil and gas and agent-based modeling was relatively unknown to the researcher. This made it important to gain a thorough understanding of the LNG market and the major social, technical, and economical trends that shape its development. It turned out that the existence of the LNG spot market was a result of force majeure rather then of intentional design. Reminiscent of the move away from bilateral contracting in the oil market in the wake of the oil shock of 1979. Unlike the crude market however, the short-term spot trade of LNG did not become the dominant trading strategy of the global LNG market. The relative importance of the LNG spot trade however demonstrated a continued growth at the expense of the traditional long-term SPA governed LNG trade. Although there seems to be an overall consensus that the spot market for LNG will eventually amount to 15-30 percent of the global LNG trade, it remains unclear how the approaching LNG spot market arrives at this stage. Consequently this research set out to understand the impact of imminent key market drivers and inhibitors on the development of the spot market for LNG.

Once the imminent key market drivers and inhibitors of the LNG spot market were identified, it was noted that a transition of the LNG-market probably requires more than changes in these exogenous drivers alone. It was found that expectations about the future market are likely to affect the trade decisions of today as well. Consequently, this research set out to assess the impact of exogenous market drivers and endogenous expectations on the strategic and managerial decisions of the market participants. The market structure that emanates from these individual decisions allows this study to make a first quantitative assessment of the perceived LNG market transition.

It proved of limited value to estimate the relative importance of the LNG spot market through mathematical future extrapolations. The discrepancies of the results, and more importantly the inability of the future extrapolations to satisfy the research objectives strengthened the researcher in its belief to use a different modeling technique. After a comparison of different modeling techniques, it turned out that the existing agent-based knowledge base of the Energy and Industry Group at the Technology, Policy and Management faculty of Delft University of Technology was the most promising starting point for this investigation. The agent-based paradigm was best equipped for the modeling of the LNG market transition as it allows the researcher to assess complex systems behavior through the interactions of smaller, simpler autonomous parts.
The LNG-model that is used to simulate the LNG market transition comprises of LNG Agents (companies engaging in the LNG trade), LNG Projects (containing the physical elements of the LNG value-chain), LNG Contracts (containing partnership details between agents) and LNG Scenarios (containing the outlook for the LNG market). Unfortunately, the simulation results did not quite meet the expectations of the researcher. With the benefit of hindsight the researcher feels that the used parameter settings of the simulation were too close apart to closely assess the relationship between the market drivers and the trade decisions. It is also believed that the simulation results of the LNG-model would have benefited from more realistic model settings. As far as the quantitative analysis is concerned however, the LNG-model proved successful in the identification of a market transition through a change in the preferred timing of investments from the LNG Agents.

The overall assessment must therefore be that the research objectives are acceptably satisfied in that it has created the possibility to explore the impact of the imminent key market drivers and inhibitors on the trade decisions from the LNG Agent through a quantitatively based agent-based model. The actual quantitative analysis however, is expected to benefit greatly from adjusted parameter settings and more realistic modeling settings.

**8.3.2 Reflection on the Modeling Process**

Prior to this research, the modeling skills of the researcher will limited to the discrete and continuous programming skills that are part the Technology Policy and Management curriculum. As such, the introduction to the agent-based modeling paradigm and the existing knowledge base of the Energy & Industry Group of Delft Technical University got off to a slow start. Understanding the existing agent-based models and the Java programming skills that were previously unknown to the researcher proved to be a daunting task.

One major benefit of the agent-based modeling approach is that it forces the researcher to look at a particular problem in a very structured and systematic fashion. If a particular relationship is unclear to the researcher the model is unforgiving and forces the researcher to rethink this relationship or come up with a reasoned assumption that allows the modeling process to proceed. In addition to the agent-based model, the researcher thus gained a more thorough understanding of the LNG market, its relationships and interdependencies than would otherwise be the case.

At first, the modeling process aimed to realistically simulate the basic structure of the LNG market and the operational processes that constitute the LNG trade. With a basic structure seemingly in place, it turned out that the perceived modeling capabilities did no longer match the research objectives of this study and that it would be doubtful if the Overall Thesis Question could be satisfactorily answered.

A different mindset proved to be the key to the containment of this developing problem. It turned out that the original modeling focus needed to be adjusted from the operational side to the strategic and managerial decisions of the market participants. It is after all here, that the decision is made between participating in the traditional long-term SPA governed LNG trade and its alternative the short-term MSA governed LNG trade.

It took an adjusted version of the stylized model of contracting from Brito and Hartley (2007) that was based on the ideas of Diamond (1984), and Diamond and Maskin (1979; 1980) to facilitate the strategic and managerial decision making of the market participants. This introduced a new problem altogether because the existing agent-based knowledge base was not yet equipped to deal with the large mathematical optimization problems that this research required.
By adding a new mathematical software package, Maple 12, to the existing software tools this problem was overcome.

Integrating the adjusting stylized model of contracting in line with the ABM paradigm proved challenging and it eventually required a optimization problem of 21 equations that supplemented another 50 to incorporate the desired model capabilities. In the course of the Maple 12 optimization the researcher gained experience with Maple debugging and correctly representing the mathematical problem.

With the LNG-model in place, it was time to run the simulation. The modeling requirements surpassed that of a normal desktop computer and it turned out that a High Performance Computing environment was needed to run the simulation. The HPC of the E&I domain proved invaluable during the simulation as it was the only way to run the LNG-model with all of the desired model capabilities across the entire scenario space. As a result of the interactions between LNG Agents and the growing number of LNG Projects in the market, the time of each simulation tick (representing half a year in reality) grew exponentially. Accordingly, the simulation data of this investigation required a model run of 550 hours with an approximate computing power of 500 modern personal computers.

The results of the LNG-model simulation were stored in a database that was accessed by the numerical computing environment of MATLAB. The data was accessed, analyzed, and visualized through MATLAB with the use of the existing knowledge base. Thus completing the modeling development process of this investigation.

In all the modeling development process was a daunting but rewarding experience for the researcher. The requirements of this investigation were such the researcher feels that the potential of the LNG-model has not yet been realized. Changing certain parameter settings, model settings, and further optimizing and debugging the LNG-model has the potential to further expand the knowledge on the decision making of agents and further improve the understanding of the LNG market transition.

8.3.3 Personal Reflections

Finally, the researcher would like to share some personal views on the entire graduation process. Starting this investigation the researcher was eager to explore the world of LNG but was unable to directly grasp the possibilities of agent-based modeling to create a better understanding of the perceived LNG market transition. Accordingly, the initial scope of this investigation was to broadly defined. Partly due to excess ambition and unrealistic expectations on behalf of the researcher, but also because of the limited knowledge on agent-based modeling. During the modeling process it became clear to the researcher that the scope of the research had to be revised. The colloquium presentation for the Energy & Industry Group further strengthened the researcher in this belief and put the modeling exercise back on track. Although this investigation meets its exploratory purposes the researcher feels somewhat disappointed that the time and effort of the model development were not fully repaid by the opportunity to present the LNG-model to the academic world and industry. This is certainly not to say that the time spend on this graduation is gone to waste, as the researcher is certainly proud on the end-product and grateful for the research experience.


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Innovation and transition of global LNG markets.
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Abstract
The LNG market is subject to considerable changes, the most principally of which is the departure from long-term project specific Sales and Purchase Agreements towards a true global LNG market with flexible spot trading governed by Master Sales Agreements. To explore this imminent transition of this market, a socio-technical system perspective is combined with principles of transition management and the agent-based modeling paradigm. A suitable definition of transition management is developed, and a conceptual model of the LNG market is specified. This consists of three interacting elements, LNG Agents, LNG Projects, and LNG Scenarios. Implementation in an agent-based simulation will allow us to explore the key factors that determine the transition from the traditional to a true global LNG market.

Keywords
innovation, transition, agent-based model, LNG

Introduction
Supply chains for liquefied natural gas, LNG, represent an option to connect geographically remote natural gas resources to the gas markets of the Atlantic Basin (US and EU) and the Asian Pacific Basin. By enabling the transport of otherwise stranded natural gas in a liquefied state, the exploitation of remote gas fields becomes competitive. The intrinsic properties of natural gas make it a clean fuel compared to coal and crude oil. By importing LNG, countries can improve the affordability, flexibility and security of their energy supply while reducing their CO\textsubscript{2} footprint. The adoption of LNG is relatively straightforward when a domestic natural gas infrastructure already exists. Traditionally, however, realization of a complete LNG supply-chain requires a multibillion dollar investment: for a typical LNG project with an annual capacity of 6 Mt (or approximately 8.3 BCM) the investment required is around US$ 5 billion (IEA 2002). As a consequence, the LNG market has largely been the domain of large oil and gas companies.

In 2002, the total LNG traded equaled 113 Mton or 6\% of global natural gas consumption (EIA 2003). Indonesia, Malaysia, Qatar and Algeria each export in excess of 10 MTA. The largest importers are Japan, South Korea and Taiwan, but EU and US importers are

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rapidly catching up. In the coming decade, a huge volume growth is expected of LNG traded–around the world, many liquefaction and regasification projects are planned and under construction– which according to (PWC 2007) results in an increase in traded volumes from 188.81 [BCM] in 2005, to 459.48 [BCM] in 2015. These developments in LNG markets together with technology development may induce significant change in the sector. The traditional LNG market with its vertical integrated supply chains and rigid long-term and high-volume contracts may give way to a rising role for short-term trade and spot sales of LNG and a more diverse scale of operation and ownership. An intriguing question therefore is how technological developments and changing LNG market conditions interact or co-evolve towards another more global LNG market, or stated otherwise: is the sector in transition?

In this paper we use a socio-technical systems perspective (based on the ideas of Hughes (1987)) to address this issue and to develop a simulation model specification and prototype. Eventually, with the model we endeavor to explore how the LNG market structure may change and whether this may lead to the accelerated adoption of innovations and vice versa. Using the model, we endeavor to determine which LNG market conditions are necessary to assist leapfrogging innovations. This paper’s structure is as follows. First, an overview is given of the rapid expansion of and innovation in the LNG market. Second, the LNG infrastructure is viewed from a transition and from a transition management perspective. To this end, transition literature is reviewed and suitable definitions are derived. Third, a conceptual model is developed and specified of the LNG market in transition. Fourth, an outlook is given of how this conceptual model is to be implemented to enable simulation. Finally, conclusions are drawn.

**LNG Market Dynamics**

**Rapid expansion of global LNG markets**

A typical LNG supply chain (Figure 1) consists of highly capital intensive technologies: liquefaction plants, dedicated transport ships, storage facilities and regasification plants. Traditionally, oil and gas companies own and invest in these components, while the natural gas markets in OECD (Organization for Economic Co-Operation and Development) countries provide demand. LNG supply chains seem to be inherently inflexible, because of the high investments, long construction times and the risk-avoiding attitude of the operating companies and financiers involved. The industries answer to cover the risks involved in such an undertaking was the Sales and Purchase Agreement (SPA). Through the inclusion of several restriction clauses, of which the Take or Pay and Destination clause are arguably the most important, LNG projects used to be referred to as ‘floating pipelines’. As a consequence, change in the sector is slow and intermittent as it goes through lumpy investments.
However, the existing markets for LNG continue to grow and new ones emerge. Meanwhile, the available portfolio of LNG technology - liquefaction, storage, transport and regasification facilities - is expanding rapidly. Currently, many investment projects are being executed and it is expected that the LNG market volume will at least double in the coming decades. According to Cedigaz, LNG’s share of the total world gas market will rise from 23.8% in 2008 to about 36% percent in 2020. Relatively speaking this increase seems rather modest, however in absolute terms it implies more than a doubling of LNG volumes traded: from 211 BCM to 510 BCM (World Energy Council 2007). The investments along the LNG value-chain however are not evenly divided as the costs of liquefaction are 30 to 45 % of the total investment compared to 15 to 25 % for regasification and 10 to 30 % for shipping (EIA 2003). This could create an imbalance in liquefaction, shipping, and regasification capacity. A larger number of players and excess capacity in regasification facilities may open up the possibilities for short-term, flexible contracts on supply, transport and delivery of LNG.

In order to acquaint the reader with the complexity of the LNG trade and create a common understanding of the LNG market, a strongly simplified representation of the LNG market as a socio-technical system is given in Figure 2. The Encyclopædia Britannica describes a markets as “a means by which the exchange of goods and services takes place as a result of buyers and sellers being in contact with one another, either directly or through mediating agents or institutions” (Britannica 2008). Applying this to the LNG market this means that the system input consists of the required investments, expertise and of natural gas. By the LNG market these are transformed to profits and to natural gas at the geographical location of consumption (e.g. the consumer market). Finally, there are the external factors that include the economic climate, technological progress, and the political goodwill.
Figure 2: The LNG market as a socio-technical system.

Leapfrogging innovations in the LNG Value Chain
Incremental and radical innovations in LNG supply chains may influence the role of LNG in the energy sector. It is not the incremental innovations that slowly drive down the cost per m$^3$ gas liquefied, transported, stored and regasified, but rather the radical innovations that may turn the sector upside down. One such potential innovation is a tanker with on-board regasification technology, or Floating Storage and Regasification Unit, an invention that has been patented in 2006 by Statoil. Such a tanker can moor in open sea, close to a harbor. From its mooring point it can connect to onshore infrastructure through a pipeline. A fixed regasification plant in the harbor area is unnecessary, only a connection to the grid infrastructure is needed. With this technology the cost and construction time of a local LNG connection to the gas grid is significantly lowered. At the other end of the LNG supply-chain, floating liquefaction is being considered. Such technology would provide a means to monetize also small remote gas fields, could avoid flaring of associated gas, and would reduce the exposure to the public (Barclay 2006). The widespread adoption of this technology could develop into a business that is worth 8.5 billion US$ by 2015 (Douglas-Westwood 2009). It would lead to increased flexibility of the LNG infrastructure and provide the opportunity for new players to enter the market. Another potential leapfrog innovation is the use of higher temperatures for LNG transport, which may be possible by using a hydrocarbon solvent. Eventually, a single tanker could then be equipped to liquefy stranded gas, store it for transport and regasify it (Rynn 2008). An system innovation is the planned construction of the Dubai LNG Trading Hub or ‘DUB’ that enables LNG suppliers and buyers to store and trade LNG over an extended period of time. Thus, the LNG trade becomes more flexible and is no longer tied to the inflexible transport arrangements. As a matter of course, economics determine the adoption of these and other innovations.
LNG Infrastructure in Transition

Definitions and Properties of Transitions from Transition Theory

“A transition is the shift from a relative stable system through a period of relatively rapid change during which the system reorganises irreversibly into a new (stable) system again” (Rotmans 1994). Transitions can be defined as “gradual, continuous processes of change where the structural character of a society (or a complex sub-system of society) transforms” (Rotmans, Kemp et al. 2001; Loorbach, van der Brugge et al. 2008). Societal transitions are defined as “structural innovations of societal systems in reaction to wicked problems threatening development” (Rotmans 2004; Timmermans accepted for publication). Shove and Walker (2007): transitions are “substantial change and movement from one state to another”. (Geels and Schot 2007) define transitions as “changes from one sociotechnical regime to another”. As defined in a major UN report: “Transitions can be defined as shifts from one mode of operation to another in society” (Matthews et al., 1997). And de Vries and te Riele (2006) state that: “They represent development paths that often have already been experienced by subpopulations and that provide insight into likely futures, dependent on economic, social, and environmental circumstances”. Van der Brugge et al. (2005) defines transitions as “structural change in the way a societal system operates”. Van der Brugge et al. (2005): “Transitions are the result of slow social change and short-term fluctuations or events that suddenly initiate a highly non-linear response.” It may be seen that these definitions are diverse and refer to several ideas of transitions. These definitions do not agree on the conceptualization of change in transitions. Transitions are characterized by

- rapid change (Rotmans 1994)
- substantial change in state (van der Brugge, Rotmans et al. 2005)
- change in regime (van der Brugge, Rotmans et al. 2005)
- change of mode of operation of society (Matthews, Rotmans et al. 1997)
- gradual and continuous change (Rotmans 1994; Loorbach, van der Brugge et al. 2008)
- structural innovations (Rotmans 2004; Timmermans accepted for publication)

Similar to the classic life-cycle of an innovation, research on past transitions (Rip and Kemp 1998; Geels and Kemp 2000; Verbong 2000; Rotmans, Kemp et al. 2001; Geels 2005; van der Brugge, Rotmans et al. 2005) resulted in the definition of four transition phases are identified in the pathway of transitions. A phase of predevelopment (1) is one of dynamic equilibrium. In the take-off phase (2) change starts to occur. During the breakthrough phase (3) visible structural changes take place. A transition ends with a stabilization phase (4), where speed of change decreases and a new dynamic equilibrium is reached. Compared to the life-cycle of innovation, a fifth phase, decline, is lacking. The multi-phase perspective is adopted in transition research (e.g. Elzen, Geels et al. 2004).

In the multi-phase perspective, three dimensions were defined: the magnitude, the speed and the time period of the change in the transition. In the literature there appears to more clarity and consensus on how the system can be characterized before and after a transition. It is a state of dynamic equilibrium (Geels 2005), or stability (Rotmans 1994).
It stands clear that from the above mentioned characterizations of change in transitions, we can identify a fourth dimension that is lacking in the multi-phase perspective: the type of the change. The multi-level perspective, as described above, touches more upon the type of change.

The multi-level perspective uses three analytical and heuristic levels for system innovations and was developed by Geels (2002). The micro-level contains technological niches, in which new technologies are protected against stringent markets. Technologies come into existence and can be further developed. When successful under protected circumstances, it is possible that a technology can break open the before stable regime at the meso-level and become part of that very regime. The meso-level holds a patchwork of regimes in a dynamic equilibrium. The regime is relatively stable and cannot easily be taken over. The macro-level contains socio-technical landscapes, with global and normally slow developments. In this formalization, transitions occur when novelties on the micro-level evolves and is taken up to modify the patchwork of regimes and eventually transforms the landscape on the macro level (Geels 2005). Several papers and books have been using the multi-level perspective to describe and analyze past transitions (e.g. Rotmans, Kemp et al. 2000; Elzen, Geels et al. 2004; Rotmans 2004; Verbong and Geels 2007).

A New Definition of Transitions

The definitions of transitions do not agree on how transitions can be formulated on those four dimensions. We have therefore developed a definition that is useful for the analysis in this paper and that is clear in all four dimensions.

The speed of the change can be fast or slow (rapid change versus gradual change). We will not limit our definition in speed, because we feel that the speed has no impact on whether it is a transition, it rather characterizes different transitions. We do not believe that a transition is only a transition if it is fast (or only if it is slow).

The magnitude of the change can be small or large (substantial). We agree that a transition is characterized by a dramatic change; thus it can be distinguished from an ordinary or incremental change.

The type of change addressed in the literature is diverse: it can be a regime change, change of model of operation, continuous change, and structural change. We propose that transitions should include both change in social characteristics of society (e.g. change in which actors are relevant, how/what decisions are made, which actors interact and how actors interact) and technical characteristics of society (e.g. change in performance of the system, type of physical installations or network structure). Based on these considerations, we come to define transitions as a “dramatic change in both technological and social characteristics of systems”.

Transition management

Transition management is a model of management of the type of change as described as transitions in societal systems (Rotmans and Kemp 2008). As the systems are complex, transition managers argue, classical command-and-control management is not possible and one should aim for adjusting, adapting and influencing (Loorbach 2007)
Governments have been trying transition management (van Volkshuisvesting Ruimtelijke Ordening en Milieubeheer 2001; Paredis 2007) and results are claimed to be promising in qualitative terms (Rotmans 2004), rather then in quantitative terms (Rotmans and Kemp 2008). Although more properties are found in the literature, the ones that can be repeatedly found are that transition management is about long-term thinking for framing short-term policy. Transition management is multi-domain, multi-actor, multi-level. It focuses on learning, aims for alignment of system innovation and system improvement and it advocates to keep a large number of options open (based on Rotmans, Kemp et al. 2001).

**Transition in LNG**

In the LNG market innovations may enable new players to enter the market and eventually transform the market structure. This paper interprets a change in market structure as a departure from the traditional LNG market, which is governed by long-term project specific Sales and Purchase Agreements (SPAs), towards a global LNG market that actively pursues more flexible spot trading models and which is governed by Master Sales Agreements (MSAs). The LNG market today is in the second stop in the pathway of transitions as changes start to occur in the social-technical aspects that govern the LNG trade. This is exemplified by the rise of the LNG spot market, which was virtually non-existent in the early nineties (e.g. 1.2% of the total trade in 1992) and represented 16% of the total LNG trade by 2005 (Morikawa 2008). It is widely expected in the industry that this share will further increase to 30% within the next decade (NGI 2007), (Aissaoui 2006) or less specific in the future (IEA 2004) (FinancialTimes 2004). We will focus on the question whether a market transition leads to the improved adoption of LNG technology related innovations and induce a regime-shift. Thus, we have framed the LNG-case to confirm some of the claims of transition theory and transition management.

The transition towards a more flexible trading model coincides with a growing uncommitted tanker fleet and the prediction that the shipping capacity will outgrow demand. This avoids the need to make long-term commitments and allows the parties involved to simply turn to the charter market. Another important enabler of LNG spot trade is the trend to initiate a new liquefaction plant without the complete contractual coverage of the produced volumes. The cause of which can be found in both technical, e.g. in pursuit of economies of scale the seize of liquefaction plants continues to increase, and social, e.g. smaller volume commitments from buyers because of the liberalization process of electricity and gas markets, aspects of the market. Examples of this trend are Malaysia LNG Tiga, Australia’s NWS Train 5 (Tusiani 2007), and Sakhalin II Phase 2 project (Ball 2004) for which the go-ahead for construction was given, despite a significant volume of uncommitted production capacity.

While these exogenous changes have initiated the transition of the LNG market and might alter its structure, this study recognizes that this process alone might not be sufficient to satisfy the conditions of a transition that are set by this paper. This makes it important to recognize that these changes, although undisputedly important, do not stand alone in realizing a transition towards a global LNG market. An interesting view in this respect is that the momentum of the LNG spot market can act as a self-reinforcing loop.
wherein expectations about the future development influence the decisions on whether or not to become active on the LNG spot market. The availability and widespread implementation of innovative technologies will also play an important part in this consideration. This is indeed the central claim of Brito and Hartley who state that “while exogenous changes in costs or demand are critical to promoting a change in market structure, there is also a substantial endogenous component. Expectations about the evolution of the market influence investments and trading decisions and can make the change in market structure much faster and more abrupt” (Brito 2007). It is our firm belief that the interplay of exogenous forces, innovative technologies, and endogenous expectations can move the market along the pathway of transition towards the breakthrough phase in which visible structural changes are the forerunner for a new stable market equilibrium.

**A Conceptual Agent-Based Model of Transitions in the LNG Market**

We propose to develop an Agent-Based Model that is to be built using our modeling framework for transitions in the energy domain (Chappin and Dijkema 2008) that was built on top of the model earlier developed and presented at ICTPI in 2007 (Chappin and Dijkema 2007). This study adopts the basic principles of (Brito 2007), (Diamond 1979), (Diamond 1980), and (Diamond 1984) in assessing the transition of the market through a stylized model of contracting. In accordance with (Brito 2007) this involves an assessment of the timing of investment and the contract negotiation process of the market participants.

**Overview of the modules**

The conceptual model consists of three major components. These are (1) the set of LNG Agents, the companies that engage in the LNG market; (2) the set of LNG Projects, each of which contains components of the LNG supply-chain; (3) the set of LNG Scenarios, which spans possible outlooks for the LNG market as illustrated in Figure 3. These three components are addressed consecutively.

The central idea is that the LNG market contains LNG Agents who invest in LNG Projects and who operate them. In order to create value, and to realize a return on investment, each LNG Agent who owns a LNG Project, for instance a liquefaction plant, needs to negotiate a contract with another LNG Agent who owns the corresponding LNG Project, a regasification terminal. The results of this process determine the credit level of the LNG Agent and its performance.
Depending on the decisions made by the LNG Agent, the LNG Project is assigned a technology, owner, location, and production level or physical flow.

The LNG Scenarios influence LNG Projects and LNG Agents. In the Scenarios, external trends determine what technologies are available. The LNG Agents’ investment and operational decisions depend on the development of the external trends, market drivers, and its inhibitors.

**LNG Project Module**

We conceptualize each LNG project to consist of four differentiating parameters Figure 4. Technology refers to the type of project, while ownership is the link between the LNG Project and its owner a LNG Agent. Location refers to the physical site of the project installation and the status describes the operational condition. The parameters are described in more detail below.
Technology
Technology is the first condition and describes the nature of the project. Depending on the needs of the market a decision is made for the creation of a new liquefaction plant, LNG tanker, or regasification terminal. In addition to the standard LNG value-chain it is also possible to select innovative technologies such as the FSRU or the storage & trading hub.

Ownership
Ownership is the link the LNG agent that owns and operates the LNG Project. In addition to the national and international oil majors, these can include independent shipping companies (BW Gas ASA, Leif Hoegh, Mitsui OSK Lines), utility companies (Kogas, Mitsui), and trade companies (Vitol, Tractebel).

Location
The location of the proposed LNG project refers to the geographical location of the technology. Although this is fixed for LNG projects such as a liquefaction plant or regasification terminal it varies for LNG tankers and FSRU. This is important because the transport costs are an important indicator for the quality of a match in the LNG trade.

Status
The status of the LNG project refers to its operational capacity. In our conceptualization, we distinguish between LNG projects that are in the planning stage, under construction, operational, and dismantled. The duration of the planning stage is closely related to the contract negotiation process of the LNG Agent. Although the construction period is highly dependent on local circumstances (Brinded 2003) estimates a typical build-up period of 15 months. Although the operational period varies between LNG Projects, a liquefaction plant is designed to accommodate a plateau production level for 20 to 30 years. During the dismantling period a LNG Project is unable to sustain its production unless it is being refitted.

Although all four factors of the LNG project are taken into consideration, the ownership relation with the LNG Agent is discussed in most detail because of its direct relationship with the timing of investment and the contract negotiation process. This study introduces the LNGAgent as the owner of the LNG project.
LNG Agent Module

As said, a LNG agent is the owner of a LNG Project. It is possible for an LNGAgent to own multiple LNG projects and built a portfolio that includes liquefaction, shipping, and regasification. The LNGAgent is also responsible for the operational decisions that ensure the continuous utilization of the LNG project in question. The success of the LNG Agent is measured in monetary terms or credit (Figure 5).

More important, however, is the fact that the LNGAgent, as the owner of the LNG project, is responsible for the creation of a partner-ship with another LNGAgent through contract negotiations. We have assumed that a partner-ship requires two corresponding LNG Projects. For example, a LNG Agent with a liquefaction plant can form a partnership with a LNGAgent that owns a regasification terminal. Without a suitable partnership it is impossible for the LNG project to create value for its owner.

We treat each LNG project separately and assess how its owner, the LNGAgent, times its investment decision, makes operational decisions, and negotiates contracts or partnerships with the owner of corresponding LNG Projects. Subject to the decisions made, the LNGAgent is assigned to one of six states for each of its LNG Projects:

0. Initial situation deciding whether to search or invest first;
1. Searching without investing;
2. Searching without a partner after investing;
3. In a poor match and searching;
4. In a poor match but not searching;
5. In a good match.

Investment Decision

For the realization of a new LNG project the LNGAgent (state 0) is faced with the decision to commence the LNG project with or without a suitable partner. This is referred to as the investment decisions and considers the LNG Agents’ timing of investment. This is illustrated by the blue arrows in Figure 6.
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Figure 6: Possible States and Actions of the LNG Agent that Coincide with the Realization of a LNG Project.

Contract Negotiation
If the LNGAgent (state 0) opts to delay its investment and search for a partner first it becomes a LNGAgent in state 1. LNGAgents (state 1) can only form a partnership with LNGAgents of the same state. The logic behind this restriction is that it is unlikely for the owner of an LNG Project (for instance a liquefaction plant or regasification terminal) to negotiate a contract with another LNG Agent that lacks the corresponding LNG Project (regasification terminal and liquefaction plant respectively). Conversely, if the LNGAgent of state 0 decides to invest in the LNG project before it searches for a partner it becomes an LNGAgent with a LNG Project but without a suitable contract (state 2). As such, it gains access to a more liquid contract market where it can form partnerships with both LNGAgents of the same state and LNGAgents that are currently in a poor match and searching (state 3). The subsequent change of state depends on the quality of the match and might result in a transition to state 3, 4, or 5. Both LNG Agents in a good match (state 5) and in a poor match but not searching (state 4) are no longer available for contract negotiations. In case of force majeure and a breach of contract state 4 and 5 LNG Agents become LNG Agents of state 2. This contract negotiation process is illustrated by the green arrows in Figure 6, while the related change in state is illustrated by the black arrows.

Operational Decisions
Finally there is the operational decision making by the LNG Agents in a match (state 3, 4, or 5) that ensures the LNG Projects output. As such, it includes decisions regarding maintenance and the production process. It should be noted that the operational decisions are not the primary focus of this analysis. This is illustrated by the red arrows in Figure 6.

LNG Scenario Module
The LNG Scenario module (Figure 7) contains the market drivers, external trends, and market inhibitors for the LNG market. Market drivers and inhibitors refer to the conditions that facilitate or restrict a change in market structure. The external trends are
beyond the influence of any particular LNG Agent, and therefore form a significant unpredictability for the development of the LNG market.

Figure 7: Conceptual Model of the LNG Scenario with the Market Drivers, External Trends, and Market Inhibitors as its Differentiating Parameters.

**Market Drivers**
Although there exist different LNG specifications (different calorific values) around the world that limit the interchangeability of LNG, this problem can be addressed through LPG stripping and nitrogen injection. It is generally expected that this technical problem will be overcome within the coming years and that LNG will become a truly homogenous commodity. Flexibility demands are becoming more important as the liberalization of electricity and gas markets have changed the requirement of LNG Agents. Technological improvements, such as the exploitation of economies of scale, enable LNG Agents to invest first before forming a partnership and hence promote change. In this study we acknowledge that a change in market structure might be hard to realize through changes in the exogenous market drivers alone but also notes that the momentum of the LNG spot market can act as a self-reinforcing process in which expectations about the future market structure are likely to influence the investment decision and contract negotiation process of the LNG Agents.

**External Trends**
It is widely expected that the demand for LNG is set to increase rapidly in the future due to declining domestic reserves in the main consuming countries (OECD) and increased demand. If the production follows demand this greatly increases the number of LNG Agents that are active on the market, and hence increases the chance of meeting a suitable partner, reduces the average transport distance and the costs of a breached contract, In the midstream segment the availability of surplus shipping capacity is considered to be an important prerequisite for the development of the LNG spot market because it guarantees LNG Agents that they can transport the LNG from the point of production to the point of consumption. Technological innovations such as the FSRU and LNG Storage & Trading hub facilitate change because they offer possibilities that are lacking in the LNG value-chain. Storing LNG for example offers LNG Agents the ability to store, trade and plan supplies of LNG over an extended period of time.

**Market Inhibitors**
Arguably the most important constraint on the availability of spot LNG is the security of supply concerns of the LNG Agent. The absolute requirement of reliable supply of some
LNG Agents effectively reinforces the status quo of long term contracts. This emphasis of security of supply (most noticeably by Japanese and Korean utility companies) means that a considerable amount of LNG effectively becomes unavailable for alternate contractual agreements and its exchange becomes insensitive to the prevailing market conditions. In some locations, permitting issues make it difficult to expand the number of LNG Projects, and thus hinder market growth and development. Finally, market access limits the free exchange of LNG and promotes the status quo.

**Towards Simulation of the LNG Market**

By definition a model is a simplified, reduced representation of reality. As a subclass of modeling, simulation modeling is used to promote understanding of a system in cases where real world experimenting proves to be to expensive or simply impossible. Agent-based modeling is advocated by this study because it is a appropriate method of analysis for systems that exhibit the following two properties: (1) the system is composed of interacting agents, and (2) the system exhibits emergent properties, i.e.. properties that arise from the interaction of agents that cannot be deduced simply by aggregating the properties of the agents (Axelrod 2006). The development of the LNG market certainly fits this profile as it was initiated by the interactions from its participants, companies in the real world, LNG Agents in the model. The adoption of this bottom-up modeling approach makes it possible to capture the complexity and dynamics of the LNG market through the assessment of flexible, autonomous, and interacting LNG Agents, each in pursuit of their own design objectives. In practice the decisions made are often the result of individual trade-offs by the LNG Agent (e.g. maximizing profit, willingness to take or refrain from risk). This makes it obsolete to poses upfront detailed information of the interdependencies in the market, rather it suffices to the have the resources and decision rules of the autonomous LNG Agents in place and look at their collective outcome.

Accordingly, this simulation focuses on the interaction of LNG Agents. Especially interesting in this respect is the emerging behavior of the LNG Agents with regards to changing investment decisions and contract negotiations, because these are clear indicators of a transition in the LNG market. Specifically this simulation is interested in the proportion of LNG that is traded under long-term Sales and Purchase Agreements in relation to the proportion of LNG that is traded under short-term Master Sales Agreements. While the LNG Agent has the ability to invest, operate, and negotiate a contract for a LNG Project, these decisions are subject to its environment and expectations. “Change is the law of life. And those who look only to the past or present are certain to miss the future” said John. F. Kennedy. As such, the LNG Scenarios serve to challenge our thinking about emerging issues and trends in the behaviour of the LNG Agents, and hence the LNG market at large. In order to assess the conditions under which a market transition will materialize this simulation model will incorporate a number of LNG Scenarios in which the market drivers, impediments and external trends are varied.

The simulation will be implemented in our software stack (Chappin 2006; Nikolic, Chappin et al. 2008; Nikolic, Dijkema et al. in print) that has been designed to serve as platform for agent-based and hybrid models of socio-technical systems (Chappin and Dijkema 2008).
**Conclusions**

Innovations and market structure co-evolve. Depending on the ruling market conditions and market dynamics a transition will or will not persevere. While there are clear signs that changes start to occur in the social-technical aspects that govern the LNG trade, it remains unclear if these are sufficient to move the market to the breakthrough phase on the pathway of transition. This study brings together a socio-technical system perspective, with the principles of transition management, and the bottom-up agent-based modeling paradigm to assess the perceived change of market structure. Note that this research does not attempt to predict ‘the LNG market of the future’ but rather it seeks to understand to what degree and under which conditions a spot market for LNG actually may develop. As such, this explorative investigation supplements the predominant qualitative literature on LNG markets and seeks to uncover the impact of imminent key market drivers and inhibitors on the transition of the market quantitatively. A conceptual model of the LNG market has been developed wherein the interactions between the set of LNG Agents, LNG Projects, and LNG Scenarios are the precursor to the identification of the key factors for a transition from the Traditional to the Global LNG market.

**References**


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Geels, F. W. and R. Kemp (2000). *Transities vanuit sociootechnisch perspectief*. Maastricht, the Netherlands, MERIT.


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Appendix II, Future Extrapolation

The future extrapolation of this study was based on data from (Boyoung 2006), (Flower 2008), (EIA 2005), Cedigaz (Morikawa 2005), and Petrostrategies (Morikawa 2008). Before the actual future extrapolation, this appendix provides an overview of the historic data that is used. Next, the Polynomial extrapolation is executed which in followed by the Verhulst extrapolation.

Overview of the Data

The data that is used for the subsequent analysis is illustrated in Table 21. It can be seen that the availability of data between the different sources. The unit of measure for data is the market share of the LNG spot market in percentages as opposed to the traditional long-term contract market.

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Table 21: Overview of the Data

Polynomial Extrapolation of the LNG Spot Market

An overview of the polynomial extrapolation for each data set is shown below. Note that the market share of the spot market, in percentages, is represented by the y-axis. The x-axis represents the year and starts to count from the first year that data is available for that particular data set. Hence for the polynomial extrapolation of Boyoung 1992 represents year 1, whereas in the polynomial extrapolation of Flower 1993 represents year 1.
Appendix II, Future Extrapolation

Boyoung

\[ y = 0.1737x^2 - 1.4418x + 4.3294 \]
\[ R^2 = 0.8554 \]

Figure 77: Polynomial Extrapolation of Boyoung

Flower

\[ y = 0.0796x^2 - 0.2317x + 2.2129 \]
\[ R^2 = 0.9657 \]

Figure 78: Polynomial Extrapolation of Flower

EIA

\[ y = 0.1022x^2 - 0.6407x + 2.8284 \]
\[ R^2 = 0.8091 \]

Figure 79: Polynomial Extrapolation of the EIA.
Appendix II, Future Extrapolation

Cedigaz

\[ y = 0.0721x^2 + 0.5825x + 0.7226 \]

\[ R^2 = 0.9762 \]

Figure 80 Polynomial Extrapolation of Cedigaz.

PetroStrategies

\[ y = 0.0991x^2 - 0.1714x + 2.2605 \]

\[ R^2 = 0.9464 \]

Figure 81: Polynomial Extrapolation of Petrostrategies.

Based on this information the polynomial extrapolation was executed until the share of the LNG spot market reached 100 percent.

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Verhulst Extrapolation of the LNG Spot Market

As the growth rate of the polynomial extrapolation spirals out of control beyond 2015 this study performs a Verhulst extrapolation. The Verhulst extrapolation is considerably more complicated then the Polynomial extrapolation in that the Mean Squared Error needs to be minimized for the following equation:

\[
P(t) = \frac{KP_0e^{rt}}{K + P_0(e^{rt} - 1)}
\]

*In which 'P' is the highest value that the share of the LNG spot market can reach if infinite time is considered. 'K' is the carrying capacity of the environment, 'r' the growth rate, and 't' the time. An overview of the Verhulst extrapolation for each data set is shown below. Note that the market share of the spot market, in percentages, is represented by the y-axis. The x-axis represents the year and starts to count from the first year that data is available for that particular data set.*

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Table 22: The Polynomial Extrapolation Results.
Appendix II, Future Extrapolation

Figure 82: Verhulst Extrapolation of Boyoung.

Figure 83: Verhulst Extrapolation of Flower.

Figure 84: Verhulst Extrapolation of EIA.
The final results of the Verhulst extrapolation are presented in Table 23.
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Table 23: The Verhulst Extrapolation Results.
Overview of the Scenario Input

The trade movements for LNG and the scenario assumptions are derived from (Insight 2007).

The main assumptions are the following:
- Companies involved in the LNG mid-stream have a legitimate strategy of overbuilding regasification capacity.
- In ‘business as usual’ cases LNG supply security will reduce principally to an issue of price.
- If the importer is seriously short of contracted gas, it should be able to import as much additional LNG as it wishes, provided it is prepared to pay the necessary price to attract cargoes away from other markets.

*Scenario A*

Uninterrupted continuation of the following trends is assumed:
- LNG becoming a mainstream arm of global gas supply;
- Market being dominated by large players;
- Investment in liquefaction plant continuing steadily;
- Regasification capacity plentiful, and only partially utilized;
- Regulatory regimes in importing countries supportive;
- LNG trade becoming global and efficient, with ‘spot trading’ in the Atlantic Basin;
- European gas market becoming more open, competitive, liquid, efficient;
- No LNG producer cartel emerging: NOC ambitions satisfied;
- Chinese demand not becoming a major direct factor.

*Scenario B*

Supply-side deficiencies occur ‘accidentally’ in an otherwise thriving LNG sector:
- Production-project delays impact on an otherwise comfortable supply picture;
- Market conditions facilitate a price-driven response;
- Supply-demand tightness directionally worsens liquidity;
- Otherwise, only marginal impact on demand and market dynamics.

*Scenario C*

Deeper supply-side shortcomings caused by disruptive cartel activity:
- Greater reductions in supply, including withholding of spare capacity;
- Limited ability for non-cartel LNG producers to make good the shortfall;
- Nature as well as volume of reduced supply causes markets to cease functioning;
- Also causes importers purposefully to reduce exposure to demand for LNG.
<table>
<thead>
<tr>
<th>Region</th>
<th>Year</th>
<th>Regasification Capacity</th>
<th>Unit of Measure</th>
<th>Total Import</th>
<th>Utilization Rate</th>
<th>Liquefaction Capacity</th>
<th>Unit of Measure</th>
<th>Total Export</th>
<th>Utilization Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>2005</td>
<td>60</td>
<td>[BCM/year]</td>
<td>18</td>
<td>30%</td>
<td>23</td>
<td>[BCM/year]</td>
<td>16</td>
<td>70%</td>
</tr>
<tr>
<td>EU</td>
<td>2005</td>
<td>89</td>
<td>[BCM/year]</td>
<td>50</td>
<td>56%</td>
<td>xxx</td>
<td>xxx</td>
<td>86</td>
<td>85%</td>
</tr>
<tr>
<td>AP</td>
<td>2005</td>
<td>372</td>
<td>[BCM/year]</td>
<td>125</td>
<td>34%</td>
<td>101</td>
<td>[BCM/year]</td>
<td>92</td>
<td>72%</td>
</tr>
<tr>
<td>MENA</td>
<td>2005</td>
<td>xxx</td>
<td>xxx</td>
<td>xxx</td>
<td>xxx</td>
<td>xxx</td>
<td>xxx</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NA</td>
<td>2010</td>
<td>174</td>
<td>[BCM/year]</td>
<td>79</td>
<td>45%</td>
<td>36</td>
<td>[BCM/year]</td>
<td>27</td>
<td>75%</td>
</tr>
<tr>
<td>EU</td>
<td>2010</td>
<td>252</td>
<td>[BCM/year]</td>
<td>152</td>
<td>60%</td>
<td>15</td>
<td>[BCM/year]</td>
<td>15</td>
<td>100%</td>
</tr>
<tr>
<td>AP</td>
<td>2010</td>
<td>406</td>
<td>[BCM/year]</td>
<td>165</td>
<td>41%</td>
<td>125</td>
<td>[BCM/year]</td>
<td>121</td>
<td>97%</td>
</tr>
<tr>
<td>MENA</td>
<td>2010</td>
<td>xxx</td>
<td>xxx</td>
<td>xxx</td>
<td>xxx</td>
<td>228</td>
<td>[BCM/year]</td>
<td>203</td>
<td>89%</td>
</tr>
<tr>
<td>NA</td>
<td>2015</td>
<td>183</td>
<td>[BCM/year]</td>
<td>117</td>
<td>64%</td>
<td>37</td>
<td>[BCM/year]</td>
<td>28</td>
<td>76%</td>
</tr>
<tr>
<td>EU</td>
<td>2015</td>
<td>346</td>
<td>[BCM/year]</td>
<td>193</td>
<td>56%</td>
<td>32</td>
<td>[BCM/year]</td>
<td>24</td>
<td>75%</td>
</tr>
<tr>
<td>AP</td>
<td>2015</td>
<td>449</td>
<td>[BCM/year]</td>
<td>188</td>
<td>42%</td>
<td>146</td>
<td>BCM / year</td>
<td>134</td>
<td>92%</td>
</tr>
<tr>
<td>MENA</td>
<td>2015</td>
<td>xxx</td>
<td>xxx</td>
<td>xxx</td>
<td>xxx</td>
<td>340</td>
<td>BCM / year</td>
<td>300</td>
<td>88%</td>
</tr>
<tr>
<td>Global</td>
<td>2015</td>
<td>1022</td>
<td>[BCM/year]</td>
<td>523</td>
<td>51%</td>
<td>555</td>
<td>[BCM/year]</td>
<td>485</td>
<td>87%</td>
</tr>
<tr>
<td>NA</td>
<td>2020</td>
<td>183</td>
<td>[BCM/year]</td>
<td>128</td>
<td>70%</td>
<td>38</td>
<td>[BCM/year]</td>
<td>30</td>
<td>79%</td>
</tr>
<tr>
<td>AP</td>
<td>2020</td>
<td>460</td>
<td>[BCM/year]</td>
<td>197</td>
<td>43%</td>
<td>164</td>
<td>BCM / year</td>
<td>138</td>
<td>84%</td>
</tr>
<tr>
<td>MENA</td>
<td>2020</td>
<td>xxx</td>
<td>xxx</td>
<td>xxx</td>
<td>xxx</td>
<td>383</td>
<td>BCM / year</td>
<td>348</td>
<td>91%</td>
</tr>
<tr>
<td>Global</td>
<td>2020</td>
<td>1071</td>
<td>[BCM/year]</td>
<td>582</td>
<td>54%</td>
<td>617</td>
<td>[BCM/year]</td>
<td>536</td>
<td>87%</td>
</tr>
<tr>
<td>NA</td>
<td>2025</td>
<td>203</td>
<td>[BCM/year]</td>
<td>126</td>
<td>62%</td>
<td>36</td>
<td>[BCM/year]</td>
<td>30</td>
<td>83%</td>
</tr>
<tr>
<td>EU</td>
<td>2025</td>
<td>418</td>
<td>[BCM/year]</td>
<td>263</td>
<td>63%</td>
<td>32</td>
<td>[BCM/year]</td>
<td>30</td>
<td>94%</td>
</tr>
<tr>
<td>AP</td>
<td>2025</td>
<td>473</td>
<td>[BCM/year]</td>
<td>214</td>
<td>45%</td>
<td>180</td>
<td>[BCM/year]</td>
<td>153</td>
<td>85%</td>
</tr>
<tr>
<td>MENA</td>
<td>2025</td>
<td>xxx</td>
<td>xxx</td>
<td>xxx</td>
<td>xxx</td>
<td>207</td>
<td>[BCM/year]</td>
<td>193</td>
<td>93%</td>
</tr>
<tr>
<td>Global</td>
<td>2025</td>
<td>1139</td>
<td>[BCM/year]</td>
<td>627</td>
<td>55%</td>
<td>650</td>
<td>[BCM/year]</td>
<td>577</td>
<td>89%</td>
</tr>
</tbody>
</table>

Table 24: Overview of the LNG Trade Movements for Scenario A.
<table>
<thead>
<tr>
<th>Region</th>
<th>Year</th>
<th>Regasification Capacity</th>
<th>Unit of Measure</th>
<th>Total Import [BCM/year]</th>
<th>Utilization Rate</th>
<th>Liquefaction Capacity</th>
<th>Unit of Measure</th>
<th>Total Export [BCM/year]</th>
<th>Utilization Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>2015</td>
<td>179</td>
<td>[BCM/year]</td>
<td>136</td>
<td>76%</td>
<td>37</td>
<td>[BCM/year]</td>
<td>34</td>
<td>92%</td>
</tr>
<tr>
<td>AP</td>
<td>2015</td>
<td>449</td>
<td>[BCM/year]</td>
<td>188</td>
<td>42%</td>
<td>146</td>
<td>[BCM/year]</td>
<td>144</td>
<td>99%</td>
</tr>
<tr>
<td>Global</td>
<td>2015</td>
<td>1022</td>
<td>[BCM/year]</td>
<td>523</td>
<td>51%</td>
<td>482</td>
<td>[BCM/year]</td>
<td>474</td>
<td>98%</td>
</tr>
<tr>
<td>NA</td>
<td>2020</td>
<td>179</td>
<td>[BCM/year]</td>
<td>152</td>
<td>85%</td>
<td>38</td>
<td>[BCM/year]</td>
<td>35</td>
<td>92%</td>
</tr>
<tr>
<td>EU</td>
<td>2020</td>
<td>383</td>
<td>[BCM/year]</td>
<td>233</td>
<td>61%</td>
<td>32</td>
<td>[BCM/year]</td>
<td>29</td>
<td>91%</td>
</tr>
<tr>
<td>AP</td>
<td>2020</td>
<td>460</td>
<td>[BCM/year]</td>
<td>197</td>
<td>43%</td>
<td>153</td>
<td>BCM / year</td>
<td>145</td>
<td>95%</td>
</tr>
<tr>
<td>MENA</td>
<td>2020</td>
<td>xxx</td>
<td>[BCM/year]</td>
<td>xxx</td>
<td>xxx</td>
<td>340</td>
<td>BCM / year</td>
<td>327</td>
<td>96%</td>
</tr>
<tr>
<td>Global</td>
<td>2020</td>
<td>1023</td>
<td>[BCM/year]</td>
<td>582</td>
<td>57%</td>
<td>583</td>
<td>[BCM/year]</td>
<td>536</td>
<td>92%</td>
</tr>
<tr>
<td>NA</td>
<td>2025</td>
<td>199</td>
<td>[BCM/year]</td>
<td>150</td>
<td>75%</td>
<td>30</td>
<td>[BCM/year]</td>
<td>31</td>
<td>103%</td>
</tr>
<tr>
<td>EU</td>
<td>2025</td>
<td>418</td>
<td>[BCM/year]</td>
<td>263</td>
<td>63%</td>
<td>32</td>
<td>[BCM/year]</td>
<td>31</td>
<td>97%</td>
</tr>
<tr>
<td>AP</td>
<td>2025</td>
<td>480</td>
<td>[BCM/year]</td>
<td>214</td>
<td>45%</td>
<td>164</td>
<td>[BCM/year]</td>
<td>153</td>
<td>93%</td>
</tr>
<tr>
<td>MENA</td>
<td>2025</td>
<td>xxx</td>
<td>[BCM/year]</td>
<td>xxx</td>
<td>xxx</td>
<td>383</td>
<td>[BCM/year]</td>
<td>363</td>
<td>95%</td>
</tr>
<tr>
<td>Global</td>
<td>2025</td>
<td>1098</td>
<td>[BCM/year]</td>
<td>627</td>
<td>57%</td>
<td>609</td>
<td>[BCM/year]</td>
<td>577</td>
<td>95%</td>
</tr>
</tbody>
</table>

Table 25: Overview of the LNG Trade Movements for Scenario B.
<table>
<thead>
<tr>
<th>Region</th>
<th>Year</th>
<th>Regasification Capacity</th>
<th>Unit of Measure</th>
<th>Total Import</th>
<th>Utilization Rate</th>
<th>Liquefaction Capacity</th>
<th>Unit of Measure</th>
<th>Total Export</th>
<th>Utilization Rate</th>
</tr>
</thead>
</table>

Table 26: Overview of the LNG Trade Movements for Scenario C.
Scenarios Demand and Supply Projections

This study uses the ‘business as usual, continuation of trends’ scenario (Table 27) of Global Insight (Insight 2007) as the point of reference for the demand and supply projections of the scenarios from the scenario logic (Table 28). In order to estimate the variation between the scenarios it divided the regasification and liquefaction capacities of Scenario A with the least optimistic scenario C, Over the Edge. The largest difference here concerns the liquefaction capacity in 2015 and amounts to 16 percent difference between scenario C and A. Taking into consideration that this is the difference between the business as usual and least pessimistic scenario, this study values the difference between most optimistic and least optimistic at 30%. Hence, a modest demand for LNG relates to a correction factor of minus 10%, whereas a surging demand for LNG refers to a correction factor of 25% (Table 29). As there is an added third external trend this leads to a maximum difference with the nil-scenario of 60% for scenario 1.

<table>
<thead>
<tr>
<th>Region</th>
<th>Year</th>
<th>Regasification Capacity</th>
<th>Total Import</th>
<th>Liquefaction Capacity</th>
<th>Total Export</th>
<th>Unit of Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>2005</td>
<td>527</td>
<td>194</td>
<td>252</td>
<td>194</td>
<td>[BCM/year]</td>
</tr>
<tr>
<td>Global</td>
<td>2010</td>
<td>862</td>
<td>302</td>
<td>403</td>
<td>366</td>
<td>[BCM/year]</td>
</tr>
<tr>
<td>Global</td>
<td>2015</td>
<td>1022</td>
<td>523</td>
<td>555</td>
<td>485</td>
<td>[BCM/year]</td>
</tr>
<tr>
<td>Global</td>
<td>2020</td>
<td>1071</td>
<td>582</td>
<td>617</td>
<td>536</td>
<td>[BCM/year]</td>
</tr>
<tr>
<td>Global</td>
<td>2025</td>
<td>1139</td>
<td>627</td>
<td>650</td>
<td>577</td>
<td>[BCM/year]</td>
</tr>
</tbody>
</table>

Table 27: LNG Trade Movements in the Different Scenarios (Insight 2007).

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Demand for LNG</th>
<th>Availability of LNG</th>
<th>Technological Innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 0</td>
<td>Neutral</td>
<td>Neutral</td>
<td>Neutral</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>Surging</td>
<td>Abundance</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>Surging</td>
<td>Abundance</td>
<td>Static</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>Modest</td>
<td>Constrained</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>Modest</td>
<td>Constrained</td>
<td>Static</td>
</tr>
<tr>
<td>Scenario 5</td>
<td>Surging</td>
<td>Constrained</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Scenario 6</td>
<td>Surging</td>
<td>Constrained</td>
<td>Static</td>
</tr>
<tr>
<td>Scenario 7</td>
<td>Modest</td>
<td>Abundance</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Scenario 8</td>
<td>Modest</td>
<td>Abundance</td>
<td>Static</td>
</tr>
</tbody>
</table>

Table 28: Overview of the Scenarios.
The results of this correction and the corresponding endogenous demand (regasification capacity) and supply (liquefaction capacity) projections for each scenario are depicted below (Table 30).

### Table 29: Calculation of the Correction Factor.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Demand for LNG</th>
<th>Availability of LNG Capacity</th>
<th>Technological Innovation</th>
<th>Correction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.6</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>1.2</td>
<td>1.2</td>
<td>0.9</td>
<td>1.3</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>0.9</td>
<td>0.9</td>
<td>1.2</td>
<td>1</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Scenario 5</td>
<td>1.2</td>
<td>0.9</td>
<td>1.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Scenario 6</td>
<td>1.2</td>
<td>0.9</td>
<td>0.9</td>
<td>1</td>
</tr>
<tr>
<td>Scenario 7</td>
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<td>1.2</td>
<td>1.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Scenario 8</td>
<td>0.9</td>
<td>1.2</td>
<td>0.9</td>
<td>1</td>
</tr>
</tbody>
</table>

The scenarios are as follows:

- **Scenario 0**: Neutral, Neutral, Neutral, 1
- **Scenario 1**: Surging, Abundance, Dynamic, 1.2
- **Scenario 2**: Surging, Abundance, Static, 1.2
- **Scenario 3**: Modest, Constrained, Dynamic, 0.9
- **Scenario 4**: Modest, Constrained, Static, 0.9
- **Scenario 5**: Surging, Constrained, Dynamic, 0.9

### Table 30: Demand and Availability Projections for Each Scenario.

<table>
<thead>
<tr>
<th>Scenario Number</th>
<th>Demand for LNG</th>
<th>Availability of LNG Capacity</th>
<th>Technological Innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 0 0 Neutral</td>
<td>2010 Neutral 862</td>
<td>2015 Neutral 1022</td>
<td>2020 Neutral 1071</td>
</tr>
<tr>
<td>Scenario 1 1 Surging Abundance Dynamic</td>
<td>2010 Surging 1379.2</td>
<td>2015 Abundance 1635.2</td>
<td>2020 Dynamic 1713.6</td>
</tr>
<tr>
<td>Scenario 2 2 Surging Abundance Static</td>
<td>2010 Surging 1120.6</td>
<td>2015 Abundance 1328.6</td>
<td>2020 Static 1392.3</td>
</tr>
<tr>
<td>Scenario 3 3 Modest Constrained Dynamic</td>
<td>2010 Modest 603.4</td>
<td>2015 Constrained 715.4</td>
<td>2020 Dynamic 749.7</td>
</tr>
<tr>
<td>Scenario 4 4 Modest Constrained Static</td>
<td>2010 Modest 603.4</td>
<td>2015 Constrained 715.4</td>
<td>2020 Static 749.7</td>
</tr>
<tr>
<td>Scenario 5 5 Surging Constrained Dynamic</td>
<td>2010 Surging 1120.6</td>
<td>2015 Constrained 1328.6</td>
<td>2020 Dynamic 1392.3</td>
</tr>
<tr>
<td></td>
<td>Scenario 6</td>
<td>Scenario 7</td>
<td>Scenario 8</td>
</tr>
<tr>
<td>----------------</td>
<td>------------</td>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td></td>
<td>Surging</td>
<td>Modest</td>
<td>Mode Abundance</td>
</tr>
<tr>
<td></td>
<td>Constrained</td>
<td>Modest</td>
<td>Abundance Static</td>
</tr>
<tr>
<td></td>
<td>Static</td>
<td>Static</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>862</td>
<td>862</td>
<td>862</td>
</tr>
<tr>
<td>2015</td>
<td>1022</td>
<td>1328.6</td>
<td>1022</td>
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<tr>
<td>2020</td>
<td>1071</td>
<td>1392.3</td>
<td>1071</td>
</tr>
<tr>
<td>2025</td>
<td>1139</td>
<td>1480.7</td>
<td>1139</td>
</tr>
</tbody>
</table>

Table 30: Results of the Scenario Adjustments.
Appendix III, Methodology

The methodology that is used for ABM and the process of structuring the model is discussed here. The most important distinction in the ontology is between nodes, edges, knowledge, and data. Nodes are the connection points of the model and are connected to one another through edges. In this ABM nodes consist of either agents or technologies with their respective economic and design properties. Connections between nodes and edges are represented by contracts on a social level and flows on a technical one. The knowledge branch serves to provide information about the operational configuration of the technology. While the technology is a black box which converts inputs into outputs, its operational configuration determines the relation between the input and output. Finally there is the data branch which contains the characteristics and properties of other objects (nodes, edges).

![Figure 87: Overview of the ABM Ontology (Chappin 2006).]
Appendix IV, LNG Spot Trade & Price Arbitrage

This appendix discusses the market clearing procedure of the LNG spot market and the principles of price arbitrage in the Atlantic and Asian Pacific Basin.

Operational Process of the LNG Spot Market

The actual operational processes of a spot market that will be used as a reference for the LNG spot market model is discussed here. Conventional spot markets operate according to four successive stages: Bidding, Clearing, Physical Delivery, and Financial Transactions (Bigatto 2000) (translated by Krause 2005).

- Bidding; during a specified period of time sellers place their production offers in terms of price and quantity while buyers submit their bids relating to the demand and the maximum price they are willing to pay.
- Clearing; after the specified period of time has passed, the market clearing price and quantity are calculated. The actual market price is determined by the intersection of both functions.
- Physical Delivery; when the trade has been settled, physical delivery takes place.
- Financial Transactions; the transaction is finalized when the buyer pays the seller the predetermined market price.

The size of the LNG spot market depends on the supply and demand for spot LNG. As such it depends on the volumes of LNG that the producer reserves for the spot trade of LNG and the buyers decision on how to split its variable demand between contractual flexibility and spot LNG (Figure 88).

![Figure 88: Market Clearing Procedure (Tchung Ming 2007).](image)

![Figure 90: New Firm and Probable Contract Volumes by Region (Jensen 2004).](image)
Price Arbitrage in the Atlantic & Asian Pacific Basin

The following example is adopted from (Jensen 2004) and explains how arbitrage operates in the Atlantic Basin. It assumes a case in there are three suppliers; Trinidad and Tobago, Nigeria, and Qatar and three customers with receiving terminal in Huelva in Spain, Everett on the US East Coast, and Lake Charles on the US Gulf Coast. The netbacks for each market are depicted in Figure 90 and show that the supplier from Trinidad receives the same netback from Huelva and Everett, which in turn are superior to the netback from Lake Charles. Note that the differences between the ex-ship price Huelva 3.00 [US$/MMBtu] and Everett 2.82 [US$/MMBtu] are offset by the transport costs. Thus, the arbitrage point that is illustrated in Figure 90 is dynamic and shifts consistently as prices on both sides of the Atlantic fluctuate.

![Figure 90: Netbacks to Huelva, Everett, and Lake Charles (Jensen 2004)](image)

With regards to the direction of cargo diversions throughout the year, Insight notes that during the winter (seasonality of the UK), Atlantic Basin LNG prices will be set by their value to Europe – the NBP (or its successor) price. “The US demand is so price elastic to gas (given their large storage and a very flexible market) that they would not generally decide to compete against Europe during winters when there would be high price differentials” (Insight 2007). During the summer however the situation changes and the price of gas will favor shipments to the US – the Henry Hub price, as this is the dominant importer during this season.

Arbitrage possibilities in the Asian Pacific will not emerge before the realization of LNG receiving terminals on the US West Coast and Mexico. If sufficient receiving capacity is realized to accommodate arbitrage, the market will behave quite differently from the Atlantic Basin market. First of all, there are larger shipping distances than in the Atlantic Basin, meaning that it requires a larger tanker capacity to take advantage of an arbitrage possibility (Jensen 2004). Table 31 illustrates the difference between the required increase in tanker capacity that is needed to take advantage of an arbitrage possibility while handling the same volume. Although these costs are at least partially offset by the higher price of natural gas on the North American West Coast, this would hinder arbitrage possibilities during times of strong tanker demand.
Both Basins will be connected through the Middle Eastern producers that are widely expected to become the swing producers of spot LNG. Important in this respect is that the traditional high prices for natural gas in Japan, and Asian prices in general, are likely to be weakened at the end of the decade due to the expiration of a significant number of Australian and Indonesian contracts (Jensen 2004).

Table 31: Required Increase in Tanker Capacity to accommodate Arbitrage

<table>
<thead>
<tr>
<th>Basin</th>
<th>From</th>
<th>Divert From</th>
<th>Divert To</th>
<th>Required Increase in Tanker Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic Basin</td>
<td>Trinidad</td>
<td>Everett</td>
<td>Spain</td>
<td>53 %</td>
</tr>
<tr>
<td>Atlantic Basin</td>
<td>Nigeria</td>
<td>Spain</td>
<td>Everett</td>
<td>43 %</td>
</tr>
<tr>
<td>Pacific Basin</td>
<td>Bolivia</td>
<td>Japan</td>
<td>Baja</td>
<td>100 %</td>
</tr>
<tr>
<td>Pacific Basin</td>
<td>Tangguh</td>
<td>Japan</td>
<td>Baja</td>
<td>110 %</td>
</tr>
<tr>
<td>Pacific Basin</td>
<td>Sakhalin</td>
<td>Japan</td>
<td>Baja</td>
<td>150 %</td>
</tr>
</tbody>
</table>
Appendix V, Exploring the Impact of Key Market Drivers

This appendix presents the simulation results of the introduction of floating liquefaction and regasification after 20 years and 10 years, a change of the default contract duration from 20 to 10 years, and a favorable meeting probability for LNG Projects that are part of a value-chain and an equal meeting probability for all LNG Projects alike.

Introduction of floating liquefaction and regasification

Figure 91: Introduction of Innovative Technologies after 20 years and the Expected Value of LNGProjects in State 1 and 2.

Figure 92: Introduction of Innovative Technologies after 10 years and the Expected Value of LNGProjects in State 1 and 2.
Change of Contract Duration from 20 to 10 Years

Figure 93: Default Contract Duration of 20 Years and the Expected Value of LNG Projects in State 1 and 2.

Figure 94: Default Contract Duration of 10 Years and the Expected Value of LNG Projects in State 1 and 2.
Appendix V, LNG Spot Trade & Price Arbitrage

Probability of Meeting Favorable for LNG Projects with (out) a Partner

Figure 95: Meeting Probability Favors LNG Projects in a LNG Value-chain and the Expected Value of LNG Projects in State 1 and 2.

Figure 96: Meeting Probability is Equal for all LNG Projects and the Expected Value of LNG Projects in State 1 and 2.
Appendix VI, Adjusted Stylized Model of Contracting

The equations of the stylized model of contracting from Brito and Hartley (2007) are depicted below. The most important adjustment to the adopted model of contracting concerns the equations for state 2 (vA2 and vA2ΞB) and state 3 (vAB3ΞA) LNG Projects with a single partner. Instead of one partner for LNG Projects in state 2, the adjusted model of contracting allows for two potential partners. If for instance a liquefaction plant (type A) is initiated in state 2 it can form a partnership with complimentary LNG Projects: the LNG tanker (type B) and regasification terminal (type C) of state 2 and state 3. LNG Projects with a single partner that continue to search can form a new partnership with the missing LNG Project (i.e. project C in this example) or try to improve their current partnership with a different LNG Project of type A and B respectively. As such, they can match with LNG Projects of all types, depending on which LNG Project initiates the new partnership. This created an optimization problem of 21 equations: 9 for the determination of LNG Projects of type A, B, and C in state 2, and 12 for LNG Projects with one partner in place. The expected search time for both projects TA2ΞB and TAB3ΞA are also provided for.

Expected Value of a LNG Project in state 0

\[ v_0 = v_2 - K \]

Expected Value of a LNG Project in state 1

\[ v_1 = e^{-rT_1} \times (pv_5 + (1-p) \times max(v_3, v_4) - K) - \frac{c(1-e^{-rT_1})}{r} \]

Expected Value of a LNG Project in state 2 when search is optimal

\[ v_2 = \frac{px_3}{x_2 + x_3 - 1} + 3 \times \frac{p - x_2 + 1}{x_2 + x_3 - 1} = \frac{(c - u_3) \times (1-e^{-rT_2})}{r} + \frac{pu_1}{r + \delta} \]

Expected Value of a LNG Project in state 2 when search is not optimal

\[ v_2 = e^{-rT_2} \times \frac{pu_1}{r + \delta} + \frac{(1-p)u_2}{r + \delta} - \frac{1 - e^{-rT_2}}{r} \]

Expected Value of a LNG Project in state 3

\[ v_3 = e^{(r+\delta)T_3} \left( \frac{x_2}{x_2 + x_3 - 1}v_5 + \frac{x_3 - 1}{x_2 + x_3 - 1} (v_5 - (v_3 - v_2)) \right) + \int_0^{T_3} e^{-(r+\delta)t}(u_2 - c)dt \]

Expected Value of a LNG Project in state 4

\[ V_4 = \int_0^\infty e^{-(r+\delta)t}u_2dt = \frac{u_2}{r + \delta} \]

Expected Value of a LNG Project in state 5

\[ v_5 = \int_0^\infty e^{-(r+\delta)t}u_1dt = \frac{u_1}{r + \delta} \]

Expected Value of a LNG Project of type A in state 2

\[ vA_2 = \frac{vA_2 \land B + vA_2 \land C}{2} \]

Expected Value of a LNG Project of type A in state 2 that partners with a LNG Project of type B
Appendix VI, Adjusted Stylized Model of Contracting

\[ VA2\Xi B = pA2\Xi 2 e^{-rA2_B2 TA2\Xi B} \left( \frac{pA2\Xi B u1AB}{rA2_B2 + \delta A} + \frac{(1 - pA2\Xi B) u2AB}{rA2_B2 + \delta A} \right) + pA2\Xi 3 e^{-rA2_B2 TA2\Xi B} \left( \frac{pA2\Xi B u1ABC}{rA2_B2 + \delta A} + \frac{(1 - pA2\Xi B) u2ABC}{rA2_B2 + \delta A} \right) - \frac{(cA - u3A)(1 - e^{-rA2_B2 TA2\Xi B})}{rA2_B2} \]

Expected Search Time of a LNG Project of type A in state 2 to find a LNG Project of type B

\[ TA2\Xi B = \frac{1}{aA2\Xi B (xB2 + pA2\Xi B (xA2\Xi B - 1))} \]

Expected Value of a LNG Project of type A with B in state 3

\[ vAB3 = vAB3 \land A + vAB3 \land B + vAB3 \land C \]

Expected Value of a LNG Project of type A with B in state 3 that partners with a LNG Project of type A

\[ VAB3\Xi A = \frac{1}{e^{(rAB + \delta AB) TAB3\Xi A}} \left( \frac{1}{xA2 + xA2\Xi AB3 - 1} (xA2\Xi AB3 - 1) \right)^{(VA2\Xi B + VB2\Xi A) + 4 pp (VA2\Xi B + VC2\Xi A)} + \frac{pAB3\Xi 2 (u2AB - cAB) e^{(rAB + \delta AB) TAB3\Xi A}}{rAB + \delta AB} + \frac{pAB3\Xi 3 (s u2A\Xi AB3 - cABC) e^{(rABC + \delta ABC) TAB3\Xi A}}{rABC + \delta ABC} + \frac{pAB3\Xi 2 (u1AB - u2AB + cAB) e^{(rAB + \delta AB) TAB3\Xi A}}{rAB + \delta AB} + \frac{1}{rAB + \delta ABC} \left( pAB3\Xi 3 s (u1A\Xi AB3 - u2A\Xi AB3 + cABC) e^{(rABC + \delta ABC) TAB3\Xi A} \right) + \frac{xA2\Xi AB3 - 1}{x2A + xA2\Xi AB3 - 1} \]

Expected Search Time of a LNG Project of type A with B in state 3 to find a LNG Project of type A

\[ TAB3\Xi A = \frac{1}{aAB3\Xi A pAB3\Xi A (xA2\Xi A - 1)} \]