universität wien

MASTERARBEIT / MASTER'S THESIS

Titel der Masterarbeit / Title of the Master's Thesis

„Are natural gas markets integrated: An analysis based on European, North American and North East Asian markets"

verfasst von / submitted by

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angestrebter akademischer Grad / in partial fulfilment of the requirements for the degree of

Master of Science (MSc)

Wien, 2018 / Vienna 2018

Studienkennzahl lt. Studienblatt / degree programme code as it appears on the student record sheet:	A 066 914
Studienrichtung lt. Studienblatt / degree programme as it appears on the student record sheet:	Masterstudium Internationale Betriebswirtschaft
Betreut von / Supervisor:	Univ.-Prof. Dr. Franz Wirl

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List of Abbreviations

billion	-	bn
British thermal unit	-	Btu
carbon dioxide	-	CO2
Commonwealth of Independent States	-	CIS
cubic feet	-	cf
cubic meter	-	m^3
Exajoule	-	EJ
Gaseous Natural Gas	-	GNG
Intergovernmental Panel on Climate Change	-	IPCC
International Energy Agency	-	IEA
Kilogramme	-	kg
kilometre	-	km
kiloton	-	kt
Liquefied Natural Gas	-	LNG
North American Free Trade Agreement	-	NAFTA
Organization of the Petroleum Exporting Countries	-	OPEC
synthetic natural gas	-	SNG
the Internal Energy Agency	-	IAE
United Kingdom	-	UK
United States dollar	-	US$
United States of America	-	USA
United States	-	U.S.
U.S. Energy Information Administration	-	EIA
U.S. Environmental Protection Agency	-	EPA

1. Introduction

Reliable and uninterrupted supply of energy is essential for modern society. Energy consumption is continuing to increase globally as population and living standards are growing. Recent developments on the supply side of energy production have shaken the global energy market. Two of those developments had a particularly strong impact: the worldwide push to reduce greenhouse gas emissions as well as the shale gas boom in the United States of America (USA). In the light of this, natural gas as an energy source is one of the central topics discussed worldwide.

Natural gas is the fossil fuel with the highest growth rate and ranks as the third most important energy source, globally. The shale gas boom in the United States has sparked the high growth rates and further exploitation is planned in South America, Europe, Africa, Asian and Australia (Nowamooz, Lemieux, Molson, & Therrien, 2015, p. 4592).

As the cleanest of the fossil fuels, and with rising amounts of supply due to technological advancement, natural gas has a lot of potential to increase its global share in the energy mix. Another benefit is caused by the fact, the natural gas power plants can efficiently increase and decrease output according to demand, thus working in unity with modern power sources like wind, solar or hydro power. Yet, compared to its substitutes natural gas faces disadvantages as well: For example, one of the disadvantages lies in the supply chain: Like all fossil fuels, natural gas is rarely produced geographically close to its areas of consumption. The transportation of natural gas encounters several difficulties. This is one of the reasons, why regional independent markets for the supply and consumption of natural gas have arisen.

Historically, there have always been differences in consumption prices for natural gas across the world. However, lately the price differences have increased significantly, especially when comparing prices between the two extremes: The United States of America on the one side and Japan on the other end of the spectrum. This may hint the lack of arbitrage possibilities between regional gas markets. In contrast to the increased price differences, new developments have improved flexibility for producers and consumers of natural gas. Technological advancement, reduced share of long-term contracts in trade agreements and a reduction of political market barriers continue to increase the number of market participants and lower the impact of long-term commitments between trading partners. Over the past two decades, a global market has begun to form for natural gas: Like oil, natural gas is transported via tankers in liquified form and thus, independent of pipeline infrastructure. In the light of these developments, this master's thesis aims to explain the recent developments in the natural gas industry, identify key market participants and analyse the question whether the natural gas market is integrated and as such can be described as a global market, or whether it is regionally segmented.

An integrated market is defined "as one in which geography or nationality [of identical goods] do not have systematic effects on transaction prices" (Goldberg & Knetter, 1997, p. 1245). Valuable metals, like gold for example, are typically used to describe integrated markets, because the physical location of trading partners is almost immaterial to the exchange. The oil market is in many ways an integrated market as well: apart from self-sufficient economies, price shocks have observable effects around the globe. However, in contrast to gold and natural gas, oil is traded in varying levels of quality, which decreases comparability of exchanges.

The opposite of integration is segmentation. A segmented market is characterized by price differences exceeding distribution and transportation costs substantially. A good example is the car market: The same model is subject to many different regulations (like safety standards) depending on in which country it is sold. Resale across borders faces complications and probable loss of warranty. Therefore, transaction costs are substantial (Goldberg & Knetter, 1997, p. 1245).

The paper is structured as follows: Firstly, related literature will be discussed. Next, chapter three highlights how natural gas compares to its substitutes and why it is such an important resource. Chapter four then focuses on the market to provide an understanding regarding the production, transportation and different market structures. Important market participants will be identified for the analysis following in chapter five. The analysis itself provides basic theoretical knowledge and hypotheses building to analyses the level of market integration. Three sets of natural gas price data will be analyzed. The first sample will be used to examine the market development between regions to identify important incidents. The second sample investigates whether prices are equal, based on the concept of the law of one price. The third sample will be used for a correlation analysis of natural gas prices. It will be discussed why strong correlation indicates market integration. The same sample will be analyzed graphically as well. Finally, the findings will be presented and discussed in chapter seven. Below, chapter 2 will discuss related literature.

2. Literature review

A number of academics have tackled natural gas market integration in the last two decades. This thesis combines about four different focus areas of previous studies: Natural gas market liberalisation, natural gas markets interdependence, price setting mechanisms for natural gas and the analysis of price divergences around the world and, lastly, the impact of LNG on natural gas markets.

In the field of market liberalisation researchers mostly focus on the United States. Since the liberalisation of the United States (US) natural gas markets, researchers have analysed the level of integration within North America. Serletis (2007) and De Vany & Walls (1993) find that the United States natural gas market is integrated. In contrast to that, Cuddington & Wang (2006) did not enough evidence, that the east and west of the USA are integrated. Kalashnikov, Matis & Pérez-Valdés (2010) provided a regression model to analyse monthly natural gas prices and consumption volumes which may be used to analyse the natural gas market in the United States. Hartley & Medlock III (2014) identify the exchange rate as one of the main influencing factors to the short time absence of oil and natural gas prices equilibria. Kleit (1998) analysed the effects on deregulation on transaction costs in North America. He found mixed effects on deregulation which led to lower transaction costs in some areas while higher costs in others. In their study from 1996 King & Cuc (1996) analysed price convergence of the North American natural gas spot market as well. They applied time-varying parameter and found while price convergence is increasing, the North American market is not fully integrated by the end of their timeframe.

For market interdependence, a number of researchers focused on arbitrage opportunities regarding market integration. Amongst others, Serletis & Herbert (1999) and Murry & Zhu (2008), analysed the North American gas market and found arbitrage opportunities. Murry & Zhu explain this by the presence of significant market power by individual market participants. In contrast to that, Brown & Yücel (2008) found only limited arbitrage possibilities due to transportation capacity constraints. Panagiotidis & Rutledge (2007) use a cointegration approach to analyse natural gas with oil prices in the United Kingdom between 1996 to 2003. They find that that both markets are integrated. An interesting model has been applied by Rodríguez-Gómez, Zaccarelli & Bolado-Lavín (2016). The authors apply the GEMFLOW model and evaluate recent infrastructure improvements and cooperation measures for natural gas in the European region. Depending availability of data, this model could be expanded globally. In their analyses, they find that while in general the natural gas grid has improved, Eastern Europe is rather vulnerable to supply shocks caused by Russian gas.

Focusing on volatility of natural gas and oil markets, Ewing, Malik & Ozfidan (2002) have found that both markets are correlating with another. The applied univariate and bivariate time-series analysis provides a good database to build the analyses on. Another model approach has been taken by Gabriel, Kiet & Zhuang (2005) who apply an equilibrium model to the natural gas market. The authors assigned different motivations to each of group of market participants. However, the model does not account for sufficient variables to model real world case studies. Krichene (2002) analysed the development of oil and natural gas prices from 1918 until 1999 with a focus on the oil price shock in the 1970s. Finding a fundamental increase in volatility of both markets following the 1973.

Inter-regional studies on the integration of regional natural gas markets are less common. Rogers (2010) found European gas markets to be integrated between 2001 and 2005.Siliverstovs et al. (2005) found deep integration within the regional markets of Europe and North America, and limited integration between the Japanese and the European gas market based on data collected between 1993 and 2004. Egging at al. (2008) analysed the European natural gas market by establishing a market equilibrium model which includes most relevant market participants. They find that the European natural gas market does not reflect the ideal outcome as average prices are more than 30% higher than predicted. The authors conclude that the market is not perfectly competitive and market participants are not able to fully utilize market power. Likewise, Lise, Hobbs and van Oostvoorn (Lise, Hobbs, & van Oostvoorn, 2008) analyse supply and demand interactions in the European region. They calculate significant risk of increasing natural gas prices due to limited transport capacities. Rogers (2010) finds correlation between gas prices in Europe at least for the years 2001-2005.

For the North American region, Park, Mjelde and Bessler (2008) find a highly nitrated natural gas market between Canada and the United States. They based their analysis on spot market prices for eight North American natural gas hubs. Wakamatsua & Aruga (2013) analysed the effects of the shale gas boom in the United States on natural gas prices in the USA and Japan. They analysed market data between 2002 and 2012 and found that while the US market had an impact prior the rise of shale gas dated to 2005, it did not so after wards. This implies lower integration between both market post 2005.

Jensen (2004) suggest that it might be necessary to differentiate between LNG and onshore pipeline markets. Due to the high costs of LNG transportation the market will never resemble the global oil market. As onshore transportation is less expensive than LNG shipping, the author suggest that regional markets like in North America are much more integrated and as such, should be considered separately. However, given the recent technological advancements in natural gas production and LNG capabilities, this analysis might not hold up today. Aune, Rosendahl and Sagen (2009) analyse the effects of increasing LNG trade caused by higher reliance on natural gas imports and estimated significant growth in trading volume over the next decades. In their model the authors use a different approach in contrast to this thesis as they focus on production capabilities and trade patterns.

Jansen et al. (2012) take an interesting approach as they analyse the motivation of Russian natural gas export policies. They assume a market share focus in contrast to profit maximization and calculate welfare gains for European customers. Considering huge price differences between Japan and the USA, some researchers analyse price divergence and why the price difference persevere for years now. Zhuravleva (2009) identified several barriers that prevent arbitrage between natural gas markets. Dehnavi, Wirl & Yegorov (2015) found arbitrage opportunities between the USA, UK and Japan. They find that there are a range of issue that hinder exploiting the arbitrage opportunities. While many issues like regulations and incompatible technologies involved may be fixed, the researches guess that motivation for change is missing at key market participants. Rising natural gas prices are expected by Lochner & Bode (2009) for the United States in their interregional natural gas market analysis. In contrast, while European and Japanese natural gas supplies will be less diversified compared to the United States, the proximity will lead to lower prices.

Similar to this thesis, there has been a study on the integration of the European, North American and Japanese natural gas markets for the time period from 1993 to 2004 (Siliverstovs, L'He´garet, Neumann, & von Hirschhausen, 2005). By applying Johansen Full Information Maximum likelihood cointegration procedure, the researchers found a deep integration within the regional markets but could only find some indication for an integration between the Japanese and the European natural gas market. Moryadee, Gabriel and Avetisyan (2014) analyse the impact of increasing volumes of LNG exports by the United States on the global natural gas markets. They found that such a scenario would decrease prices in Europe and Asia significantly implying that given enough transportation capacity, more interregional trade is feasible. The authors applied the game theoretical model called World Gas Model.

Lastly, the impact of LNG has been discussed by many academics. For example, Kumar et al. (2011) summarize the recent developments for LNG and natural gas prices and estimate increasing importance of this energy source. Another analysis of the effects on increased LNG trade on natural gas market integration has been taken by Neumann (2009). Similar to this thesis, the author analyses 2,000 European and North American daily spot prices and finds increasing convergence of both markets in the timeframe of 1999 to 2008.

Information of previous work using the law of one price on natural gas markets was limited. Vany and Walls (1996) conducted a study published in 1996 to analyse arbitrage possibilities within cities. They found that open access to transportation infrastructure is fundamental to realize market integration. There is room for improvement on two levels: first, up to date information is needed as markets develop over time. Second, few studies have focused on global market integration.

The next chapter will present the characteristics of natural gas and compare natural gas with its substitutes.

3. A comparison of energy sources

This chapter will take a comparative look at the research object – natural gas - and its substitutes. Robert W. Howarth, Renee Santoro and Anthony Ingraffen write: “Many view natural gas as a transitional fuel, allowing continued dependence on fossil fuels yet reducing greenhouse gas emissions […] compared to oil or coal over coming decades” (2011, p. 680). This statement is a good start into this chapter as it addresses many important aspects characterizing natural gas: Its role as a transitional fuel, the impact of emissions and its place amongst other energy sources over the next decades. All these are important to understand the importance of natural gas within the modern world. To support this, the most common energy sources including natural gas will be presented and differentiated in this chapter. While a full analyse would exceed the limits of this thesis, the comparison aims to provide a basic understanding of the different forms of energy sources.

Most academics differentiate between two major groups of energy sources: fossil fuels and renewables (Siliverstovs, L’He´garet, Neumann, & von Hirschhausen, 2005) (Jensen, 2004). The key difference between the two is the fact that fossil fuels are limited in their supply while renewable energy sources are not. Fossils fuels have been created naturally over millions of years. Once the supply of fossil fuels has been consumed, it is gone. In contrast, renewable energy sources come in endless supply. Although to be more accurate, a further differentiation between ‘exhaustible’ and ‘inexhaustible’ renewable energy sources can be made.

Aquatic, wind, solar and geothermal energy sources, for example, are inexhaustible, while other renewable sources like wood, bioethanol and biodiesel are exhaustible. Inexhaustible energy sources cannot be depleted by human activity. Renewable but exhaustible energy sources are often called biofuels. (Layton, 2008, p. 439). Biofuels can be defined as any energy source that is derived from plants, algae and animal waste (termed ‘biomass’). While biomass can be replenished within a relatively short amount of time, it does require additional input like water, nutrition and the right living conditions. (Jacobson, et al., 2013, p. 587). In theory, the supply of biomass can be fully consumed with no more possibility to produce more. Currently, biofuels are a niche energy source (Lehman & Selin, 2018). Consequently, this paper will neglect the differentiation between exhaustible and inexhaustible energy sources. The focus will be on the differentiation between renewable energy sources and fossil fuels.

For some time now, another characteristic of energy sources has received major attention: the amount of carbon dioxide that is released into the atmosphere due to energy consumption. The abbreviation for the chemical molecule is termed CO_2 while the quantity of carbon dioxide is typically referred to as 'CO_2 emission'. From a scientific perspective energy is not consumed but rather converted into a different form of energy[1] (Harman, 1982, p. 12). During the conversion of energy, carbon-based energy sources like natural gas release CO_2. Carbon dioxide has been identified as one of the key drivers for global warming (Borchers, Duke, & Parsons, 2007) (Nordhaus W. , 2014, p. 2). Its aggregate state is gaseous, and it has been a steady constituent in the breathable air since before humans existed on the planet. It has a strong effect on the global temperature level. When the concentration of carbon dioxide increases, the global temperature is increasing as well and vice versa[2] (Cubasch, et al., 2001, p. 559). While the planet earth has seen multiple phases of higher and lower concentrations of CO_2 in the atmosphere, the impacts of changing temperature levels one the life forms on this planet are extensive.

Global warming will lead to eradication of various plants and animals. Billions of Euro are going to be expended to limit the adverse effects on human civilization (Kang, Khan, & Ma, 2009) (United Nations Development Programme, 2016, pp. 14-22). For example, the Intergovernmental Panel on Climate Change (IPCC) lists the annual monetary equivalent created by forests in the United States of America (USA) to regulate climate at a range of one to six billion US Dollar. While the pollination of crops by insects is estimated at 153 billion € globally. Global warming would significantly reduce these and other benefits (Oppenheimer, et al., 2014).

Due to those dire consequences of global warming, international attention towards the rising CO_2 levels has been increasing and increasing effort is being put in place to limit the CO_2 concentration in the atmosphere (McKenzie, Newman, & Adgate, 2012) (Bhore, 2016). As one of the key drivers for global warming, energy sources are directly affected by decisions to reduce CO_2 emissions. For instance, the United States Environmental Protection Agency (EPA) reports that 91% of all greenhouse gas emissions in the United States (U.S.) were primarily caused by fossil fuels in 2015 (United States Environmental Protection Agency, 2017, pp. 102-104).

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[1] e.g. electric power is converted to thermal energy (heat) and electromagnetic radiation (light)
[2] However, carbon dioxide is only one of many factors that influence global temperature levels

From a chemical point of view fossil fuels are hydrocarbons. Hydrocarbons are organic compounds that consist of the elements of hydrogen and carbon. Coal represents the solid form of hydrocarbons, while oil is liquid and natural gas is gaseous. When hydrocarbons are combusted, the elements react with oxygen to carbon dioxide, hydrogen oxide (water) and energy. Thus, due to their chemical composition, all fossil fuels release CO_2 when combusted (Wheeler, 2010, p. 6).

The release of carbon dioxide is not just linked to the combustion of carbon-based energy sources. Further processes which influence the level of CO_2 are amongst others: harvesting, refining and accessing the energy source, like building the machinery, transport of infrastructure, set up etc. (Center for Climate and Energy Solutions, 2017). Yet, the conversion stage is most commonly at the centre of academic and political attention (Searchinger, et al., 2009). Moreover, there are a range of different substances apart from CO_2 that contribute to global warming. All gases that contribute to global warming, for example Methane and Nitrous Oxide, are called greenhouse gases (US Environmental Protection Agency, 2016). To limit the scale of this paper, this thesis will compare just the amount of carbon dioxide that is released during the combustion process.

Building on this, renewable energy sources have the major advantage of releasing zero CO_2 when used to produce energy. Yet, there is one other energy source which shares this advantage but is not part of the renewables group: nuclear energy. While nuclear energy technically relies on fuel to produce energy, this comparison separates nuclear energy from coal, oil and natural gas due to the absence of CO_2 emissions. Consequently, this thesis will broadly differentiate between renewables, fossil fuels and nuclear power for the comparison below.

Yet, before going into detail, another important factor that goes hand in hand with energy production is a concept called ‘externalities’. The International Monetary Fund defines externalities as: “indirect effects have an impact on the consumption and production opportunities of others, but the price of the product does not take those externalities into account. As a result, there are differences between private returns or costs and the returns or costs to society as a whole.” (International Monetary Fund, 2010). In other words: Externalities are intended or unintended side effects which can occur in every economical action. For any product or service to be considered an externality, it must not show up in accounting of the company that triggered it. Externalities can be either negative or positive depending on their influence on a third party (the first and the second party being the seller and the buyer, respectively). For example, bees may have the positive side effect of increasing the fertility of nearby flowers. The importance here is that the beekeeper does not charge the businesses that grow flowers for this service. Another example is a forester whose trees reduce the CO_2 level in the air.

Negative externalities on the other hand are much more common, as for example construction workers produce noise that disturbs other people. While smokers harm nearby people mentally and physically (Andreas A., 1994, pp. 50-60). Usually affected people receive no compensation for the noise and or toxic fumes produced by tobacco products. Consequently, this would be negative externalities.

Fundamentally, all people around the world are - or going to be - negatively influenced by global warming even though only a small amount of people conduct energy transformation on a major base. This group does not regularly compensate their victims for emissions and, consequently, CO_2 as a by-product of energy production often fulfils the condition of a negative externality. However, the damage that is caused by externalities is difficult to measure (Scholz, 2000, p. 40). While academics have tackled this issue, this thesis does not pursue this goal (e.g. (National Research Council, 2010). Instead, externalities will be presented by providing examples.

To sum up, there are many important factors to consider when comparing energy sources. The thesis does not aim to tackle this topic in its entirely. Yet, many important factors that define natural gas in its role as an energy source like availability, usage, productivity, carbon dioxide emissions and externalities will be addressed. Next, each relevant energy source will be described in more detail. Subchapter 3.1 deals with fossil fuels, followed by subchapters 3.2 and 3.3 for nuclear power and renewable energy, respectively.

3.1 Fossil fuels

Fossil fuels used to be faunae and florae that existed millions of years ago. Over time and under specific external conditions, like high levels of temperature and high-pressure levels, the remains transformed into fossil fuels (natgas, Background, 2013). Fossil fuels: Coal, oil and natural gas, are very valuable and impact the live of billions of people on a daily basis (Morris, Fossil Fuels, 2007, p. 4) (Curley, 2012, p. 11). Each of them will be described below, starting with coal.

3.1.1 Coal

Coal has been used as a combustible to create heat for a very long time (Harper, 2016). Next to wood, coal is second oldest energy source that has been used on a large scale. There is evidence that Coal has been used on the European continent dating back to 2,000 BCE. It was used on larger scales in the ancient civilizations of China, Greece and Rome (Curley, 2012, pp. 89-90) Coal began forming during the Carboniferous Period some 300 million years ago. Over time, layers of dead plants piled up above each other and the pressure levels at the bottom layers increased. Due to the high pressure the faunae and florae were concentrated and – over a very long time - turned into the mass we call coal.

There are three major types of coal: lignite, bituminous coal and anthracite. A regular coal deposit consists of all three types, located in layers on top of each other. The top layer usually consists of lignite, mostly referred to as 'brown coal'. Brown coal has been subject to lower pressure levels compared to the other two types of coal. As a result, its contents are not as concentrated as bituminous coal and anthracite. In many ways brown call is inferior to the other two types in terms of quality (Kopp, 2016). The middle layer of a coal deposit is made up of bituminous coal. This is the most common form of coal used today and is often known as black coal. Lastly, the bottom layer consists of coal variance called anthracite. Anthracite is also of black appearance like bituminous coal. However, while being superior in terms of quality, it is harder to extract and of lower availability compared to bituminous coal (Morris, Fossil Fuels, 2007, pp. 6-7).

Today, coal is mostly used for electricity production (King H. , 2016). According to Enerdata 7,749 megatonne (Mt) of coal have been consumed in 2015. Almost half of this has been consumed by China[3] alone; followed by India, the United States of America and Germany. Furthermore, China is also the biggest producer of coal with about 46%, followed by the United

[3] Regarding terminology in this paper: The Peoples Republic of China will be referred to as China, while the Republic of China will be referred to as Taiwan

States (10.7%) and India (9.9%) (Enerdata, 2016). Compared to total energy consumption in 2013, coal had a share of 11.5% (International Energy Agency, 2015). As coal's natural state is solid it can easily be transported as general cargo without fulfilling special transportation requirements. Coal is usually transported by rail or by water. For example, rail transportation of coal accounted for about 58% of total US coal transport in 2004 (National Research Council, 2007, p. 80).

There are two ways to extract coal: Either coal is directly mined from the surface, or it is mined underground. Surface mining is usually less expensive compared to underground mining, unless the coal seam is too deep below the ground. In this case, the cost for removing all materials to allow surface access is higher than the additional costs of underground mining. Another advantage of surface mining is a higher extraction rate: coal can be mined faster on the surface and a higher percentage of the available coal supply can be economically extracted (90% for surface mining compared to 55% for underground mining) (National Research Council, 2007, pp. 60-61).

One factor for comparison of non-renewable energy sources is energy density (Layton, 2008). For simplicity reasons oil, natural gas and nuclear power will be compared to coal in this section using 1.0 kg of bituminous coal as the benchmark. Similarly, the amount of CO_2 emissions released during the combustion of oil and gas will be compared to the levels of coal. As stated by the U.S. Energy Information Administration 205.7 pounds of CO_2 are released when one million British thermal units (Btu) of energy is generated with coal (U.S Department of Energy, 2016). A Btu is the amount of energy needed to increase the temperature of 500 millilitre (ml) of Water from 39.2° Fahrenheit to 40.2° Fahrenheit (WebFinance, 2016).

In addition to carbon dioxide, air pollutants like sulphur dioxide and mercury - which are injurious to human health - are released during coal combustion (de Melo-Martín, Hays, & Finkel, 2014, p. 1117). Other external cots of energy production by coal include damage to the local environment surrounding coal mines: for example, water ways can be affected by collapses of underground mining facilities and underground mine fires can occur after a mine has been closed. Also, surface mining affects the landscape around the coal mine as a lot of material needs to be replaced in order to access a coal seam. After mining operations have concluded, the local environment at the mine is either artificially reconstructed or left destroyed (National Research Council, 2010, p. 79).

To ascertain the supply of fossil fuels, two terms need to be differentiated: reserves[4] and resources. 'Resource' refers to the total supply of a fossil fuel that is known. Reserve is more specific in the way that the term conveys the supply that under current prices and technologies is economical feasible to produce. Thus, resources at least equal in amount compared to reserves (Donev, Stenhouse, & Hanania, 2016). For example, the EIA estimates the natural gas resources of the USA at about 53,002 billion m^3 compared to 9,575 billion m^3 reserves in 2014 (U.S. Energy Information Administration, 2017, p. 133). When it comes to coal reserves, global supply was estimated at 20,661 Exajoule (EJ) in 2015 (Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), 2015, S. 33). An Exajoule represents 10^{18} Joule and is widely used to compare the energy output of different energy sources. For comparison, the energy consumption of the whole planet was estimated at 540 EJ in 2015 (Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), 2015, S. 34).

The International Energy Agency (IAE) expects that the total primary energy production of coal remains somewhat stable for the next 20 years. Due to rising energy demand in general, the share of coal will experience a relative drop in total energy supply. However, should the world community actively pursue the 2° Celsius goal (to limit the effects of global warming), decreasing demand to about half of today's levels is anticipated (International Energy Agency, 2015, p. 46). Similarly, Enerdata forecasts a drop of 20% of today's coal share by 2040 in their most likely future scenario (Enerdata, 2016, p. 23).

This concludes the section about coal, the next section highlights the fossil fuel oil.

3.1.2 Oil

Compared to coal, oil is a relatively new source for energy generation and its rise began with the commercial use of the internal combustion engine in the second half of the 19th century (Encyclopædia Britannica, 2017). Although there is evidence that oil was used for medical and military purposes more than 2,000 years ago (Wheeler, 2010, p. 10). Oil originates from aquatic animals and plants that existed more than 500 million years ago. The remains of these lifeforms

[4] The term reserves in this chapter equals proven reserves in contrast to unproven reserves that can be found in other literature

were preserved within ground sediments and underwent chemical changes caused by biological processes as well as high temperature and pressure levels towards the product known as oil today (Curley, 2012, p. 3).

The raw material from conventional oil production is called crude oil. It is transported to a refinery to separate crude oil into a variety of petroleum products like gasoline, diesel fuel and asphalt (U.S. Department of Energy, 2016). Additionally, oil is used to create chemicals and plastics, which are used in a variety of products (Sherman, 2004, p. 8). Oil is predominantly used in the transport sector with a share of 63.8% in 2013 (International Energy Agency, 2015, p. 33).

The conventional supply of oil is located in underground reservoirs. Oil rigs, either onshore or offshore, extract the fluid to the surface. The most common nonconventional source of oil comes in the form of so called oil sands. These are certain sands which contain a thick oily substance which can be refined into synthetic crude oil. One ton of oil sand will produce about half a barrel of synthetic crude oil. However, oil generated from oil sands consumes significantly more water and energy in the production process compared to conventional oil sources (National Research Council, 2010, p. 172).

As the natural state of oil is liquid, transportation is somewhat more complicated compared to coal. Thus, special transport infrastructure is needed. Crude oil and oil products are commonly transported either in pipelines or tankers. Accidental release of oil may occur at any stage between production and consumption. This may potentially contaminate large quantities of water, plants and animals within the surrounding environment. For example, about nine thousand tons of oil have been unintentionally released into the water system in the United States of America between 1990 and 1999. The affected water needed to be treated before being safe for consumption (National Research Council, 2010, pp. 173-174).

Oil has a higher energy density compared to coal. 1.59 kg of coal are needed to achieve the equivalent energy outcome of 1 kg of oil[5] (European Nuclear Society, 2016). Additionally, oil emits 23.6% less CO_2 compared to coal (U.S Department of Energy, 2016). The share of oil consumption in the global energy mix equated 39.9% in 2013. As oil is mostly used for transportation, its share in electricity generation was just at 4.4% (International Energy Agency, 2015). The United States consumed 18.4%, China 12.3% and India 4.5% of total oil consumption

[5] oil refers here to gasoline

in 2015. When it comes to production, in 2015the United States lead the global refined oil production with 20.1%, followed by China (12.3%) and Russia (6.6%) (Enerdata, 2016). When it comes to crude oil production, Saudi Arabia lead the field with 12.9% in 2014, closely followed by Russia and the United States (International Energy Agency, 2015, p. 11).

In 2015, total oil reserves were estimated to equal 9,149 EJ. This number can be differentiated into 7,144 EJ of conventional oil reserves and 2,005 unconventional oil reserves (Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), 2015, S. 33). Similar to coal, the IEA expects steady production levels, with a downward trend if an emission reduction policy is pursued (International Energy Agency, 2015, p. 46). Enerdata forecasts that the share of oil in total energy supply drops by about 28% by the year of 2040 (Enerdata, 2016, p. 23).

The next section deals with natural gas in comparison to its substitutes, chapter 4 will provide more detailed information on sources, transportation and storage of natural gas.

3.1.3 Natural gas

One of the earliest mentions of natural gas being used comes from the Chinese mainland about 500 BCE. Natural gas was collected to boil water via rudimentary bamboo pipelines (Sherman, 2004, p. 10). From the late 18th century onwards in England, natural gas was used to fuel street lights before being replaced by electrical energy much later (natgas, History, 2013). Historically, natural gas used to be merely a by-product of oil production. Underground oil reservoirs often contain natural gas as well. Its origin is very similar to that of oil, however the necessary conditions for the transformation of organic matter to natural gas are less strict compared to the conditions for oil (Curley, 2012, p. 12). Oil is more common in reservoirs which have experienced lower temperature levels. Reservoirs between one and two kilometres (km) below the ground mostly contain oil and some quantities of natural gas, while reservoirs deeper below the ground contain more and more quantities of natural gas. At the lowest levels natural gas can be found in its highest quality (natgas, Background, 2013).

The highest quality of natural gas consists solely of methane, which is gaseous, colourless and odourless. However, often other components like ethane, propane, butane, nitrogen, hydrogen and CO_2 can be found in natural gas compounds. These can influence the colour, odour and flammability (Curley, 2012, p. 13).

Methane gas is not solely found in underground reservoirs. Some life forms produce methane as well. Certain microorganisms use chemical processes to break down organic matter. Methane is a product of a number of such processes. These microorganisms can be found in different species, including humans and cows. With the right technology, the methane can be collected and used in the same fashion as natural gas from underground reservoirs. Similarly, the chemical process can be duplicated to reduce the difficulties of collecting methane from animals (natgas, Background, 2013).

On a global scale, natural gas is mostly used for electricity and heat generation. In the transport sector, natural gas accounted for 6.9% in 2013 (International Energy Agency, 2015, p. 34). Due to the lower density compared to oil as well as coal, natural gas is costlier to contain for storage and transportation (Jensen, 2004, p. 5)[6]. Conventional natural gas reserves were estimated at 7,260 EJ, while unconventional natural gas reserves were estimated at 258 EJ in 2015 (Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), 2015, S. 33). Chapter 4 will further analyse natural gas reserves.

The share of natural gas consumption in the global energy mix equated 15.1% in 2013. The share in electricity generation was at 21.7% (International Energy Agency, 2015). The United States consumed 21.8%, Russia 13.0% and China 5.2% of total natural gas consumption in 2015. In terms of production, the United States were leading as well. Their share of total production was 21.4% in 2015. Russia had a share of 18.1% and Iran was in third place with 4.9% (Enerdata, 2016).

The energy density of natural gas lies between that of coal and oil. 1.35 kg of coal are needed to produce the equivalent energy outcome of 1 m^3 of natural gas (European Nuclear Society, 2016). This can be observed in the automobile sector for example: The range of gas powered vehicles is lower compared to oil powered vehicles assuming identical sized fuel tanks. In contrast, compared to oil and coal, natural gas emissions are at 56.9% matched to the level of coal (U.S Department of Energy, 2016). Consequently, natural gas has the lowest CO_2 emissions of this group of fossil fuels.

[6] More on this in section 4.2

However, this does not mean that natural gas is automatically the better choice compared to oil and coal when it comes to limiting the effect of global warming. As described above, natural gas consists predominantly of methane. Methane is considerably more harmful[7] to the atmosphere compared to CO_2. There is a constant risk of an uncontrolled release of natural gas into the atmosphere, as it is lighter than breathable air[8]. The effects on global warming are about 90 times greater when comparing the impact of methane with carbon dioxide (Jacobson, et al., 2013, p. 587). Furthermore, methane remains ten times as long in the atmosphere than carbon dioxide (Nowamooz, Lemieux, Molson, & Therrien, 2015, p. 4593).. Thus, natural gas needs to be combusted to benefit from its better environmental characteristics.

Another negative effect of the combustion of natural gas is the release of very small particles. These are generally referred to as 'PM X', where 'X' denotes the specific diameter of the relevant particle in micro meters. These particles can bypass the outer layers of protection of the human body and enter the lungs. Once inside, the particles significantly increase the risk of premature mortality. Natural gas combustion emits PM 2.5 particles directly. In addition, other gases which can form PM 2.5 particles via chemical reactions in the atmosphere are released during combustion as well.

One further advantage of natural gas is in the transportation sector. As an energy source for transportation, natural gas benefits from an advantageous characteristic: When it comes to safety, the auto ignition temperature of natural gas is about 580°C, while gasoline already auto ignites at temperature levels of 280°C (Safety Storage Centre, 2016). Thus, the likelihood of an explosion is lower compared to gasoline powered cars. Additionally, natural gas-powered cars have lower noise emissions due to the physical aspects of natural gas engines (Logistik Initiative Hamburg, 2015, p. 13). Other possible external costs include but are not limited to: pollution and destruction of ecosystems due to mining or drilling operation as well as increased international conflicts to secure energy sources (McCubbin & Sovacool, 2013, p. 429).

When it comes to the most efficient applications, natural gas is best used in power plants to produce electricity. It is less efficient than oil when used for transportation and both, coal and oil,

[7] 86 times as bad over a 20-year period and 34 times as bad over a 100-year period (Davies, et al., 2014, p. 240)

[8] As oil-based fuels are harmful for all animals and plants they get into contact with and are reducing water quality levels, it is debatable whether an uncontrolled release of oil base fuels is comparatively better for the environment than an uncontrolled natural gas release

are more efficient for heating (Jacobson, et al., 2013, p. 587). The use of natural gas for the supply of electricity is expected to experience at slight increase for the next 20 years (International Energy Agency, 2015, p. 46). According to Enerdata, by 2040 the share of natural gas will remain stable at about 20% of total energy supply (Enerdata, 2016, p. 23). Chapter 4 of this thesis will expand this data further.

This concludes the overview to the fossil fuel group. Next nuclear power as an energy source will be presented.

3.2 Nuclear power

Necessarily, to the use of Uranium as a power source followed the scientific discovery of the atom and nuclear fission. Most of the required findings were made in the first half of the 20th century. The first full-scale power plant started operating in 1956 and since then, nuclear energy has become an established power source (Weart, 1988). For nuclear fission, two chemical elements can be used: plutonium and uranium.

For the civilian use of nuclear power enriched uranium dioxide is the dominant source (Morris, Nuclear Power, 2007, pp. 14-15). Uranium is a metal that is mined in multiple locations around the world. In 2015, about 60,500 tonnes of Uranium have been minded globally. At this level, the global supply of Uranium will last for more than 200 years (Bundesanstalt für Geowissenschaften und Rohstoffe, 2016, pp. 54, 56). When it comes to the energy density the values for the Uranium Isotope U-235 will be considered. Uranium has a extensively higher energy density compared to fossil fuels. 2.7 million kilogramme (kg) of coal equivalent are needed to generate the energy produced during one complete fission of a single U-235 atom (European Nuclear Society, 2016).

Nuclear power is generally used in power plants to generate electricity and amounted to 10.6% of world electricity generation in 2013 (International Energy Agency, 2015). In 2015, 441 nuclear plants were operating globally, with 65 additionally under construction and 8 decommissions. Kazakhstan lead global uranium production with about 23.8 kiloton (kt), followed by Canada and Australia which each about 13.3 kt and 5.7 kt of uranium production respectively

(Bundesanstalt für Geowissenschaften und Rohstoffe, 2016, pp. 56, 58). When it comes to demand, the United States consumed about 18.7 kt of uranium in 2015. The second biggest consumer was France with 9.2 kt, followed by China with 8.2 kt (Chepkemoi, 2017).

The major problem of nuclear power is the unsolved question how radioactive material can be safely contained. Radioactive decay emits radiation that is very harmful to organic matter. During nuclear power generation, radioactive waste is produced that continues to emit radiation for thousands of years (Morris, Nuclear Power, 2007, pp. 16-17). Thus, the material needs to be isolated for a long period of time while posing constant danger to its surroundings. This does also apply for the active use of nuclear material in power plants: While the risk of accidents is very low, failure is not improbable. In such an event, the consequences for the environment are catastrophic: As the 2011 accident at the nuclear power plant in Fukushima Daiichi showed, vast areas of land have become inhabitable for humans. Plant and animal life is toxic. As of November 2016, areas more than 50km from the nuclear power plant away display dangerous levels of radiation (Radioactivity Measurement and Investigation Project, 2016). Naturally, the transportation of radioactive material requires specially designed transport packaging as well (World Nuclear Transport Institute, 2012, p. 6).

The IEA expects a significant increase of nuclear power supply until 2040. Even more, if the 2° Celsius goal is actively pursued (International Energy Agency, 2015, p. 46). This goes in line with the estimations of the German Federal Institute for Geosciences and Natural Resources, which sees demand growth due to increasing nuclear power production capacity in Asia and the long-term commitment to nuclear power of several European countries (Bundesanstalt für Geowissenschaften und Rohstoffe, 2016, p. 58).

This concludes the subchapter for nuclear power. Following, the group of renewable energy sources will be described.

3.3 Renewables

Renewable energy sources for electricity generation have been on the rise for the last decades only. However, there have been some early applications of renewable energy sources (e.g.

wind and water mills) (Musgrove, 2010, pp. 15-21). There are multiple sources of renewable energy: Geothermal, wind, solar and aquatic/hydro are amongst the most prominent forms.

Geothermal energy can be harnessed due the fact that temperatures are much higher below the ground than above the ground. The centre of the Earth is very hot and temperature levels decrease further away from the core. In certain areas, the distance between economically achievable debts with high temperate is short enough for commercial energy generation. When it comes to wind energy, changing patterns in temperature levels affect Earth's weather which in turn causes wind that can be used to generate power. Aquatic energy can be generated by aqua damns using river currents and by utilizing tidal energy. Tides are directly caused by the gravity of the moon during its orbit around the earth. In turn, solar energy originates from the radiation emitted by the Sun. (Layton, 2008, pp. 439-440).

The main argument in favour of renewable energy sources is the lack of disadvantages regarding the problems for non-renewables mentioned earlier. There are no carbon emissions released during the electricity generation process, endless supply and there are no long-term storage and radiation issues (de Melo-Martín, Hays, & Finkel, 2014, p. 1117) (Slovic, Flynn, & Layman, 1991). McCubbin and Sovacool (2013, p. 438) estimate that by using wind power in the USA (Altamont Pass) external costs caused by fossil energy sources can be reduced by 560 million to 4,380 million United States dollar (US$) until 2031.

Renewables may decrease dependency for some countries on fuel imports (Dusmanescu, 2017, pp. 393-394). However, renewables' energy efficiency depends on the natural environment of their location. For example, solar energy benefits from areas with higher sunshine duration and intensity, and hydro power depends on suitable aquatic locations. For example, Norway and Finland are both developed economies in Northern Europe. In 2013, Norway had an installed hydro power capacity of 31 Gigawatt (International Energy Agency, 2015, p. 20) while in 2011, the similar sized Finland only had an installed capacity of 3 Gigawatt (World Energy Council, 2016).

Yet, renewable energy sources are not without disadvantages. The infrastructure requirements are usually higher compared to non-renewable energy sources to achieve similar levels of electricity output. The phenomenon of externalities applies to renewables as well. For instance, wind turbines lead to death of birds and bats (de Melo-Martín, Hays, & Finkel, 2014, p.

1117). However, a study reported that wind turbines led to a very low casualty rate of avian life compared to other human build structures (Erickson, et al., 2001, p. 19).

The global share of electricity generation of renewable energy sources totalled 22.0% in 2013. Hydro power alone contributed 16.3% of that (International Energy Agency, 2015). While under certain circumstances the price for renewable energy can compete with the more traditional energy sources, generally speaking renewable energy is still more expensive in comparison (Christ & Bothe, 2007, p. 6). This applies especially, if the issue of storage is considered. A traditional power plant for coal can be booted up and down following the local demand within hours. Power plants for gas are even more suited as their boot up time is considerably lower (National Research Council, 2010, p. 124). In contrast to that, solar power plants only generate electricity during the day with varying output levels depending on solar intensity. Similar to that, wind power depends on wind intensity. Thus, in general renewable energy sources follow supply in contrast to coal, gas, oil and nuclear power who can follow demand. Hence, technologies that can store peak energy supply for renewable energy sources are needed to assure that the demand can be met all the time (de Melo-Martín, Hays, & Finkel, 2014, p. 1117).

Regarding renewable energy costs, Borchers, Duke and Parsons conducted a study with participants from the state of Delaware, USA. They found that their study had a positive willingness to pay for renewable energy (2007, p. 3333). In contrast to that, a study from 2010 made in Germany, a country with a comparatively positive attitude to renewable energy, found that at least 75% of the participants were not willing to accept a price premium that would cover the additional costs for renewable energy. While the small premium was accepted, the respondents' willingness to pay a premium did not meet the expected extra costs for renewable energy production (Gerpott & Mahmudova, 2010, p. 315).

The growth experienced by renewable energy sources will continue for the next decades. As hydro power is limited in its expansion capacities, other renewable energy sources will benefit stronger (International Energy Agency, 2015, p. 47). Enerdata expects that the share of renewable energy sources will increase to levels between 23% and 38% of total energy supply by 2040, depending on the political will to decrease CO_2 emissions (Enerdata, 2016, p. 23).

This completes the section about renewables. This chapter concludes with a summary of the findings.

3.4 Comparison summarized

The following table summarizes the key findings of this chapter.

Type	Coal	Oil	Natural Gas	Nuclear Power	Renewables
Energy Density	1.59 kg	1,00 kg	1,18 kg	~0 kg	Not applicable
CO_2 amount for one mil Btu	205.7 pounds	184,9 pounds	116,6 pounds	0 pound	0 pound
Reserves	20,661 EJ	9,149 EJ	7,318 EJ	106.48 mil EJ	infinite
2013 total primary energy share	29.9 %	31.1 %	21.4 %	4.8 %	13.8 %[9]

Table 1 - Comparison of Energy Sources

Source: findings above

As it is shown, natural gas excels only if the field of carbon dioxide emissions when compared to the other two fossil fuels. It has the lowest supply of energy and the energy density is in the middle of the two. Adding to this, transportation is also more complicated due to its gaseous form. However, the lower carbon dioxide emissions and the availability of natural gas are enough to warrant its relevance in energy production.

The goal of the following part is to provide the baseline for the understanding of the global supply and demand situation of natural gas. Thus, the next chapter will focus entirely on natural gas to provide more detailed information about how and where it is produces, where it is consumed and how it is transported. With that knowledge, the price development and level of market integration will be analyzed in chapter 5.

[9] 10.2% are labeled as biofuels which includes waste. Waste includes industrial waste and municipal waste, which may not be considered renewables. Thus, the actual share is lower than the given percentage. However, it was not possible to provide an estimation for the share of industrial waste and municipal waste.

4. Natural gas in detail

This chapter aims to give the reader an understanding of the supply and demand side of natural gas. The dynamics of production, transportation and consumption of natural gas will be presented. Afterwards, by adding price developments to the picture, chapters five then seeks to find and present arguments in favour and against the existence of a global integrated market for natural gas.

This chapter is organised as following: First, an overview for the global natural gas cycle is given. This overview groups all countries into regions in order to simplify as well as structure important regional areas for further analysis. Next, subchapter 4.1 will highlight the different production methods of natural gas. Subchapter 4.2 focuses on transportation and storage. Finally, three regions have been selected for deeper examination in subchapter 4.3. For each region, the basic conditions regarding demand and supply will be portrayed and special characteristics of each region will be highlighted.

When dealing with quantities of natural gas, different measurement units exists: Cubic feet (cf) is mostly used by American sources, while cubic meter[10] (m^3) is more commonly used by organizations based in countries that follow the metric system. Both refer to the volume of natural gas given normal temperature and pressure levels. In the previous chapter, British thermal units (Btu) have already been introduced. In contrast to cubic feet and cubic meter, Btu refers to the energy output of natural gas. A single cubic foot is equivalent of roughly 1,027 Btu (natgas, Background, 2013).

Due to the nature of natural gas, prior to its extraction the total available supply of natural gas can only be estimated. There exist a range of different organization who give estimates over the available supply of natural gas for individual counties. For comparative reason, this chapter will provide natural gas reserve data from two sources: the EIA and the intergovernmental Organization of the Petroleum Exporting Countries (OPEC).

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[10] About 35.3 cf of natural gas equal 1 m^3 of natural gas

Table 2 aims to give an overview about different regions regarding basic setting for the supply and demand of natural gas. The table divides all of the world's economies into seven regions and lists each of the region's quantity of natural gas regarding reserves, production and consumption for the year of 2014. The region of 'North America' consists of Canada, the United States of America and Mexico, while 'North East Asia' consist of Japan, South Korea (Republic of Korea) and China. The third region in the first column consist of the countries of Europe, Turkmenistan and the Commonwealth of Independent States (CIS). The Commonwealth of Independent States was formed after the dissolution of the Soviet Union in 1991. Currently, there are nine Member states: Armenia, Azerbaijan, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan and Uzbekistan (Apergis & Payne, 2010, p. 651). Apart from the North American, North East Asian and European region, all other economies are associated to their natural region. The detailed composition of all regions can be found in Appendix I. The last row of Table 2 displays the difference between production and consumption. The quantities are given in billion (bn) m³.

	natural gas in bn m³ for 2014			
Region	Reserves	Production[11]	Consumption[12]	Δ
North America	11,955	942	945	-3
Remaining America	7,663	167	169	-2
Europe, CIS and Turkmenistan	69,976	1,101	1,125	-24
Africa	14,494	212	129	83
Middle East	80,190	626	442	184
North East Asia	3,275*	133*	363	-230
Remaining Asia & Pacific	13,668	384	358	26
Total	201,221	3,565	3,531	34[13]

Table 2 - Regional overview natural gas data

Sources: *(Organization of the Petroleum Exporting Countries, 2015, pp. 94-101)* & *(International Energy Agency, 2016, p. 33)*

** OPEC source did not provide individual estimation for South Korea regarding reserves and production, and for Japan regarding reserves. This is mostly due to the low amounts in the respective categories. Consequently, the discrepancy is neglectable.*

[11] Here 'production' refers to marketed production

[12] The estimations for 'consumption' originate from the IEA because the OPEC source does not provide data for this category. As both organization use different sources for the underlying data, there is no perfect match. Still, absolute accuracy of the data is not required to exemplify the fundamental trend.

[13] Due to several reasons including different sources and rounding, the numbers do not at up

Table 2 shows several important facts: The Middle East region possesses the largest quantities of available natural gas as well as having the largest production surplus. The region consisting of Europe, Turkmenistan and the countries of the CIS (often referred to as 'Eurasia') lead the field regarding production and consumption of natural gas. The second biggest producer and consumer region is North America. This region is characterized by a relative balance of production and consumption quantities. Another important region is North East Asia which experiences the largest deficit of all regions, especially given the fact that this region encompasses only three economies. Summarizing, the Middle East and Africa are surplus regions, America is roughly balanced, and Europe and Asia are deficit regions. These findings are in line with other academics, e.g. Tsafos (2015) and Bilgin (2009, pp. 4482-4483). Another interesting observation is that the supply – production ratio is highest for the Middle East and lowest for North America. Assuming similar levels of production and comparable quantities of reserves for the future, North America will have depleted most of their local supply of natural gas within twelve years. In comparison, the local supply of the Middle East will last for more than a century.

To limit the scale of this paper, three regions have been chosen for further analysis: The North American region, the European and CIS region, including Turkmenistan, and the North East Asia region. All of the world's most natural gas consuming economies can be found within this sample. Thus, the sample suffices to address the research questions. Also, with Russia and the USA the two leading producers of natural gas are included. As it will be shown in the following subchapters, Europe and North East Asia showcase two different characteristics of natural gas trading: Europe's supply originates to a large extend from within the region while North East Asia's supply comes mostly from outside the region. While the composition of the regions might seem somewhat arbitrary at first, this goes in line with other academic literature (Siliverstovs, L'He´garet, Neumann, & von Hirschhausen, 2005, p. 605), (Bilgin, 2009) & (Neumann, 2009, pp. 187-188). As it will be shown next, the countries within the regions share some characteristics that separate them from countries outside of the respective region. Each of the three regional sections in subchapter 4.3 will describe the regional markets' needs regarding supply and demand.

4.1 Production of natural gas

As described in subchapter 3.1, natural gas is found in underground reservoirs. Organizations search for natural gas and set up wells for extraction (natgas, Background, 2013). Set up and drilling can last in a period between six months and up to ten years. Total supply of a well is not known beforehand. Additionally, the productivity of a well declines over time. Thus, supply uncertainties occur in natural gas production (natgas, Industry and Market Structure, 2013).

Until recently, natural gas has been extracted predominantly from underground caverns where it has been trapped either directly during the transformation of biomass into natural gas, or when the gas moved towards the surface due to geological activity. The process of extracting natural gas from underground reservoirs is called conventional natural gas production. Yet, large quantities of natural gas can be found outside of underground caverns. Certain impervious rock layers contain natural gas as well. Due to technological advancements and rising prices for natural gas consumption, these sources have become economically feasible to extract. Today, shale rock beds provide a common source for natural gas production. This type of extraction is called unconventional natural gas production, hydraulic fracturing, and 'fracking'. Natural gas from shale rock formations is sometimes referred to as 'shale gas' (Finkel, Selegean, Hays, & Kondamudi, 2013). However, natural gas produced with this method is identical to conventional natural gas (Finkel & Hays, 2013, pp. 889-890). The production of natural gas from unconventional sources can lead to higher domestic energy security or even export opportunities for countries, that have limited conventional natural gas sources as well as enabling employment and economic opportunities (Popkin, Duke, Borchers, & Ilvento, 2013, pp. 62, 67, 68).

The basic method of hydraulic fracturing to access natural gas outside of large underground cavers have been used in the United States of America for 60 years. Yet, it is the relatively new technique of horizontal drilling that is the base for the increasing share of hydraulic fracturing in natural gas production (Rivard, et al., 2014, p. 65). Basically, the method can be described as following: Firstly, a vertical well is drilled to reach the natural gas formations usually located about one kilometre deep. Secondly, the well is expanded vertically to cover a wider area. The target zones are usually less than 100 metres in diameter. Thirdly, under high pressure fluids are injected into the gas containing layers of earth below the surface. This clears a way for the trapped gas to reach the natural gas production site on the surface (Rivard, et al., 2014, p. 64). However, the fluids can be collected only partially (McKenzie, Newman, & Adgate, 2012, pp. 79-80). The two main components of these fluids are water and sand. Additionally, about one percent of the fluid is a mix of different chemicals. For example, acids will open cracks in the layers of soil, while lubrication agents reduce friction. Other substances are gelling agents, breaking agents, corrosion inhibitors and biocides (Finkel & Hays, 2013, p. 190).

The special substances are source for widespread concern as they are suspected to be a source of substantial ground water contamination (Tollefson, 2013). Research about this concern and possible ways to reduce contamination is currently underway (e.g. (Lavoie, et al., 2013), (Tilley & Muehlenbachs, 2013) and (Nowamooz, Lemieux, Molson, & Therrien, 2015)). Finkel et al. (2013) observed, that the production of milk decreased in areas where gas is being produced unconventionally in comparison to areas with no unconventional gas production between 1996 and 2011. The decrease has been especially strong after 2007. This correlates with the increasing number of unconventional drilling activities for natural gas since the mid-2000s (Finkel, Selegean, Hays, & Kondamudi, 2013). Additionally, the process of horizontal hydraulic fracturing often requires large amounts of fresh water which will be unusable after the process (Rivard, et al., 2014, p. 69). On average, 7.5 to 18 million litres of fluids will be used during the production process of a single well.

From 10% to 70% of the fluids used in the production of horizontal hydraulic fracturing are resurfacing during the process (de Melo-Martín, Hays, & Finkel, 2014, p. 1115). There are two major methods to store the fluids as sewage plants are not able to remove the chemicals (Finkel & Hays, 2013, p. 890) (Vengosh, Warner, Jackson, & Darrah, 2013, pp. 865-866). In some areas is the United States the fluids are collected and stored in tanks while in other areas the fluids are infused into saline aquifers deep underground (Rivard, et al., 2014, p. 68). Furthermore, after a well has been abandoned it needs to be sealed to prevent any leakage of methane or fluids (Nowamooz, Lemieux, Molson, & Therrien, 2015, p. 4596). Yet, there are incidences were the fluids contaminated the environment due to failures to seal them (Rivard, et al., 2014, p. 69) (Vengosh, Warner, Jackson, & Darrah, 2013, p. 865). Due to this, groundwater contamination and methane leakage were the consequence (Nowamooz, Lemieux, Molson, & Therrien, 2015, p. 4592).

Finkel and Hays (2013, p. 890) report that 3% to 8% of methane is either vented or leaks during the operating time of well. This is twice as much compared to the conventional production of natural gas. A study analysing air emissions in the US state of Colorado found that higher proximity to unconventional drilling wells and higher risks of cancer go hand in hand (McKenzie, Newman, & Adgate, 2012, p. 83). In general, horizontal hydraulic fracturing requires more intense drilling and production activities, leads to more traffic, pollution and higher risks of contamination (de Melo-Martín, Hays, & Finkel, 2014, p. 1115) (Vengosh, Warner, Jackson, & Darrah, 2013, p. 864) (Davies, et al., 2014, p. 239). Furthermore, hydraulic fracturing activities can reduce economic opportunities for agriculture and tourism for a long time (de Melo-Martín, Hays, & Finkel, 2014, p. 1114).

With rising public attention to the risks of unconventional natural gas production and high external costs, the future success of this method depends on the technology and the organizations involved to minimize environmental damage (Nowamooz, Lemieux, Molson, & Therrien, 2015, p. 4593). Furthermore, it is not clear yet whether cleaner characteristics of natural gas compared to oil and coal can be kept with higher emissions from unconventional natural gas production (de Melo-Martín, Hays, & Finkel, 2014, p. 1117).

Next to conventional and unconventional natural gas extraction, there are a number of different methods to produce natural gas: Green natural gas (also called green gas) and synthetic natural gas are amongst the most common alternatives. Green gas is produced from organic matter in a refinery. For example, grain and industrial by-products can be used in a process of fermentation to produce a gas with about 60% methane. By further refining the gas, almost pure methane can be collected. The product is chemically equivalent to refined natural gas from conventional sources (Verbio, 2016). Synthetic natural gas is a product where one fossil fuel, usually coal, is converted to natural gas. This process requires a lot of energy and water[14], but can be economical. For example, in 2011 China proposed to build a range of synthetic natural gas plants to increase natural gas production. The country aims to reduce its coal dependency to combat environmental contamination, like reducing CO_2 emissions and other pollutants that cause the high levels of smog in its cities (Shiao, Luo, & Wen, 2013). From this section onwards, unless otherwise mentioned 'natural gas' will refer to natural gas produced from underground reservoirs.

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[14] According the authors, one cubic meter of synthetic natural gas requires 6-10 liters of freshwater to produce

As described above, unconventional natural gas production has been a major factor in global natural gas production in recent years. The USA spearheaded this development. Natural gas production peaked in 1973 with about 22.6 trillion cf in the United States. As conventional natural gas sources depleted over time and new domestic sources were more difficult to access production as well as productivity in the USA declined for decades. This trend stopped with the rise of unconventional natural gas sources: by 2008, the previous production record was broken when domestic natural gas production exceeded 26 trillion cf (National Research Council, 2010, p. 109). It is estimated that the US will overtake the current leading natural gas producer Russia by 2023 (International Energy Agency, 2016). As of now, natural gas production benefits mostly the domestic US market as export capacity is limited. Only two LNG export facilities have been operational in 2017. Yet, four more facilities are expected to be operational by 2020 (The Walt Street Journal, 2018).

As stated above, Russia is currently the largest producer of natural gas. The country is hugely depended on oil and natural gas export and relies on an established pipeline network mostly towards Europe where it defends its dominating market share (Ocelík & Osička, 2014, pp. 97-98). Third in line of natural gas production is Iran which is located in a low demand region and relies on exporting most of its production via sea towards the closest demand markets of Europe and East Asia (Bilgin, 2009, pp. 4482-4483).

This concludes this subchapter about the production side of natural gas. Next, transportation and storage of natural gas will be addressed.

4.2 Transportation and storage of natural gas

Like oil and coal, natural gas production sites are located geographically distant to consumption sites. Hence, transport and storage infrastructure need to be in place for an effective value chain. Gas carrier or gas tanker ships transport natural gas by sea, while tanker trucks and special railway carriages can transport it by land. Additionally, pipelines for natural gas transport have been used for decades and more projects are currently under way. This section will briefly cover the different transport methods for natural gas while considering its physical condition.

The dominant way of transporting natural gas in its gaseous form is via pipeline. In comparison to transportation in gas tanks, pipelines are significantly more cost-efficient (National Research Council, 2010, p. 116). When longer distances must be covered with pipelines, natural gas is pressurized to reduce its volume. Compressor stations are placed at intervals usually between 60 and 170 kilometres along the pipeline (natgas, The Transportation of Natural Gas, 2013).

While pipelines are a very efficient way of transportation, they have disadvantages. Pipelines require high investment costs even on favourable terrain. The investment costs depend primarily on the pipeline diameter but is also affected by terrain, population density and climate (Lochner & Bothe, 2009). Continued maintenance is needed, and costs rise with distance covered and more difficult terrain. Long term contracts are required, as otherwise customers may shift interest in other energy sources or alternative natural gas providers.

In addition, pipelines are seldom perfectly sealed, low amounts of methane leaks which has impacting consequences on the global temperature levels as described in chapter 3 (National Research Council, 2010, p. 116). It is difficult to provide quantities for distances of natural gas transports within pipelines, because natural gas is not shipped to specific points, but rather drawn from natural gas pressured pipelines (compare (Dennis, 2005, p. 29)). British Petroleum reported that the share of internationally pipeline transported natural gas was at 68% in 2015 (BP, 2016, p. 29).

While natural gas has a gaseous natural state, it can be liquefied. To achieve this state, natural gas is cooled down to a temperature of -162° Celsius as well as pressurized by a factor of 600 (Rogers H. , 2010, p. 3). Furthermore, the substance is cleaned and consists primarily of methane (CH_4) with small amounts of ethane, propane, butane and pentane. The product of this process is widely referred to as liquefied natural gas (LNG). Compared to gaseous natural gas (GNG), liquefied natural gas's volume is one part in six hundredth. Hence, LNG is much more efficient to transport compared to GNG (Logistik Initiative Hamburg, 2015, p. 12).

However, as with GNG, LNG requires special processing and transport facilities. The supply chain consists of a liquefaction facility, transportation vessels and a regasification facility. All three elements require high investment costs but offer flexibility as they are not fixed to one another. The temperature and pressure level need to be maintained at all time to ensure save transportation (Lochner & Bothe, 2009).

The major benefit of LNG transport compared to GNG transport is flexibility. As described above, GNG relies mainly on pipelines to cover medium to long distances. This goes hand in hand with high investments and long-term commitment. Here, LNG offers an alternative as transport vehicles offer higher flexibility between producers and consumers. Especially, if large pipeline distances must be covered by sea. For example, a pipeline network from the natural gas producers in the Middle East to natural gas consumers in Japan would not be economical. Instead, both sides can invest into LNG-terminals that can convert natural gas to either GNG or LNG to fill tanker ships that transport LNG between the Middle East and Japan. From those terminals, natural gas can be regasified and introduced to an existing pipeline infrastructure or be kept in its liquid form and transported to demand centres (Rogers H. , 2010, p. 3).

LNG is mostly used for international transportation via sea. In 2013 roughly 69% of natural gas was traded with pipelines within regions. 31% was traded by LNG transport. (Tsafos, 2015). For example, in the United States, natural gas is predominantly transported via the 300 thousand miles long domestic pipeline network (National Research Council, 2010, p. 111). More than 90% of imported natural gas is transported via pipeline from Mexico and Canada. The remaining quantities are supplied as LNG from Trinidad across the Gulf of Mexico, and from Norway, Egypt, Nigeria and Qatar across the Atlantic Ocean (National Research Council, 2010, p. 111).

The rising development of the LNG market can be observed when looking at the Panama Canal which is an important connection between the Atlantic Ocean and the Pacific Ocean: The share of LNG exports from the United States experiences the highest growth rate at the canal. There was no LNG business in 2015 while for 2017 total LNG shipments were reported at 6 million mt. 45% of United States LNG exports pass through the Panama Canal (The Walt Street Journal, 2018)

Europe is mostly supplied via pipelines as well. There are multiple pipelines running from Russia across Eastern Europe towards Central European consumers. New pipelines like North Stream 1 and 2 towards Germany and Blue Stream towards Turkey are being added as well. Yet, the European Union is focusing to support construction of LNG import facilities to increase flexibility to cover European natural gas demand. In Poland, such a facility is already operational and imports LNG from Norway, North Africa and the United States. More facilities are being constructed (Rodríguez-Gómez, Zaccarelli, & Bolado-Lavín, 2016).

Storage is an important topic for natural gas. Until recently, natural gas has been mostly used for heating. Hence, demand has been higher during winter than during summer. Because of this, natural gas can be described as a seasonal good. Production on the other hand is not dependent on the time of the year. To meet higher demand during winter, excess production during the rest of the year is build up and stored. Still, with the emergence of power plants and engines that use natural gas the demand is equalizing over the year. While in winter the need for heating is higher, during summer more air condition systems need electricity. Due to this demand for storage to meet changing levels in demand is becoming less important. However, the storage capacities can be used to speculate for higher profit margins (Storage of Natural Gas, 2013).

According to the U.S. Energy Information Administration (EIA) storage capacity in USA constituted to 3,899 Trillion cubic feet (cf) (International Energy Agency, 2016). In the US, depleted reservoirs make up the vast majority of natural gas storage. Salt caverns and aquifer[15] supply about 15% storage capacity in total (natgas, Storage of Natural Gas, 2013). The total reported capacity was at 8.4 trillion cf in 2007, which equals 32% of total US demand in 2014 (National Research Council, 2010, p. 111). Japan and South Korea for example, lacking natural (geological) natural gas storage opportunities, rely on LNG storage tanks to store natural gas over extended periods of time (Rogers H. , 2010, p. 32). The available storage capacity can be an important factor contributing to consumer prices for natural gas (Brown & Yücel, 2008).

This concludes subchapter 4.2. The next subchapter will focus on natural gas consumption regions.

4.3 Consumption regions and market liberalisation

To understand the implications of natural gas market price it is important to understand what natural gas prices reflect on individual local markets. According to studies, not even 50% of natural gas prices reflect actual supply and demand price finding mechanisms. Tsafos estimates, that 19% of natural gas prices are oil linked, 33% are regulated by governmental bodies either above or below production costs while about 5% are set by other factors, e.g. hybrid mechanisms (2015).

[15] Aquifers are repurposed underground water reservoirs

This in turn shows, that once can expect that only about 43% of global natural gas prices follow market forces. This somewhat hinders a price-based analysis for market integration. However, this does not prohibit market integration as oil-based and regulated natural gas prices may follow global trends as well.

As stated in chapter 3, natural gas does seldom experience different levels of quality. As such, in market terms, natural gas is a commodity. When it comes to markets, commodity markets in general are volatile. As chapter 5 will show, natural gas prices are especially volatile – in fact, it is one of the most volatile commodities marketed. As with most commodities, natural gas can be traded financially as well as physically. Financial trading is in simple terms characterized as buying and selling of natural gas without physical delivery of the good. Financial trading of natural gas has an impact of natural gas prices as well (Serletis & Herbert, 1999).

The physical market can be further differentiated into a market for 'spot' trading and into a market for 'futures' trading. 'Futures' refers to a contract where natural gas is traded well in advance (usually at least one month ahead). An important market for futures in the USA is the New York Mercantile Exchange (NYMEX). Alternatively, natural gas can be traded in spot markets in which the commodity is sold and bought each day for direct transfer. Under normal conditions, futures prices will be lower compared to spot prices as with future contracts the risk of holding the commodity moves from the seller to the buyer (Murry & Zhu, 2008).

'Hubs' are used as physical trading locations. Hubs are located all over the world, the most well-known one being 'Henry Hub'. Henry Hub is located near New Orleans, USA and is a major connection point for sixteen pipelines and as such connected to the major production facilities as well as LNG terminals of the United States (Brown & Yücel, 2008). Each hub exits as a separate market, mostly at pipeline intersections, where the laws of supply and demand lead to an individual price for natural gas at this location. Consequently, different prices for natural gas exist within the United States. Due to competition, the difference in price between hubs can be attributed mostly to the physical distance between hubs. The price premium is therefore referred to as 'location differential' (natgas, Marketing, 2014) (Murry & Zhu, 2008).

Physical contracts include 'Swing', 'baseload' and 'firm' contracts. In a swing contract both parties agree on a rough amount of natural gas to be delivered on a short-term basis. Baseload contracts are similar to swing contracts. The major difference is that both parties state their willingness to meet the exact contracted amount of natural gas. The firm contract goes one step further. Both parties are obligated to trade the contracted amount (natgas, Marketing, 2014).

Thus, it is important to understand that there are different price-setting mechanisms in place around the world. This is true for regions as well as for individual countries. Only North America has a single pricing system, other places have multiple systems that coexist. In Europe, as much ass 40% of natural gas prices are still linked to oil. The situation for the Asia-Pacific area is similar. As it was shown at the beginning of this chapter, both, Europe and East Asia are the major import regions for natural gas. Hence, most natural gas imports go to regions with the highest share of oil-linked prices. Depending on the current oil prices, this may be a huge price driver. However, both these regions experience a transition for higher shares on actual market based natural gas pricing (Jensen, 2004).

A liberal market is featured by third party access to networks, private companies and division of ownership for transport infrastructure, production and sale. The United States were the first major country to move to gas-to-gas price competition. Up until the 1970s, natural gas prices in the USA were regulated. By the end of the that decade, prices for natural gas were so low that investments into new production capacity were not economically viable. Thus, regulations for the domestic market were lowered which gradually led the competition-based model existing today (von Hirschhausen & Engerer, 1998, p. 1119). Apart from the United Kingdom, Europe took much longer to transition towards the competition-based model. Here, the major influencing factor was the high oil prices at the turn of the century. Compared to the development in the US, which took about fifteen years, Europe is changing at a slower pace. This can be partly attributed to the high share of pipeline-based international long-term contracts. Especially in countries with high shares of Russian natural gas there is little push towards hub-based pricing (Bilgin, 2009).

In Asia, the market development lags behind even that of Europe. Here, long-term contracts dominate the trade as well. In many countries supply security is favored over lower prices. The market is dominated by local monopolies with little incentive to change the system. The regional market is not as integrated as the European and North American markets. Hubs, which might offer alternative prices, are of lower importance in Asia compared to their western counterparts (Rogers H. , 2010, p. 37) .

The next sections will analyse the situation in each of the three regions in closer detail starting with North America.

4.3.1 North America

This section will cover the three large economies of North America: Canada, the United States of America and Mexico. These three nations form the North American Free Trade Agreement (NAFTA) which enables free trade between the nations. For 2014 the EIA lists the reserves of the USA at about 9,575 billion Cubic Meter (m^3), of Canada at about 1,898 billion m^3 and of Mexico at about 482 billion m^3 (U.S. Energy Information Administration, 2016). In comparison, OPEC estimates the reserves at about 9,580 billion m^3 for the USA, 2,028 billion m^3 for Canada and 347 billion m^3 for Mexico in 2014 (Organization of the Petroleum Exporting Countries, 2015, p. 94).

To extend the information presented in the beginning of this chapter in Table 3, the following table compares Canada, Mexico and the USA regarding natural gas statistics for 2014.

	natural gas in bn m^3 for 2014						
Country	Reserves	Production	Consumption	Δ	Export	Import	Δ
Canada	2,028	161	116	45	79	22	57
USA	9,580	730	755	-25	43	76	-33
Mexico	347	51	74	-23	0	20	-20
Total	11,955	942	945	-3	122	118	4

Table 3 - Region 1 natural gas data

Sources: (Organization of the Petroleum Exporting Countries, 2015, pp. 94-101) & (International Energy Agency, 2016, p. 33)

The United States of America surpass Mexico and Canada when comparing quantities of reserves of natural gas as well as annual production and consumption. Secondly, the USA as well as Mexico are net importers of natural gas while Canada is a net exporter. The differences in import-export and production-consumption do not match. This is caused by at least two circumstances: One the one hand, the quantities are estimates and different sources had to be consulted to collect the information. On the other hand, the USA are exporting large quantities of natural gas before covering their own consumption requirements, which can blur the results. This will be covered more in debt below.

The United States of America are the leading consumer and producer of natural gas globally. Additionally, the USA hold large resources of natural gas. The share of natural gas in the United States' energy mix has been increasing over the past decades from 23% in 1990 to 29% in 2015. This was the largest increase of any primary energy source during this timeframe[16]. In the same time, the quantity of natural gas consumption increased by 44% to about 28.2 quadrillion Btu in 2015 (U.S. Energy Information Administration, 2017, p. 7).

The share of natural gas in the Canadian energy mix increased from 31% in 2010 (Statistics Canada, 2016) to 34.6% in 2015. This equals total natural gas consumption of about 6.1 quadrillion Btu in 2015 (Statistics Canada, 2017). Similarly, the share of natural gas in Mexico's energy mix increased from 2000 by 6% to a total of 32% in 2014 (International Energy Agency, 2016, p. 18). In 2014, natural gas consumption in Mexico was about 2.4 quadrillion Btu (U.S. Energy Information Administration, 2016).

The technique of unconventional natural gas extraction and the willingness to embrace the technology have led to a boom in natural gas production in the United States of America (Finkel & Hays, 2013, p. 890). This is mostly due to unconventional natural gas production. Between 2006 and 2010 unconventional natural gas production from shale deposits grew by 48 percent per year (McKenzie, Newman, & Adgate, 2012, p. 79). The share of shale gas to total natural gas production in the USA increased from 2% in 2001 to 40% in 2012 and is projected to supply half of the USA natural gas production by 2035 (de Melo-Martín, Hays, & Finkel, 2014, p. 1114) (Finkel, Selegean, Hays, & Kondamudi, 2013, S. 190). This equates annual shale gas production of 340 billion m^3 (Vengosh, Warner, Jackson, & Darrah, 2013, p. 864).

Still, the negative side effects of the method of horizontal hydraulic fracturing[17] have not gone unnoticed. There is no common acceptance of shale gas practices by all states in the United States. While states like Texas and Pennsylvania have embraced the method, other states like New York and Vermont have put up hindrances to the development. Although the available reserves or

[16] see Appendix II Table I for further data
[17] As discussed in section 4.1

the lack of natural gas deposits in the respective states might have a strong impact on the decision-making process (de Melo-Martín, Hays, & Finkel, 2014, p. 1115). Additionally, some researchers suggest that many of shale gas production sites are not sustainable at current price levels (Hughes, 2013, p. 307).

Natural gas imports and exports are continuing to equalize each other for the United States of America. In the early years of the 21^{st} century, net imports of natural gas reached about 3.6 quadrillion Btu. Due to rising production levels of natural gas within the USA the net imports decreased to roughly 1 quadrillion Btu in 2015 and are expected to decrease further (U.S. Energy Information Administration, 2017, p. 10). Consequently, the United States are on a path to become a net exporter of natural gas during the next years. Still, due to its geography imports from Canada will remain to be an important source of natural gas in the future.

Canada is currently the fifth largest producer of natural gas globally. As production exceeds domestic consumption, about 47% of natural gas is exported (Rivard, et al., 2014, p. 64). The Canadian distribution network is highly integrated with that of the USA: Via pipelines, the excess volume of natural gas is exported from western and eastern Canada into the U.S., while on the other hand the United States are supplying some natural gas to central Canada in turn (Statistics Canada, 2016).

Currently, Canadian production of natural gas from unconventional sources started after that of its southern neighbor and is still developing. Beginning in 2005, by 2012 more than 1,000 wells have been constructed for unconventional natural gas production (Rivard, et al., 2014, p. 65). Unconventional natural gas production technology doubled Canada's natural gas reserves (de Melo-Martín, Hays, & Finkel, 2014, p. 1114).

In 2015, the North American region accounted for 17.6% of total int. pipeline imports, 3% of total int LNG imports, 17.6% of total pipeline exports and only 0.2% of total global LNG exports. 92% of natural gas imports within North America were delivered by pipeline (BP, 2016, p. 29).

For the same year, nearly 100% of pipeline imports to US came from Canada, while US LNG imports mostly came from Trinidad & Tobago, with low quantities from Norway and Yemen. LNG has a share of 3.5 % of total imports in the US. Canadas pipeline imports originated fully from US, while the 3% share of LNG came from Trinidad & Tobago and Europe. Mexico also sources 100% of pipeline imports from US. However, LNG imports have a share of about 25% and were regionally diversified (BP, 2016, p. 28).

Due to an overall surplus of natural gas in the North American region, new areas of demand like transportation and LNG exports are currently explored (Tsafos, 2015). 160 pipeline companies operate more than 480 thousand kilometres of pipelines in the US. 148 billion cubic feet transport volume per day (natgas, Industry and Market Structure, 2013). As a result of the geographical size of the US, the distribution of natural gas from production locations to consumers is extensive. For the year of 2013 more than 40 thousand unconventional gas wells have been listed which were spread over 20 different states (Rivard, et al., 2014, p. 64). The most productive area for shale gas is the Marcellus Shale located in north-eastern United States (U.S.) (Popkin, Duke, Borchers, & Ilvento, 2013, p. 62).

When it comes to the market for natural gas in North American region, until recently the regulations for each of the three economies were quite different from each other. The US market is often called the most developed gas market in the world (Murry & Zhu, 2008, p. 765). This refers to the dynamics of the market caused by the continuous liberalisation starting in 1992 with the order 636 by the Federal Energy Regulatory Commission (Brown & Yücel, 2008, pp. 2441-2442) (Jensen, 2004). For example, pipeline companies are prohibited from natural gas trade (Rogers H. , 2010, p. 7). Increase of natural gas production in USA has effects on price within USA and North America. The next chapter will analyse whether the price shocks have an effect on natural gas prices in other countries outside of the North American region.

In Canada, natural gas market deregulation started in 1985 triggered by the developments in the United States. Before that, natural gas prices were set by the government. Mecixo in turn is not quite as liberated due to monopolistic structures. However, as most natural gas is imported from the US, prices follow market forces (Rogers H. , 2010, pp. 8-9).

4.3.2 Europe

The European region is the second region in focus of this chapter. As with North America, table 4 shows the European market fundamentals.

Country	natural gas in bn m³ for 2014						
	Reserves	Production	Consumption	Δ	Export	Import	Δ
Russia	49,541	643	454	189	195	29	166
Turkmenistan	9,934	74	25	49	46	0*	46
Poland	69	6	18	-12	0*	12	-12
Ukraine	952	20	41	-21	0*	19	-19
Germany	63	10	79	-69	15	106[18]	-91
Italy	56	7	62	-55	0	56	-56
Netherlands	1,044	70	40	30	59	17	42
Norway	2,654	111	6	105	107	0*	107
United Kingdom	452	38	70	-32	11	43	-32
Europe, CIS and Turkmenistan[19]	69,976	1,101	1,125	-24	494	542	-48

Table 4 - Region 2 natural gas data

Sources: (Organization of the Petroleum Exporting Countries, 2015, pp. 94-101) & (International Energy Agency, 2016, p. 33)

** OPEC source did not provide individual estimation for Poland and Ukraine regarding exports, and for Turkmenistan and Norway regarding imports. This is mostly due to the low amounts in the respective categories. Consequently, the discrepancy is neglectable.*

The reserves of Europe excluding Russia are comparatively low: For example, Germany, Italy, the United Kingdom (UK), Netherlands, Norway and Poland according to the EIA were at about 3,567 billion m³ of natural gas reserves in 2014[20] (U.S. Energy Information Administration, 2016). OPEC lists the combined reserves of the group at about 4,401 billion m³ in 2014 (Organization of the Petroleum Exporting Countries, 2015, p. 94). In contrast, Russia held reserves according to the EIA of about 47,819 billion m³ (U.S. Energy Information Administration, 2016) and according to OPEC of about 49,541 billion m³ (Organization of the Petroleum Exporting

[18] In the source, the import value for Germany is comparatively high compared to other sources, e.g. Enerdata shows the import volume for Germany in 2014 as 67.6 bn m³ (Enerdata, 2016)
[19] In contrast to tables 1,2 and 4, table 3 omits a number of countries from the table due to the high number of countries within the region. Thus, the numbers do not add up.
[20] The Netherlands and Norway contribute the majority with 85%.

Countries, 2015, p. 94) in 2014. Russia holds has more reserves than any other country. OPEC data for Spain was not available for the selected timeframe. However, as Europe's third biggest LNG importing economy the country will included in the subsequent analyses as well (Dehnavi, Wirl, & Yegorov, 2015, p. 19).

In 2015, European pipeline imports accounted for 59% of global pipeline imports. The respective share of LNG was 16.3%. 88% of natural gas in Europe is supplied by pipeline (BP, 2016, p. 29). While the UK is more liberalised, continental Europe is less so. Oil-indexed long-term contracts are still widespread. However, often these contracts allow for the flexibility: it is possible to reduce or delay contracted volume (Rogers H. , 2010, pp. 23-24).

The European region is in many ways the most diverse of all the mentioned natural gas regions. It is the only place in the world where natural gas demand is falling. Likewise, European production is decreasing as well. Thus, higher shares of natural gas are imported via pipelines from North Africa and Russia, while LNG import capacities are being expanded. There are currently about 21 LNG import terminals in Europe. Spain owning seven facilities, France and Italy each owning three, two in the UK and one in Portugal, Belgium, the Netherlands, Poland, Lithuania and Greece, respectively (european network of transmission system operators, 2015/2016). With more being planned or already under construction, European natural gas imports have larger diversification possibilities.

Shale gas plays a much smaller role in Europe compared to the USA. Some countries like France and Bulgaria even outright banned its development. Others, like UK and Poland are more eager to explore shale gas opportunities (de Melo-Martín, Hays, & Finkel, 2014, p. 1115) (Vengosh, Warner, Jackson, & Darrah, 2013, p. 864).

Russia owns huge natural gas resources and, historically, mostly supplied its European neighbours. In 2015, 83% of exports were transported to Europe (BP, 2016, p. 28). Nowadays, Russia focuses on connecting the pipeline network to East Asian consumers (von Hirschhausen & Engerer, 1998, p. 1113) (Tsafos, 2015). Shale gas reserves in Russia are extensive as well (Finkel & Hays, 2013, p. 892). Due the historical integration and the location of its central Asian neighbours, Russia plays an important role as transit country for CIS country and Turkmenistan (von Hirschhausen & Engerer, 1998, p. 1114).

When it comes to market liberalisation the situation in Europe is quite diverse as well. Great Britain liberated its market not long after North America. Cost-based pricing was favoured in contrast to the Central European value-based pricing approach (Rogers H. , 2010, p. 18). Central Europe is slowly reforming the previous heavily oil-indexed structures (von Hirschhausen & Engerer, 1998, p. 1112 & 1117). However, as long-term contracts typically have a duration of up to 25 years, fast changes are hindered. In 2005, 70% of all North European natural gas contracts were pegged to oil. By 2015, this share has fallen to below 10% (european network of transmission system operators, 2015/2016).

There are a number of important hubs in Europe. To name a few: NBP in Great Britain, TFF and Zee in the Netherlands and GAS and NCG in Germany. The hubs provided alternatives for spot-trading to the previously dominant long-term contract agreements in Central Europe (Rogers H. , 2010, pp. 19, 23-24).

4.3.3 North East Asia

The North East Asian region is the third and final region in focus of this chapter. Table 5 shows the North East Asian market fundamentals.

	natural gas in bn m³ for 2014						
Country	Reserves	Production	Consumption	Δ	Export	Import	Δ
China	3,275	128	185	-57	0*	56	-56
Japan	0*	5	131	-126	0*	124	-124
South Korea	0*	0*	47	-47	0*	49	-49
Total	3,275	133	363	-230	0	229	-229

Table 5 - Region 3 natural gas data

Sources: (Organization of the Petroleum Exporting Countries, 2015, pp. 94-101) & (International Energy Agency, 2016, p. 33)

** OPEC source did not provide individual estimation for South Korea regarding reserves and production, and for Japan regarding reserves. Additionally, no export values are provided. This is mostly due to the low amounts in the respective categories. Consequently, the discrepancy is neglectable.*

For 2014 the EIA lists the reserves of the China at about 4,391 billion Cubic Meter (m^3), of South Korea at about 6 billion m^3 and of Japan at about 20 billion m^3 (U.S. Energy Information Administration, 2016). In comparison, OPEC estimates the reserves at about 3,275 billion m^3 for China in 2014 (Organization of the Petroleum Exporting Countries, 2015, p. 94). Unfortunately, OPEC does not provide estimates for Japan and South Korea at this time.

In 2015, North East Asia accounted for 55.5% of total int. traded LNG imports, and LNG has a share of 85% of all imports in North East Asia (BP, 2016, p. 29). Japan and Korea lack domestic production and rely on imports. North East Asia essentially created and dominated LNG market since 1970s and continuous to do so: In 2010 Japan and Korea were the first and second biggest LNG importers worldwide (Dehnavi, Wirl, & Yegorov, 2015, p. 19).

China has a 50-50 share of LNG imports to natural gas imports via pipeline. Its supplier base is rather diverse. The highest share of LNG comes from Australia (27.5%), while pipeline imports mostly originate from Turkmenistan (82%) and Myanmar (12%). Japans LNG imports come mostly from Australia as well, followed by Malaysia, Russia and United Arab Ermirates. South Korea imports from Quatar, Oman, Indonesia, Malaysia and Russia to the most part (BP, 2016, p. 28).

The North East Asian market is considered the least liberal out of the three regions (Rogers H. , 2010, pp. 29-32). Due to the high reliance on imports to meet domestic demand, natural gas prices are amongst the highest in the world (Tsafos, 2015). China is building up its domestic production including shale gas, however, due to rising consumption levels it will remain reliant on imports (de Melo-Martín, Hays, & Finkel, 2014, p. 1114). In Addition, unfavourable terrain at the shale gas locations and limited access to modern drilling technology hampers natural gas production. However, it is expected that China significantly expand its shale gas production capabilities by 2025 (Yegorov & Dehnavi, 2014, pp. 14, 15 & 18).

While in other regions LNG technology offered and continues to offer changes to increase market liberalisation the situation in North East Asia is different. Since the regions has been relying on LNG for so long, long-term LNG risk-sharing contracts are common. Each agreement consists of self-contained elements: liquefaction and regasification facilities and transport vessels are specified with little room for flexibility. Originally, prices were pegged to oil. Fue to high oil prices in the 1990s the system was adapted a bit. However, agreements remained long-term (Rogers H. , 2010, pp. 29-32). Consequently, during the 2010s long-term prices are finally able to adjust the global trend for liberal natural gas markets. This development started somewhat earlier in Japan as due to peaking demand following the accident at the Fukushima nuclear power plant, additional capacity was not bound to long-term contracts (Dehnavi, Wirl, & Yegorov, 2015, p. 19).

To sum, market liberalisation is increasing across all three regions. Due to innovative production technologies natural gas supply can keep up with growing natural gas demands. In Europe and East Asia spot market trading is slowly getting as important as it is in North America. LNG technology increases flexibility for all parties involved and as markets integrate, more information becomes available. The biggest obstacles to further market integration are the lack of gas-to-gas pricing and high shares of inflexible long-term contracts in certain regions. Gas markets rely on the availability of expensive transport infrastructure. While historical being regionally diverse, global gas markets become more interconnected due to the development of LNG.

This concludes chapter 4. Next, the analytical part of this thesis will begin.

5. Natural gas market integration

The previous chapter gave an understanding about production and transportation capabilities as well as details about the three important geographical areas regarding natural gas consumption. With this knowledge, now the attention shifts towards developing means in order to answer the research question: whether the markets for natural gas are integrated, and thus, there is a global market for natural gas. As stated before, an integrated market is defined as being not affected by price distortions caused by nationality or distance (Goldberg & Knetter, 1997, p. 1245). This chapter is organized as follows: First, the price development for natural gas of all three regions will be presented. Second, a theoretical approach to test market integration is established. Three hypotheses that aim to find enough reasons to either accept or reject the research question will be developed and tested. The hypotheses testing is built on two arguments regarding the characteristics of an integrated market: First, local price shocks should have significant global consequences. Subchapter 5.2.3 will explain the reasoning for this argument and sets up Hypothesis 3. Secondly, an integrated market makes arbitrage possible. Consequently, import prices across different geographical areas should be equal except for a distance component. Following this argument, hypotheses 1 and 2 will be set up in subchapter 5.2.2.

5.1 Price development of natural gas

Before going into the statistical part of this thesis starting in subchapter 5.2, first there will be an overview of the absolute and relative price developments in Europe, North America and East Asia. The data has been sourced from the World Bank. Regional prices have been weighted for each region. In addition to the information provided in the previous chapter, the regional prices provide important insights to the market development of all three regions. Figure 1 shoes the price development from 1977 to 2015.

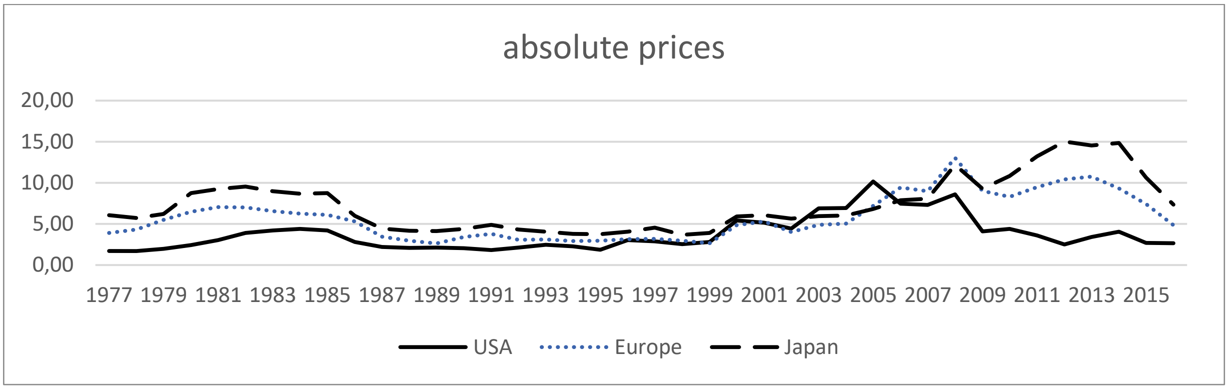

Figure 1- Absolute price development (1/2)

Source: World Bank (The World Bank Group, 2017) and own calculations

When comparing the absolute natural gas prices of the USA, Europe and Japan between 1977 and 2015, the first observations is that for most the most part price in the US are the lowest while price in Japan are highest. European prices are somewhat in the middle of the two extremes. Also, an alignment of prices can be observed until 2007: For Europe and Japan prices were decreasing, while the US experienced a slight increase of prices. However, the price reduction does not continue until 2007. Instead, since 1999 price have been increasing for all countries until the end of the first decade of the twenty-second century. Since 2000, price volatility is especially strong. Even in the most liberalized North American market long-term pipeline and LNG contracts were commonly used until 2005 (Dehnavi, Wirl, & Yegorov, 2015, p. 11).

Figure 2 highlights the last third of the timeframe in higher detail.

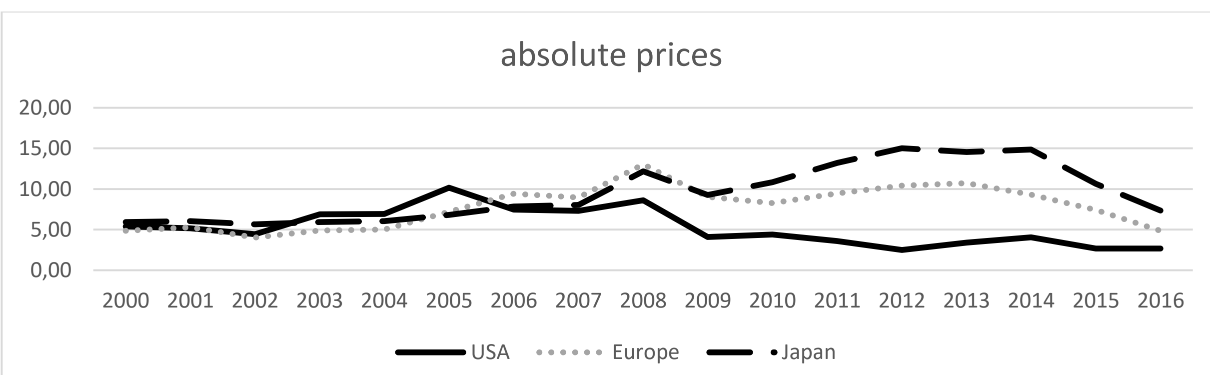

Figure 2 - Absolute price development (2/2)

Source: World Bank (The World Bank Group, 2017) and own calculations

In this figure it is observable that from 2002 to the end of 2005 US prices were higher compared to Europe and Japan. Since then however, prices have been decreasing. Japan experienced as especially strong increase of prices starting in 2007 with a maximum deviation to the US between 2011 and 2014. Since then, prices are aligning again. Between 2006 and 2009 highest natural gas prices can be observed in Europe. European prices continue on a high level until 2014 when prices are aligning towards the US level.

Especially in the timeframe after the year of 2000 prices reflect imported historical events. The shale gas boom in the United States started in 2007 when the production share of shale gas on total natural gas production in the US rose from 5% to over 40% in just six years (U.S. Energy Information Administration, 2017). The US natural gas supply increased at the same time as the global economy was in recession following the financial crisis. Due to much higher supply than demand in the USA, domestic gas prices fell (Yegorov & Dehnavi, 2014, p. 3). However, impact on Europe and Japan was low. In contrast prices for Japan experienced the opposite development.

When the nuclear power plant Fukushima Daiichi accident happened in Eastern Japan in early 2011, Japan shut down all of its nuclear power plants. Consequently, more electrical energy had to be produced by other means. Due to its geographical distance to other countries. Japan is not able to directly import electrical energy in large quantities. Thus, energy had to be produced by fossil power plants. Here, LNG imports play an important role. This resulted in continuing high prices for natural gas for Japan.

The Japanese price spike can be observed when comparing relative prices between both countries:

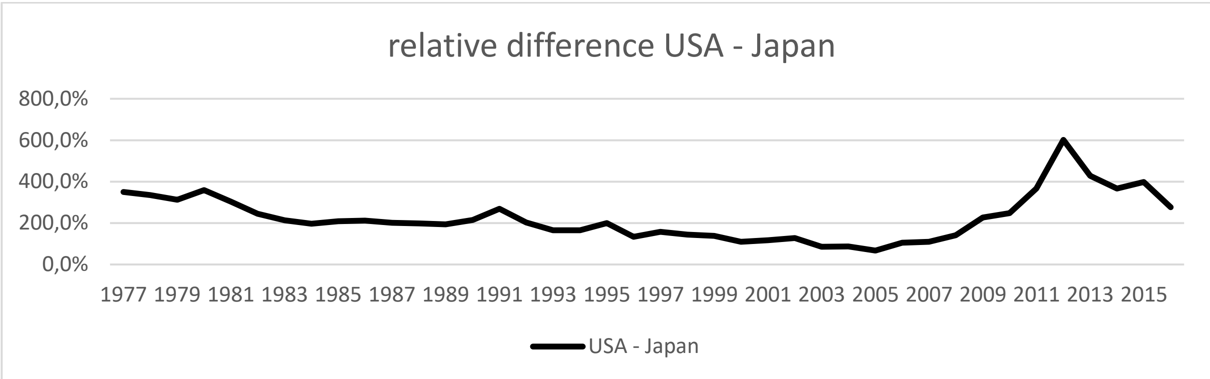

Figure 3 - Relative price development USA-Japan

Source: World Bank (The World Bank Group, 2017) and own calculations

Between the start of the timeframe in 1977 and the start of the shale gas boom in North America, relative prices differences decreased from more than 350% towards 100% in 2005. Since then, price difference increased until the peak in 2012 and since then have been decreasing again. Although at the end of the observation period in 2015, relative price differences are closer to the starting level in 1977 than to the lowest point in 2005.

The price development between the USA and Europe mirrors that of USA and Japan as the next chart shows:

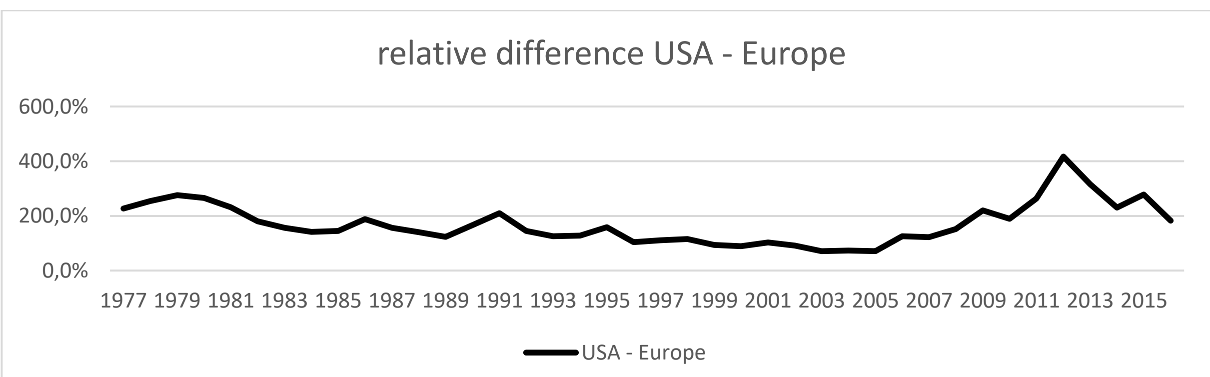

Figure 4 - Relative price development USA-Europe

Source: World Bank (The World Bank Group, 2017) and own calculations

The chart shows that relative prices decreased over time from above 200% in 1977 to below 100% in 2005. Since then, due to lower absolute price in the USA, the relative price difference rose to a maximum of ~400% in 2012 before dropping again.

The similarity of both the US-Japan and the US-Europe comparison can be also observed in the Europe-Japan chart below:

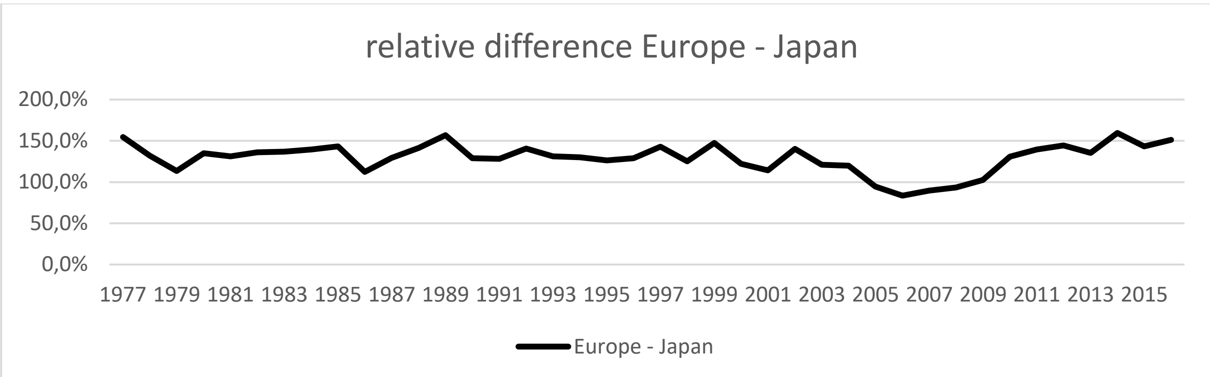

Figure 5 - Relative price development Europe-Japan

Source: World Bank (The World Bank Group, 2017) and own calculations

The chart shows that relative price differences between Europe and Japan are much more stable compared to the two charts including the United States above. The relative price differences between Europe and Japan are mostly between 100% and 150%. The peak in the year of 2012 is not particularly noteworthy in this comparison. This could also be observed in figures 1 and 2 – absolute prices for Europe and Japan stayed at similar relative levels throughout the peak price timeframe.

To sum up, there are significant absolute price differences between the three regions North America, Europe and East Asia. The price development between 1977 and 2015 is characterized by a trend of lower prices and general alignment until 1999 when prices rose for all regions. However, while prices in North America stabilized and continue to decrease since 2007, prices for Europe and Japan remained high until 2014/15.

This high price difference will be further analysed in the following sections.

5.2 Theories and hypothesizes

This subchapter deduces the theoretical baseline for the statistical analyses used to test for the integration of natural gas markets. To start with, necessary assumptions will be discussed.

5.2.1 Assumptions

Different price-finding systems are in place across North America, Europe and North-East Asia. While the national market price follows the law of supply and demand in the United States of America, the Chinese national market price is regulated by the government. Because of this, using the reported national market prices for each nation would distort the comparison. To avoid this national market prices will be neglected.

In a trade of goods between nations, usually the quality of the good matters. However, as explained before, natural gas is a good that is not affected by different levels of quality. Goods like this are defined as commodities (Investopedia, 2016). If profit maximization from natural gas exporters is assumed and markets are indeed integrated, the monetary value that is given by importing countries in exchange for the supply of natural gas, is not subject to the same pricing-system as each importing country's market price. Consequently, by collecting import prices for the supply of natural gas, the issue of price distortions that modify national market prices can be disregarded. Thus, this thesis utilizes the reported import prices for each of the sample economies for comparison.

Following this thought, it is more important to investigate if import prices affect national prices in countries that import a significant amount of their natural gas, because the higher a nation's relative reliance on imports, the better import prices reflect 'true'[21] market prices. This is the main reason why net exporting countries like Russia and Canada are not covered for hypotheses testing below.

[21] i.e. not distorted

There will be an additional mismatch of the countries covered in the previous chapter and within this part of the thesis: Firstly, due to data availability it was not possible to establish a core set of countries that would be sufficient to answer the research question. Secondly, the approach to encompass as many countries as possible in each section to maximize the coverage was deemed to be excessive for the scale of this paper. Thus, a number of countries have been selected with two goals in mind: Have as much data available as possible and include as many countries as necessary, while limiting the number where possible. The final list of countries is as follows: Europe will be represented by Germany, Hungary, Italy, Spain and the UK. North America will be represented by the United States of America, while Japan and South Korea will represent East Asia.

As it has been established in the previous chapter, the European market is very fractured. Hence, no single country would be sufficient to establish universal characteristics of the price setting mechanism of the entire continent. Germany is the biggest natural gas consumer within the region and sources its natural gas from a diverse set of suppliers. Hungary is one of the few Eastern European countries with available data. Italy and Spain are both large economies in Europe that source their supply of natural gas via pipeline as well as LNG shipments. The United Kingdom's natural gas market is the most liberal of the European markets. Due to the dominant position of the United States in the North America region, it was not deemed necessary to include Mexico as well. On the other hand, regarding North East Asia it was not possible to collect enough comparable data for the Chinese case to justify an inclusion here.

The next two subchapters will develop arguments that either speak in favour or against the existence of an integrated global market for natural gas. Three hypotheses will be set up in order to test the data sample. Below, the first two hypotheses, based on the law of one price, will be presented.

5.2.2 The law of one price

The concept of the law of one price is rather simple: Any good that is sold in the same quantity and quality must have the same price regardless of the location. Otherwise, arbitrage would be possible. Hence, entrepreneurial traders would buy quantities of the good in cheaper locations and sell it at more expensive locations for a profit (Rashid, 2007, pp. 84-85). In the long run, this would equalize prices across all locations until arbitrage is no longer possible (Murry & Zhu, 2008, p. 752).

There are several major limitations to this concept: First, market barriers cannot exist. Secondly, profit maximizing behaviour is presumed. Additionally, it is assumed that transportation and distribution is costless (Goldberg & Knetter, 1997, p. 1245). Each limitation effects the analysis for market integration differently. Regarding the first limitation: when market barriers between economies are in place, the market is segmented (Nordhaus W. , 2009). Profit maximization is already part of the assumption for this analysis as established in the previous subchapter. The third limitation can be accounted for by adding transportation and distribution costs to the concept. In the next step, these costs will be separated from import prices. If the resulting prices are equal, the concept of the law of one price applies. Thus, the "markets can be seen as fully integrated" (Siliverstovs, L'He´garet, Neumann, & von Hirschhausen, 2005, p. 605). As explained in the previous chapters, natural gas is a commodity and as such unaffected by different levels of quality. Hence, under these assumptions, the concept of the law of one price can be applied to the case of natural gas.

As specified above, this paper uses import prices for the analysis. Lacking the ability to identify the transportation costs component of import prices[22], a simplified solution will be used: Firstly, it will be presumed that import prices across all countries are equal to each other. This would be the case if natural gas markets were fully integrated and transport and distribution costs did not exist. Next, two countries will be paired and the difference between the import prices will be calculated. This variable is then assumed to be the transportation cost component[23]. Finally, two possible outcomes will be differentiated: the difference is either a) below a certain threshold[24] or b) above this threshold. In case of outcome a), it is assumed that import prices of the two covered nations are equal. The price difference results from transportation and distribution costs and both markets are integrated. If b) applies, the price difference is of such significance, that transportation

[22] Data of this detail is not available. See (Murry & Zhu, 2008) regarding the difficulty of finding a pricing model for natural gas (p. 758). In absence of a model, one would need to access exporters' internal cost structure which is far beyond the scope of this thesis.
[23] There are more costs involved in the transaction between trading partners. It will be assumed that these are accounted for in the transportation cost variable.
[24] The threshold will be specified in chapter 6

and distribution costs are not sufficient to explain the price difference. The markets are segmented. Thus, hypothesis 1 states:

Hypothesis 1: **The price difference for natural gas between countries is explained by the transportation cost component.**

Following, the formula for the variable that represents the transportation cost component will be derived. Suppose that natural gas is marketed in two countries. *A* denotes country A, and *B* denotes country B. The currency price of a single unit of natural gas is represented by *p*. *E* denotes the exchange rate of *B*'s currency per unit of *A*'s currency. The basic formula representing the concept of the law of one price is then

$$p_A = Ep_B \tag{1}$$

Introducing the transportation cost component variable *ε*, which is specific to the trade between country A and B, to the formula gives

$$p_A = Ep_B + \varepsilon_{AB} \tag{2}$$

Transposing the formula for ε gives:

$$\varepsilon_{AB} = p_A - Ep_B \tag{3}$$

Formula 3 will be used to test hypothesis 1. However, even if the transportation cost variable is within acceptable levels, the result is not sufficient to conclude that the markets are integrated. In order to improve the reliance of this analysis, another dimension will be added: time. This leads to hypothesis 2:

Hypothesis 2: **Price differences between two countries are stable over time.**

Comparing the calculated transportation cost component of the same country-pair over multiple time periods makes it possible to observe whether the observation is lasting. Consequently, the variable for time *t* is added and gives formula 4

$$\varepsilon_{AB_t} = p_{A_t} - Ep_{B_t} \tag{4}$$

The comparison of the transportation cost variable between two economies over several time periods will have one out of four different results: a) all ε remain at the same value or vary only slightly over time, b) the value increases over time, c) the value decreases over time, or d) the value does not resemble any observable trend over time.

Outcomes b) and c) are interchangeable, as switching the first country from position A to position B and the second country from position B to A, will change the outcome from b) to c) or vice versa. Outcome b) and c), as well as outcome d) show that prices between the two countries are not coupled. Either one or both countries experience price changes independent of each other. Consequently, both markets are not integrated with each other. Only outcome a) does not necessarily imply that both markets are segmented. However, outcome a) requires a positive result from hypothesis 1.

By combining both observations, firstly the transportation cost variable is below a certain threshold, and, secondly, the variable does not vary over time, it is justified to call both markets integrated. Thus, the variable for the transportation cost component should be similar if not identical between two nations over time.

Testing for hypotheses 1 and 2 gives results for a pair of countries. The test can also be applied for two separate import prices of the same nation: Often, natural gas import prices are divided by mode of transportation: Either pipeline or LNG import. Thus, prices for pipeline imports can be compared to prices for LNG imports for a single nation.

Finally, both hypotheses do not only have be accepted for a specific pair of nations, rather all import price pairs need to fulfil the conditions. The goal of this thesis is to analysis whether natural gas markets are integrated globally. Consequently, all possible pairs need to be compared with each other.

This concludes the preparation for the first part of the analysis. Next, the concept of market interactions and hypothesis 3 will be presented.

5.2.3 Market interaction

In contrast to analysing the cause for price differences between countries, this subchapter approaches the question whether markets are integrated from another perspective. One observation that can be made when analysing integrated markets is that price changes are mirrored in many different countries. The oil price shocks of the 70s and 80s of the 20th century affected oil prices across continents (Nordhaus W. , 2009). When OPEC announces that its member states are going to reduce oil production, one can observe rising oil prices globally (Kaufmann, Dees, Karadeloglou, & Sanchez, 2004, pp. 67-68). While oil prices are not the same in every country, they are affected by the fundamentals of the oil market. In integrated markets, price shocks have global effects. (Tsafos, 2015).

The question is whether this applies to natural gas markets as well. Are prices in Japan affected if Canada reduces natural gas production? Since the shale gas boom in the United States, the gap in natural gas prices between the US and Japan increased substantially (Rogers & Stern, 2014). This implies that both markets are segmented from each other. With the use of statistics, this thesis aims to find out whether this applies to natural gas markets in general. This is done by doing a correlation analysis. If price correlation between countries is positive and high, natural gas markets are integrated. Thus, the hypothesis for the second part of the analysis states:

Hypothesis 3: Price correlation between import prices is positive and high

Correlation is represented by the correlation coefficient *r* with values ranging between -1 for perfect negative correlation and +1 for perfect positive correlation. Hypothesis 3 will be accepted if $r >= 0.8$.

There are two major ways to test correlation: Either by calculating the Spearman's rank correlation coefficient (Spearman correlation) or by calculating the Pearson correlation coefficient (Pearson correlation). Spearman correlation is better suited to this type of analysis because one of its assumptions is a monotonic relationship between both variables, while Pearson correlation assumes a linear relationship. A linear price relationship implies that both prices increase or decrease at the same rate, while a monotonic relationship only implies that both prices increase and decrease together. Coming back to the example of the oil market, prices do not necessarily increase and decrease at the same rate globally. Consequently, assuming a linear relationship cannot be justified. Additionally, Spearman correlation is less dependent on variables that are distributed normally (Kowalski, 1972, p. 11).

In addition to the correlation analysis, a graphical analysis based on the same data will presented subsequent to the correlation analysis. Based on the arguments and test preparations of the previous chapter, this chapter is structured as follows: First, subchapter 5.3 will present the data sample and present the test results. Subchapter 5.4 will then introduce the data sample for the second part of the analysis[25].

5.3 Test for LOP

In order to test for market integration based on the concept of the law of one price, annual import prices for eight countries located in three different geographical regions have been collected. The countries for reach regions have been chosen based on availability of data and geographical representation. Europe is represented by Germany, Hungary, Italy, Spain and the United Kingdom. The United States have been selected for North America while the Republic of Korea and Japan stand for East Asia. The data was taken from publications of the International Energy Agency (Natural Gas Information, 2016). The timeframe begins in 2008 and ends in 2015. There is a differentiation between the type of import: LNG and pipeline. In the sample, only Spain, Italy and the United States import significant quantities with the use of both technologies[26]. Consequently, for Japan, Korea and United Kingdom just LNG import prices are analysed. Likewise, there are only pipeline import prices for Hungary and Germany.

Based on the formula presented in above, the price differences of all possible import price pairs have been calculated. For each covered year, this leads to 55 separate observations. With a

[25] The two analyses use a different sample.
[26] Pipeline import prices for the United Kingdom have not been published.

total of 440 observations. As established in the previous chapter, hypothesis 1 will be accepted if the price difference between two separate import prices is below a certain threshold. This threshold is supposed to cover costs arising from transportation and distribution. A flexible threshold has been calculated based on the data from Dehnavi, Wirl & Yegorov (2015, p. 38). The authors calculated a range of transportation costs between the USA, UK and Japan. Based on the distance between those markets, the author of this thesis weighted the costs and calculated the average transportation costs per distance of 100 kilometres. The resulting costs are roughly 0.01 US$ per 100km. Consequently, if ε_{AB} is equal or smaller than 0,01 US$ at a distance between both markets of 100 km, hypothesis 1 will be accepted. Next, a distance matrix was set up in order to account for the varying distances between each of the included countries. The matrix can be found in Appendix III table III[27].

Table 6 shows the result for the year of 2009.

import price differences in US$ per mbtu 2009	GER pipeline	HUN pipeline	ITA pipeline	SPA pipeline	ITA LNG	SPA LNG	UK LNG	JAP LNG	KOR LNG	US LNG	US pipeline
GER pipeline		-1,21	-0,58	1,06	0,61	1,77	4,04	**-0,76**	-2,03	3,95	4,41
HUN pipeline	1,21		0,63	2,27	1,82	2,98	5,25	**0,45**	**-0,82**	5,16	5,62
ITA pipeline	0,58	-0,63		1,64	1,19	2,35	4,62	**-0,18**	-1,45	4,53	4,99
SPA pipeline	-1,06	-2,27	-1,64		-0,45	0,71	2,98	-1,82	-3,09	2,89	3,35
ITA LNG	-0,61	-1,82	-1,19	0,45		1,16	3,43	-1,37	-2,64	3,34	3,80
SPA LNG	-1,77	-2,98	-2,35	-0,71	-1,16		2,27	-2,53	-3,80	2,18	2,64
UK LNG	-4,04	-5,25	-4,62	-2,98	-3,43	-2,27		-4,80	-6,07	**-0,09**	**0,37**
JAP LNG	**0,76**	**-0,45**	**0,18**	1,82	1,37	2,53	4,80		-1,27	4,71	5,17
KOR LNG	2,03	**0,82**	1,45	3,09	2,64	3,80	6,07	1,27		5,98	6,44
US LNG	-3,95	-5,16	-4,53	-2,89	-3,34	-2,18	**0,09**	-4,71	-5,98		0,46
US pipeline	-4,41	-5,62	-4,99	-3,35	-3,80	-2,64	**-0,37**	-5,17	-6,44	-0,46	

Table 6 - Natural gas import price difference in 2009

Sources: (International Energy Agency, 2016) and own calculations

[27] The distances were calculated for the shortest line between capitals. Especially for the distances between Europe and North East Asia, LNG shipments must travel longer distances. To account for inaccuracy, the transportation cost threshold has been applied not as strictly for the test of hypothesis 1.

Each ε_{AB} where hypothesis 1 is accepted has been highlighted in bold in table 6 For example, in 2009 this applies for the German and Japanese import prices. The price difference between both markets is 0.76 US$/mbtu. The distance between both markets has been determined as 8,926 kilometres. Thus, the individual threshold for the acceptable price difference between German and Japanese markets is 0.89 US$. As the actual price difference is below this threshold, H1 is accepted. The other pairs were Hungary and Japan, Italy pipeline and Japan, Hungary and Korea, UK and US pipeline as well as UK and US LNG. The results for the years of 2008. 2010, 2011, 2012, 2013, 2014 and 2015 can be found in Appendix II table IV, V, VI, VII, VIII, IX and X respectively.

Table 7 sums up the findings. The horizontal axis consists of 55 combinations of countries and means of transportation. The vertical axis represents the year. Each 'x' stands for the acceptance of hypothesis 1 for the respective year-pair combination.

Year	GER pipe & HUN pipe	GER pipe & ITA pipe	GER pipe & ITA LNG	GER pipe & SPA pipe	GER pipe & SPA LNG	GER pipe & UK LNG	GER pipe & US pipe	GER pipe & US LNG	GER pipe & JAP LNG	GER pipe & KOR LNG	HUN pipe & ITA pipe	HUN pipe & ITA LNG	HUN pipe & SPA pipe	HUN pipe & SPA LNG	HUN pipe & UK LNG	HUN pipe & US pipe	HUN pipe & US LNG	HUN pipe & JAP LNG	HUN pipe & KOR LNG	ITA pipe & ITA LNG	ITA pipe & SPA pipe	ITA pipe & SPA LNG	ITA pipe & UK LNG	ITA pipe & US pipe	ITA pipe & US LNG	ITA pipe & JAP LNG	ITA pipe & KOR LNG
2008																		x									
2009									x									x	x							x	
2010																			x								
2011			x																								
2012																											
2013				x																							
2014								x						x													
2015					x			x			x		x				x				x				x		

Year	ITA LNG & SPA pipe	ITA LNG & SPA LNG	ITA LNG & UK LNG	ITA LNG & US pipe	ITA LNG & US LNG	ITA LNG & JAP LNG	ITA LNG & KOR LNG	SPA pipe & SPA LNG	SPA pipe & UK LNG	SPA pipe & US pipe	SPA pipe & US LNG	SPA pipe & JAP LNG	SPA pipe & KOR LNG	SPA LNG & UK LNG	SPA LNG & US pipe	SPA LNG & US LNG	SPA LNG & JAP LNG	SPA LNG & KOR LNG	UK LNG & US pipe	UK LNG & US LNG	UK LNG & JAP LNG	UK LNG & KOR LNG	US pipe & US LNG	US pipe & JAP LNG	US pipe & KOR LNG	US LNG & JAP LNG	US LNG & KOR LNG	JAP LNG & KOR LNG
2008											x			x						x								
2009																			x	x								
2010																												
2011							x																					
2012																												
2013																												
2014																												
2015					x						x					x												

Table 7 - Acceptance of hypothesis 1

Source: own calculation

As it turns out, hypothesis 1 can be rarely accepted. In most cases import prices vary strongly between countries. Out of the 480 possibilities, only 5% meet the criteria. This is especially surprising for the US, were similar prices between LNG and pipeline imports are expected due to the high share of short market trading.

Additionally, there is no single market pair, for which H1 could be accepted more than twice. Consequently, hypotheses 2 cannot be accepted.

Before discussing the findings and consequences of this analysis in subchapter 6.3, the correlation analysis based on the concept of market interactions will be presented next.

5.4 Test for market interactions

To analysis whether natural gas market fundamentals affect prices in different regions, this subchapter calculates the price correlation of different import price pairs. For this purpose, monthly import prices have been collected from the International Energy Agency (Natural Gas Information, 2016). The data sample starts in January 2012 and ends in December 2012 resulting in a total of 48 observations for countries where only one type of import has been disclosed by the IEA. Thus, countries like Spain, were prices for LNG imports and pipeline imports are distinguished from each other, 96 observations have been collected. There are two exceptions: Firstly, there was no data available for Italian LNG imports in November 2013. Second, for the month of November in 2014 there was no data available for the USA as well. To account for this, in both instances the missing data was approximated by calculating the average of the preceding and following month.

Additionally, the import prices for Europe and North East Asia have been combined to calculate a price that represents each region. In reduce distortions, the import prices of each category have been weighted to import volumes. For example, if Germany accounted for 42% of total pipeline imports of all European pipeline importing countries in the month of February 2013, the import price for that month was weighted with 42% in the European pipeline import price for February 2013. Volumes for Europe have been collected from Eurostat (2016), while volumes for Japan and South Korea have been collected from Fairplay (2016). However, for the year of 2012 no volumes were reported for Japan and Korea separately. Thus, equals weights were assumed for this year.

The United States of America represent the North American region. The prices for Europe and North America are divided between LNG import prices and pipeline import prices. With this data, it is possible to not only analyse the correlation between nations, but also between regions as a whole.

Figure 6 shows the descriptive statistics for the data sample.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Pipe Ger	48	5.62	11.59	9.3575	1.89743
Pipe Hungary	48	6.23	13.18	10.3933	2.02783
Pipe Italy	48	6.19	13.81	10.7646	2.23606
Pipe Spain	48	6.19	11.20	9.7488	1.45415
LNG Italy	48	4.99	13.62	10.2927	2.68716
LNG Spain	48	5.78	10.78	9.1994	1.61034
LNG UK	48	5.00	10.61	7.8452	1.59411
LNG Japan	48	8.61	18.30	14.8571	2.91041
LNG S.Korea	48	8.83	16.93	14.2621	2.47543
Pipe U.S.	48	2.90	17.00	6.4231	2.89185
LNG U.S.	48	1.97	8.89	3.6254	1.57645
Pipe Europe	48	5.84	12.05	9.8310	2.00284
LNG Europe	48	4.96	11.28	8.9265	1.84661
LNG East Asia	48	8.67	17.15	14.5779	2.69611
Valid N (listwise)	48				

Figure 6 - Descriptive Statistics

Sources: (International Energy Agency, 2016), (Eurostat, 2016), (Fairplay, 2016) and own calculations

For the period 2012-2015, it can be seen, that import prices were lowest for US LNG and highest for Japanese LNG. In general, North East Asia experiences the highest average prices, while North America is characterized by the lowest average prices. European prices tend to lie in between with LNG prices below that of pipeline prices. In addition, the difference between average LNG and pipeline prices in the United States is significantly higher to average European prices.

Figure 7 shows that apart from LNG import prices for the United Kingdom, normal distribution is not significant. Thus, one of the conditions for Pearson correlation does not apply.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pipe Ger	.234	48	.000	.863	48	.000
Pipe Hungary	.247	48	.000	.885	48	.000
Pipe Italy	.218	48	.000	.879	48	.000
Pipe Spain	.261	48	.000	.786	48	.000
LNG Italy	.185	48	.000	.891	48	.000
LNG Spain	.231	48	.000	.790	48	.000
LNG UK	.082	48	.200*	.958	48	.086
LNG Japan	.304	48	.000	.756	48	.000
LNG S.Korea	.219	48	.000	.831	48	.000
Pipe U.S.	.133	48	.032	.897	48	.001
LNG U.S.	.199	48	.000	.773	48	.000

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Figure 7 - Tests of Normality

Source: own calculations

Next, the correlation coefficient for Spearman correlation has been calculated for a several pairs of import prices. The pairs have been grouped two ways: One the one hand by region, and on the other hand by medium of import, e.g. pipeline or LNG shipments. The calculation will show whether import prices within each region correlate.

Figure 8 shows the analysis results for pipeline import prices in Europe.

Correlations

			Pipe Ger	Pipe Hungary	Pipe Italy	Pipe Spain
Spearman's rho	Pipe Ger	Correlation Coefficient	1.000	.906**	.871**	.848**
		Sig. (2-tailed)	.	.000	.000	.000
		N	48	48	48	48
	Pipe Hungary	Correlation Coefficient	.906**	1.000	.889**	.853**
		Sig. (2-tailed)	.000	.	.000	.000
		N	48	48	48	48
	Pipe Italy	Correlation Coefficient	.871**	.889**	1.000	.855**
		Sig. (2-tailed)	.000	.000	.	.000
		N	48	48	48	48
	Pipe Spain	Correlation Coefficient	.848**	.853**	.855**	1.000
		Sig. (2-tailed)	.000	.000	.000	.
		N	48	48	48	48

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 8 - Correlations European pipeline prices

Source: own calculations

As it can be seen, correlation between the countries is positive and high. Consequently, hypotheses 3 can be accepted for European pipeline import prices. The data is not significant, which implies the absence of systematic relationship between the variables. This is not surprising, as import prices have little impact on each other. The goal of this analysis is testing for high positive correlation between prices. The significance of the correlation will be neglected.

Next, the findings of the correlation analysis for the European LNG market will be presented.

Correlations

			LNG Italy	LNG Spain	LNG UK
Spearman's rho	LNG Italy	Correlation Coefficient	1.000	.671**	.550**
		Sig. (2-tailed)	.	.000	.000
		N	48	48	48
	LNG Spain	Correlation Coefficient	.671**	1.000	.745**
		Sig. (2-tailed)	.000	.	.000
		N	48	48	48
	LNG UK	Correlation Coefficient	.550**	.745**	1.000
		Sig. (2-tailed)	.000	.000	.
		N	48	48	48

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 9 - Correlations European LNG prices

Source: own calculations

Figure 9 shows that the correlation between European LNG prices are positive, but not as high as European pipeline prices. No correlation coefficient has at least a value of 0.8. Accordingly, hypothesis 3 cannot be accepted.

For North East Asia, the results are similar:

Correlations

			LNG Japan	LNG S.Korea
Spearman's rho	LNG Japan	Correlation Coefficient	1.000	.730**
		Sig. (2-tailed)	.	.000
		N	48	48
	LNG S.Korea	Correlation Coefficient	.730**	1.000
		Sig. (2-tailed)	.000	.
		N	48	48

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 10 - Correlation North East Asian import prices

Source: own calculation

As it can be seen in figure 10, the correlation between the import prices of South Korea and the import prices of Japan are not high. Thus, hypothesis 3 cannot be accepted. Since the United States are solely representing the North American region, no regional correlation analysis has been conducted. Instead, the results of the correlation analysis between the weighted regional import prices presented next.

Correlations

			Pipe Europe	LNG Europe	LNG East Asia	Pipe U.S.	LNG U.S.
Spearman's rho	Pipe Europe	Correlation Coefficient	1.000	.868**	.409**	-.360*	.105
		Sig. (2-tailed)	.	.000	.004	.012	.476
		N	48	48	48	48	48
	LNG Europe	Correlation Coefficient	.868**	1.000	.485**	-.330*	.146
		Sig. (2-tailed)	.000	.	.000	.022	.322
		N	48	48	48	48	48
	LNG East Asia	Correlation Coefficient	.409**	.485**	1.000	.054	.419**
		Sig. (2-tailed)	.004	.000	.	.716	.003
		N	48	48	48	48	48
	Pipe U.S.	Correlation Coefficient	-.360*	-.330*	.054	1.000	.552**
		Sig. (2-tailed)	.012	.022	.716	.	.000
		N	48	48	48	48	48
	LNG U.S.	Correlation Coefficient	.105	.146	.419**	.552**	1.000
		Sig. (2-tailed)	.476	.322	.003	.000	.
		N	48	48	48	48	48

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 11 - Correlations regional import prices

Source: own calculations

The correlation analysis depicted in figure 11 has several outcomes: Firstly, correlation is high within Europe. Second, there is negative correlation between Europe and US pipeline prices, that is stronger than the positive correlation between Europe and US LNG prices. Third, there is some positive correlation between North East Asia and the other two regions, although US pipeline price are almost not correlated with North East Asian prices at all. And finally, the positive correlation between US LNG and pipeline prices is not very strong. Consequently, hypothesis 3 can only be accepted for the European natural gas market.

An additional result of the analysis presented in figure 11 is noteworthy: The correlation between European and North American, as well as the correlation between North East Asia and US pipeline prices is significant. This implies, that it is very likely, that the relationship between those markets is systematic. While it would be interesting to explore this further, this is beyond the scope of this paper.

Based on the data sample, a number of charts have been plotted to offer an alternative way to observe natural gas markets interactions. While subchapter 5.1 discussed general trends, the following chart empathize on higher levels of detail. Figure 12 shows the first chart. It comprises all collected data.

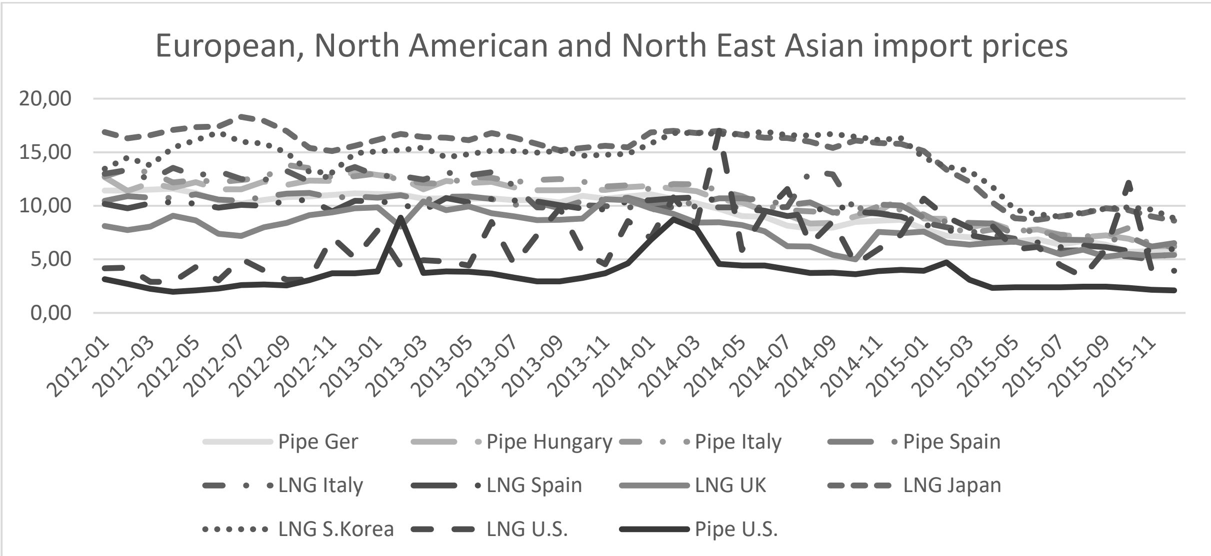

Figure 12 - European, North American and North East Asian import price development

Source: own calculations

At the start of the timeframe, natural gas prices in North East Asia are more than three times as high as US prices. Since the final months of 2014, price in the region have been declining, although the price difference to Europe and, especially the US is still significant. European prices are more diverse in the beginning of the period but are aligning towards each other while slowly decreasing. US prices are more volatile than prices in other regions. Also, in contrast to Europe and North East Asia, natural gas price did not decrease significantly.

Each region will be shown in detail below, afterwards, the findings of both analyses will be discussed in the following subchapter.

Figure 13 shows pipeline and LNG import prices for Europe.

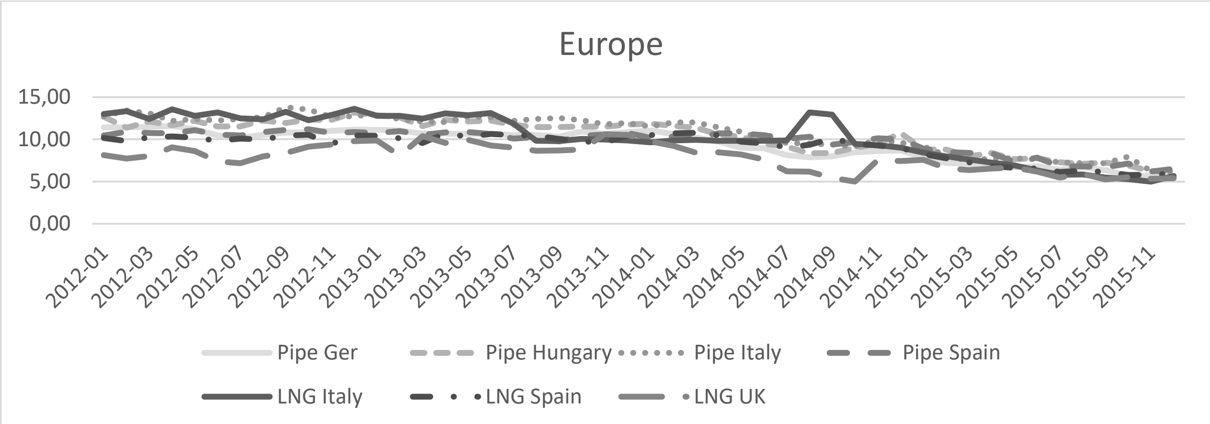

Figure 13 - European import price development

Source: own calculations

This chart supports the findings of figure 12: European prices have converged and decreased significantly over the timeframe. Separate charts for LNG and pipeline price can found in Appendix III, figures 2 and 3 respectively. Following, the situation for Japan and South Korean is displayed.

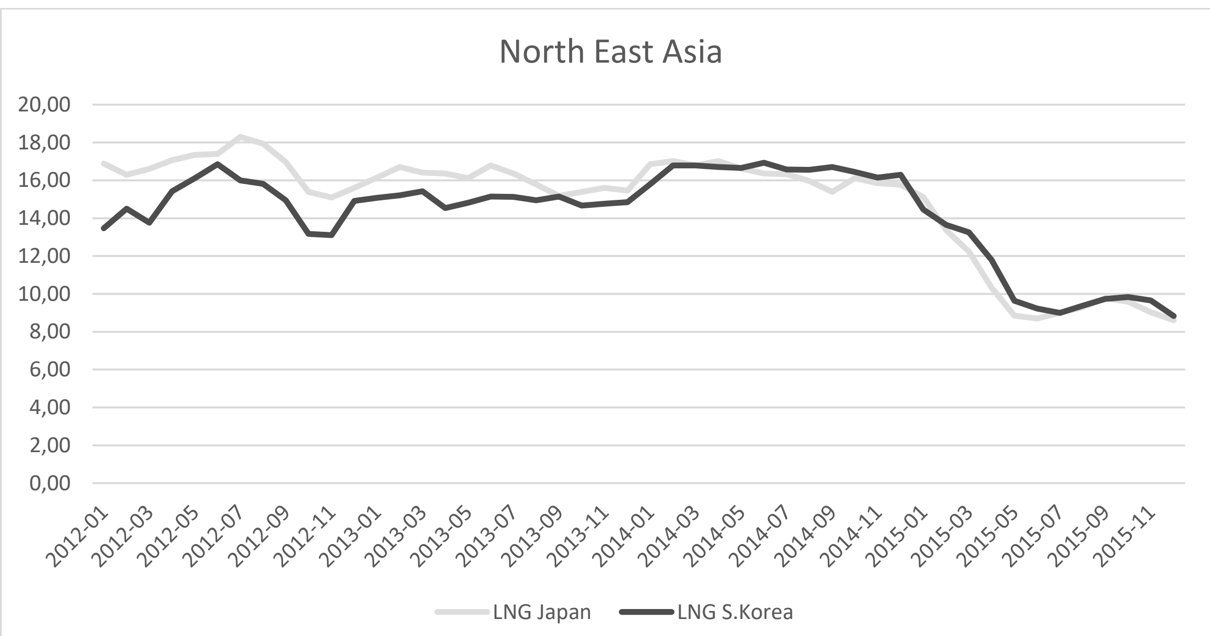

Figure 14 - North East Asian import price development

Source: own calculations

Graphically, the two markets as seen in figure 14 seem to correlate highly, especially since the third quarter of 2013. It seems likely, that the correlation coefficient for both markets would be higher, if 2012 would be removed from the calculation. Over the time frame, prices in North East Asia have halved. In contrast to this trend, there were two significant periods of increased prices almost mirrored by both countries: The first in 2012 and the second one for the whole year of 2014.

The price development for the United States of America will be presented next.

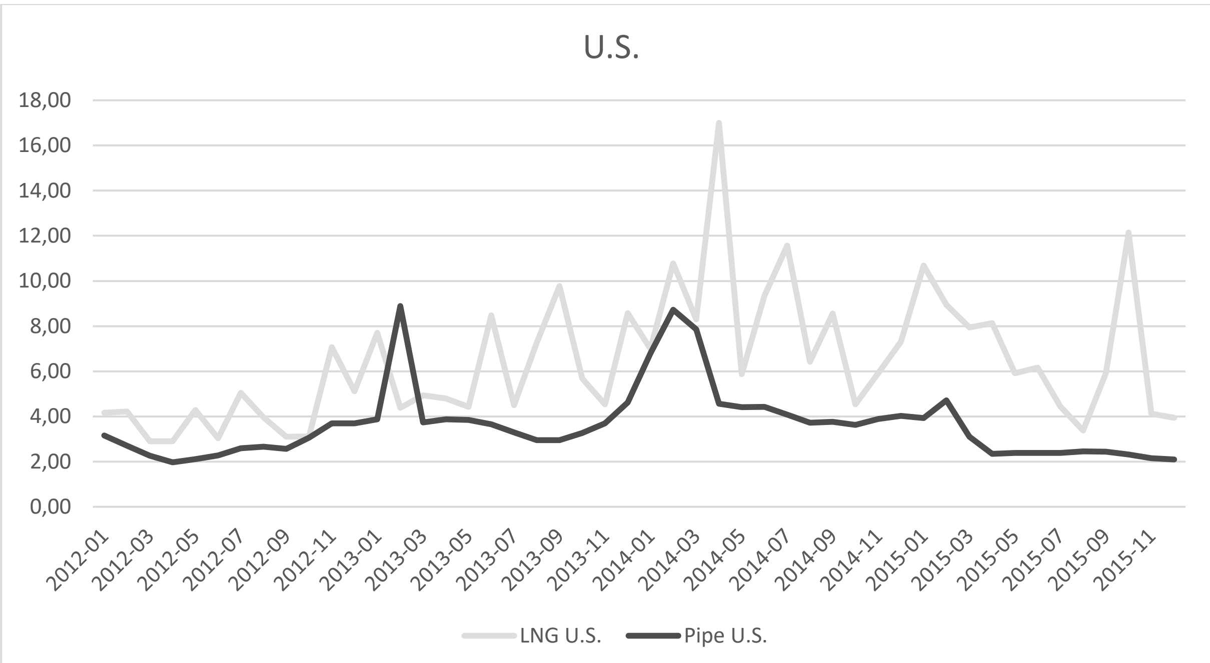

Figure 15 - US import price development

Source: own calculations

Figure 15 shows that prices in the US are at the end of the timeframe at almost the same level than at the beginning of the timeframe. This contrasts the overall declining prices that can be observed in Europe and North East Asia. However, prices in the USA are still significantly lower than in the other two regions. Also, US prices experienced several price increases, the import price for LNG is especially volatile. For the first halve of 2014, US prices peaked. This is somewhat similar to the development of North East Asian prices during that timeframe, as shown in figure 14.

This concludes the presentation of the analysis results. Next, the findings of both analyses will be compared and discussed.

6. Discussion

This part of this thesis will summarize and discuss the findings of the previous chapter. As table 7 summarized, over the course of 8 years, the price difference between any two import prices of the same year is only 25 times below the threshold. The threshold has been defined as the value specific to each pair of variables, below which the price difference is not violating the concept of the law of one price, as established in subchapter 5.2. Considering the sample size of 55 variable pairs over 8 years, a total of 25 times is a surprisingly low amount. Especially within Europe, the price differences, even when accounting for transportation costs, are surprisingly high. The situation is similar for the US market: the price differences between LNG and pipeline imports are rather high. Future research into this characteristic would be interesting.

When it comes to hypothesis 2, as it turns out, the highest number of occurrences, where a specific pair of variables was below the threshold for more than one year, was two years. This is only a quarter of the total timeframe. Thus, hypothesis 2 cannot be accepted. and, based on the concept of the law of one price natural gas markets are not integrated.

The second analysis, presented in the previous subchapter, is based on a different approach. By testing the correlation between monthly import prices, as well as examining the graphical representation of the data sample, the degree of market interaction was determined. It has been established in subchapter 5.3, that market integration is assumed if price correlation is high. This has only been the case for the European pipeline markets, although correlation between pipeline and LNG markets within Europe has been quite high as well (the pair Spain-pipe and Italy-LNG is just above a correlation coefficient of 0.8, see Appendix III figure 1 for all European results). None of the other regional markets is characterized by high price correlation. The regional comparison revealed even negative correlation between US pipeline prices and European prices. Under these conditions, hypothesis 3 can only be accepted for the European pipeline market. As a result, based on the correlation analysis, natural gas markets are not integrated either.

Finally, there is the graphical analysis, which is based on the same data as the correlation analysis. Given the somewhat arbitrary nature of judging interrelations of variables by examining graphs, the graphical analysis can only support the findings of the previous two analyses by offering another perspective. In general, a monotonic relationship between the variables can be observed: Over the timeframe, European and North East Asian import prices are decreasing, while US prices are stable. As time progressed, the European, as well as the North East Asian prices were aligning, implying correlation might increase in future months. Overall, there was little indication, that the findings of the other two analyses were wrong: Based on the two data samples, natural gas markets are segmented.

The final part of this chapter will list a number of possible limitations to the findings of this thesis.

7. Limitations

There are at least three sets of limitations to this thesis: The first set is based on the data samples and calculations. The import prices have been collected from a single source. A diversification of data sources would increase the robustness of the findings. Goldberg & Knetter (1997, p. 1247) state that most price information is based on price indices, resulting in arbitrary results. Also, a longer time frame would increase the value of the findings. In addition, lacking a pricing model for natural gas, the threshold for the transportation cost component is not immune to fault.

The second set of limitations is based on the assumptions: Firstly, assuming profit maximizing behaviour is probably to simple. On the one hand, exporters might not be able to switch trading partners due to existing contracts. On the other hand, increasing transport capacity in order to improve arbitrage opportunities takes a very long time. Apart from the time commitment, huge investments are required, and investors are uncertain whether the arbitrage opportunities will exist long enough for their investments to return profit (Dehnavi, Wirl, & Yegorov, 2015, p. 22).

Finally, energy security is a very important issue for nations. The absence of politics in natural gas trading is highly unlikely. Rather the opposite is true: Von Hirschhausen & Engerer (1998, p. 1117) state that the natural gas sector is highly influenced by politics. Consequently, politics need to be accounted for when analysing natural gas markets. This completes chapter 6. Below, the thesis will be concluded.

8. Conclusion

The aim of this master's thesis was to analyse whether natural gas markets are integrated or segmented. To prepare the analysis-part of the thesis, chapters three and four covered different aspects: The former established natural gas as an energy source while the latter acknowledged important regional areas. Natural gas shares many of the benefits of fossil fuels, like abundance of reserves and high energy density, without being as bad when it comes to CO_2 emissions. However, compared to coal and oil transportation and storage is significantly more complicated, requiring high initial investments and long-term commitment. This may be one of the explanations, why the market for natural gas is not as integrated as the market for oil. Chapter four explained that supply and demand of natural gas is not evenly distribution across the globe. While the North American region is self-sufficient, Europe and North East Asia are highly dependent on imports. A large share of natural gas imports in Europe comes from within the region, especially if Russia is considered part of the region. In contrast to that, North East Asia primarily relies on imports from outside of the region. China holds considerable reserves but is currently not exploiting them.

Chapters five and six constitute the analytical part of this thesis. Two concepts were introduced in chapter five: Firstly, the concept of the law of one price, and second, the concept of price interactions based on market fundamentals. In theory, each was sufficient to find enough evidence for the presence of market integration. Based on the concept of the law of one price, two hypotheses were developed. It was argued, that when both hypotheses could be accepted, the markets would be integrated. However, even when accounting for transportation costs, the annual price differences between markets were too high. Also, the price differences were not consistent over time. Consequently, it was established that from the perspective of the law of one price, natural gas markets are segmented. The second analysis was based on the hypothesis, that when markets are integrated, prices correlation is positively high. Thus, a correlation analysis was conducted. The results were in line with the first analysis: natural gas markets are segmented. Apart from the European natural gas market, the data did not reveal high correlation. Finally, price development of natural gas over time was charted and analysed. It revealed that between 2012 and 2015 natural gas prices decreased considerably in North East Asia and Europe. For both regions, correlation seemed to increase over time. The US situation was quite different: The price fluctuation was very high, especially for LNG imports. This characteristic is probably a consequence of the fact that the

US market is the most liberal of all markets analysed. However, the UK market is regarded as similarly liberal and did not show the same characteristics.

Consequently, based on the data analysed in this thesis, natural gas markets are not integrated. There is little evidence to assume this will change in the future. There seems to be no lack of arbitrage opportunities, still price difference remains high. Probable causes for the lack of further market integration are uncertainty of future price developments and the absence of political will to remedy the situation. Although these considerations are very interesting to pursue, there are beyond the scale of this paper.

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10. Appendix I - list of regional nation groupings

With adaptations from: OPEC Annual Statistical Bulletin (2015), p. 109 - 110

'North America' consists of: Canada, United States and Mexico.

'Remaining America' composed of: Antigua, Argentina, Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, British Virgin Islands, Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Falkland Islands (Malvinas), French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Montserrat, Netherlands Antilles, Nicaragua, Panama (including Panama Canal Zone), Paraguay, Peru, Puerto Rico, St Kitts-Nevis-Anguilla, St Lucia, St Vincent, Suriname, Trinidad & Tobago, Turks and Caicos Islands, United States Virgin Islands, Uruguay and Venezuela.

'Europe, CIS and Turkmenistan' contains: Austria, Belgium (including Luxembourg), Cyprus, Denmark (including Faroe Islands), Finland, France (including Andorra and Monaco), Germany, Gibraltar, Greece, Iceland, Ireland, Italy (including San Marino and the Holy See), Malta, Netherlands, Norway (including Svalbard and Jan Mayen Islands), Portugal, Spain (including Canary Islands), Sweden, Switzerland (including Liechtenstein), Turkey, United Kingdom, Bosnia and Herzegovina, Croatia, Macedonia, Serbia and Montenegro, Slovenia, Albania, Armenia, Azerbaijan, Belarus, Bulgaria, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Poland, Romania, Russia, Slovakia, Tajikistan, Turkmenistan, Ukraine and Uzbekistan.

'Africa' includes: Algeria, Angola, Benin, Botswana, British Indian Ocean Territory, Burkina Faso, Burundi, Cameroon (United Republic of), Cape Verde, Central African Republic, Chad, Comoros, Congo (Republic of the), Congo (Democratic Republic of the), Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia (The), Ghana, Guinea, Guinea-Bissau, Côte d'Ivoire, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, St Helena, São Tomé and Príncipe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudans (including South Sudan and Sudan), Swaziland, Tanzania, Togo, Tunisia, Uganda, Western Sahara, Zambia and Zimbabwe.

‘Middle East’ consist of: Bahrain, Islamic Republic of Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates (UAE) (Abu Dhabi, Ajman, Dubai, Fujairah, Ras al-Khaimah, Sharjah, Umm al-Qaiwain), Yemen and other Middle East.

‘North East Asia’ contains: Japan, Korea (Republic of) and China.

‘Remaining Asia & Pacific’ composed of: Afghanistan, American Samoa, Antarctica, Australia, Bangladesh, Bhutan, Brunei, Cambodia, Canton and Enderbury Islands, China Hong Kong Special Administrative Region (SAR), China Macau SAR, Chinese Taipei, Christmas Island, Cocos (Keeling) Islands, Cook Islands, Fiji, French Polynesia, Guam, India, Indonesia, Johnston Island, Kiribati, Korea (Democratic People’s Republic of), Lao People’s Democratic Republic, Malaysia, Maldives, Midway Islands, Mongolia, Myanmar, Nauru, Nepal, New Caledonia, New Zealand, Niue, Norfolk Island, Pacific Islands (Trust Territory), Pakistan, Papua New Guinea, Philippines, Pitcairn Island, Samoa, Singapore, Solomon Islands, Sri Lanka, Thailand, Tokelau, Tonga, Tuvalu, Vanuatu, Vietnam, Wake Island, Wallis and Futuna Islands.

11. Appendix II - Additional ~~T~~tables

Table I - USA Primary Energy Consumption by Source in percent

	USA Primary Energy Consumption by Source in %				
Year	Coal	Natural Gas	Oil	Nuclear	Renewables
1990	23	23	40	7	7
2000	23	24	39	8	6
2005	23	23	40	8	6
2010	21	25	36	9	8
2014	18	28	36	8	10
2015	16	29	37	9	10

Source: U.S. Energy Information Administration. (2017). *Monthly Energy Review January 2017.* Washington: U.S. Energy Information Administration, page: 7 and own calculations

Table II – USA Natural gas imports and exports

	Natural Gas in quadrillion Btu		
Year	Imports	Exports	Net Imports
1950	0	0.027	-0.027
1960	0.161	0.012	0.149
1970	0.846	0.072	0.774
1980	1.006	0.049	0.957
1990	1.551	0.087	1.064
1995	2.901	0.156	2.745
2000	3.869	0.245	3.624
2005	4.450	0.735	3.715
2010	3.834	1.147	2.687
2011	3.555	1.519	2.036
2012	3.216	1.633	1.583
2013	2.955	1.587	1.368
2014	2.763	1.528	1.235
2015	2.786	1.800	0.986

Source: U.S. Energy Information Administration. (2017). *Monthly Energy Review January 2017.* Washington: U.S. Energy Information Administration, page: 10 and own calculation

Table III – capital distance matrix

direct distances between capitals in km	GER	HUN	ITA	SPA	UK	JAP	KOR	US
GER		689	1,187	1,871	933	8,926	8,136	6,718
HUN	689		813	1,976	1,451	9,056	8,178	7,343
ITA	1,187	813		1,364	1,437	9,868	8,980	7,225
SPA	1,871	1,976	1,364		1,265	10,774	10,007	6,095
UK	933	1,451	1,437	1,265		9,569	8,867	5,904
JAP	8,926	9,056	9,868	10,774	9,569		1,154	10,916
KOR	8,136	8,178	8,980	10,007	8,867	1,154		11,176
US	6,718	7,343	7,225	6,095	5,904	10,916	11,176	

Source: https://www.distancecalculator.net

Table IV – 2008 import price differences in US$ per mbtu

import price differences in US$ per mbtu 2008	*GER pipeline*	*HUN pipeline*	*ITA pipeline*	*SPA pipeline*	*ITA LNG*	*SPA LNG*	*UK LNG*	*JAP LNG*	*KOR LNG*	*US LNG*	*US pipeline*
GER pipeline		-0.47		1.90		2.28	2.29	-1.14	-2.65	1.66	3.10
HUN pipeline	0.47			2.37		2.75	2.76	**-0.67**	-2.18	2.13	3.57
ITA pipeline											
SPA pipeline	-1.90	-2.37				0.38	0.39	-3.04	-4.55	**-0.24**	1.20
ITA LNG											
SPA LNG	-2.28	-2.75		-0.38			**0.01**	-3.42	-4.93	-0.62	0.82
UK LNG	-2.29	-2.76		-0.39		**-0.01**		-3.43	-4.94	**-0.63**	0.81
JAP LNG	1.14	**0.67**		3.04		3.42	3.43		-1.51	2.80	4.24
KOR LNG	2.65	2.18		4.55		4.93	4.94	1.51		4.31	5.75
US LNG	-1.66	-2.13		**0.24**		0.62	**0.63**	-2.80	-4.31		1.44
US pipeline	-3.10	-3.57		-1.20		-0.82	-0.81	-4.24	-5.75	-1.44	

Source: (International Energy Agency, 2016) and own calculations

Table V – 2010 import price differences in US$ per mbtu

import price differences in US$ per mbtu 2010	GER pipeline	HUN pipeline	ITA pipeline	SPA pipeline	ITA LNG	SPA LNG	UK LNG	JAP LNG	KOR LNG	US LNG	US pipeline
GER pipeline		-1,57	-0,61	0,56	-0,83	0,91	2,50	-2,97	-2,12	3,26	3,67
HUN pipeline	1,57		0,96	2,13	0,74	2,48	4,07	-1,40	**-0,55**	4,83	5,24
ITA pipeline	0,61	-0,96		1,17	-0,22	1,52	3,11	-2,36	-1,51	3,87	4,28
SPA pipeline	-0,56	-2,13	-1,17		-1,39	0,35	1,94	-3,53	-2,68	2,70	3,11
ITA LNG	0,83	-0,74	0,22	1,39		1,74	3,33	-2,14	-1,29	4,09	4,50
SPA LNG	-0,91	-2,48	-1,52	-0,35	-1,74		1,59	-3,88	-3,03	2,35	2,76
UK LNG	-2,50	-4,07	-3,11	-1,94	-3,33	-1,59		-5,47	-4,62	0,76	1,17
JAP LNG	2,97	1,40	2,36	3,53	2,14	3,88	5,47		0,85	6,23	6,64
KOR LNG	2,12	**0,55**	1,51	2,68	1,29	3,03	4,62	-0,85		5,38	5,79
US LNG	-3,26	-4,83	-3,87	-2,70	-4,09	-2,35	-0,76	-6,23	-5,38		0,41
US pipeline	-3,67	-5,24	-4,28	-3,11	-4,50	-2,76	-1,17	-6,64	-5,79	-0,41	

Source: (International Energy Agency, 2016) and own calculations

Table VI – 2011 import price differences in US$ per mbtu

import price differences in US$ per mbtu 2011	GER pipeline	HUN pipeline	ITA pipeline	SPA pipeline	ITA LNG	SPA LNG	UK LNG	JAP LNG	KOR LNG	US LNG	US pipeline
GER pipeline		-0,54	**-0,14**	1,04	-1,15	1,50	2,01	-4,15	-2,09	5,11	6,57
HUN pipeline	0,54		0,40	1,58	-0,61	2,04	2,55	-3,61	-1,55	5,65	7,11
ITA pipeline	**0,14**	-0,40		1,18	-1,01	1,64	2,15	-4,01	-1,95	5,25	6,71
SPA pipeline	-1,04	-1,58	-1,18		-2,19	0,46	0,97	-5,19	-3,13	4,07	5,53
ITA LNG	1,15	0,61	1,01	2,19		2,65	3,16	-3,00	**-0,94**	6,26	7,72
SPA LNG	-1,50	-2,04	-1,64	-0,46	-2,65		0,51	-5,65	-3,59	3,61	5,07
UK LNG	-2,01	-2,55	-2,15	-0,97	-3,16	-0,51		-6,16	-4,10	3,10	4,56
JAP LNG	4,15	3,61	4,01	5,19	3,00	5,65	6,16		2,06	9,26	10,72
KOR LNG	2,09	1,55	1,95	3,13	**0,94**	3,59	4,10	-2,06		7,20	8,66
US LNG	-5,11	-5,65	-5,25	-4,07	-6,26	-3,61	-3,10	-9,26	-7,20		1,46
US pipeline	-6,57	-7,11	-6,71	-5,53	-7,72	-5,07	-4,56	-10,72	-8,66	-1,46	

Source: (International Energy Agency, 2016) and own calculations

Table VII – 2012 import price differences in US$ per mbtu

import price differences in US$ per mbtu 2012	GER pipeline	HUN pipeline	ITA pipeline	SPA pipeline	ITA LNG	SPA LNG	UK LNG	JAP LNG	KOR LNG	US LNG	US pipeline
GER pipeline		-1,07	-1,77	0,27	-1,93	0,91	2,69	-5,69	-3,69	6,87	8,33
HUN pipeline	1,07		-0,70	1,34	-0,86	1,98	3,76	-4,62	-2,62	7,94	9,40
ITA pipeline	1,77	0,70		2,04	-0,16	2,68	4,46	-3,92	-1,92	8,64	10,10
SPA pipeline	-0,27	-1,34	-2,04		-2,20	0,64	2,42	-5,96	-3,96	6,60	8,06
ITA LNG	1,93	0,86	0,16	2,20		2,84	4,62	-3,76	-1,76	8,80	10,26
SPA LNG	-0,91	-1,98	-2,68	-0,64	-2,84		1,78	-6,60	-4,60	5,96	7,42
UK LNG	-2,69	-3,76	-4,46	-2,42	-4,62	-1,78		-8,38	-6,38	4,18	5,64
JAP LNG	5,69	4,62	3,92	5,96	3,76	6,60	8,38		2,00	12,56	14,02
KOR LNG	3,69	2,62	1,92	3,96	1,76	4,60	6,38	-2,00		10,56	12,02
US LNG	-6,87	-7,94	-8,64	-6,60	-8,80	-5,96	-4,18	-12,56	-10,56		1,46
US pipeline	-8,33	-9,40	-10,10	-8,06	-10,26	-7,42	-5,64	-14,02	-12,02	-1,46	

Source: (International Energy Agency, 2016) and own calculations

Table VIII – 2013 import price differences in US$ per mbtu

import price differences in US$ per mbtu 2013	GER pipeline	HUN pipeline	ITA pipeline	SPA pipeline	ITA LNG	SPA LNG	UK LNG	JAP LNG	KOR LNG	US LNG	US pipeline
GER pipeline		-1.23	-1.60	**0.14**	-1.44	0.50	1.30	-5.29	-4.25	4.06	7.07
HUN pipeline	1.23		-0.37	1.37	-0.21	1.73	2.53	-4.06	-3.02	5.29	8.30
ITA pipeline	1.60	0.37		1.74	0.16	2.10	2.90	-3.69	-2.65	5.66	8.67
SPA pipeline	**-0.14**	-1.37	-1.74		-1.58	0.36	1.16	-5.43	-4.39	3.92	6.93
ITA LNG	1.44	0.21	-0.16	1.58		1.94	2.74	-3.85	-2.81	5.50	8.51
SPA LNG	-0.50	-1.73	-2.10	-0.36	-1.94		0.80	-5.79	-4.75	3.56	6.57
UK LNG	-1.30	-2.53	-2.90	-1.16	-2.74	-0.80		-6.59	-5.55	2.76	5.77
JAP LNG	5.29	4.06	3.69	5.43	3.85	5.79	6.59		1.04	9.35	12.36
KOR LNG	4.25	3.02	2.65	4.39	2.81	4.75	5.55	-1.04		8.31	11.32
US LNG	-4.06	-5.29	-5.66	-3.92	-5.50	-3.56	-2.76	-9.35	-8.31		3.01
US pipeline	-7.07	-8.30	-8.67	-6.93	-8.51	-6.57	-5.77	-12.36	-11.32	-3.01	

Source: (International Energy Agency, 2016) and own calculations

Table IX – 2014 import price differences in US$ per mbtu

import price differences in US$ per mbtu 2014	GER pipeline	HUN pipeline	ITA pipeline	SPA pipeline	ITA LNG	SPA LNG	UK LNG	JAP LNG	KOR LNG	US LNG	US pipeline
GER pipeline		-0.81	-1.35	-1.06	-0.52	-0.73	1.78	-7.20	-7.36	**0.66**	4.03
HUN pipeline	0.81		-0.54	-0.25	0.29	**0.08**	2.59	-6.39	-6.55	1.47	4.84
ITA pipeline	1.35	0.54		0.29	0.83	0.62	3.13	-5.85	-6.01	2.01	5.38
SPA pipeline	1.06	0.25	-0.29		0.54	0.33	2.84	-6.14	-6.30	1.72	5.09
ITA LNG	0.52	-0.29	-0.83	-0.54		-0.21	2.30	-6.68	-6.84	1.18	4.55
SPA LNG	0.73	**-0.08**	-0.62	-0.33	0.21		2.51	-6.47	-6.63	1.39	4.76
UK LNG	-1.78	-2.59	-3.13	-2.84	-2.30	-2.51		-8.98	-9.14	-1.12	2.25
JAP LNG	7.20	6.39	5.85	6.14	6.68	6.47	8.98		-0.16	7.86	11.23
KOR LNG	7.36	6.55	6.01	6.30	6.84	6.63	9.14	0.16		8.02	11.39
US LNG	**-0.66**	-1.47	-2.01	-1.72	-1.18	-1.39	1.12	-7.86	-8.02		3.37
US pipeline	-4.03	-4.84	-5.38	-5.09	-4.55	-4.76	-2.25	-11.23	-11.39	-3.37	

Source: (International Energy Agency, 2016) and own calculations

Table X – 2015 import price differences in US$ per mbtu

import price differences in US$ per mbtu 2015	GER pipeline	HUN pipeline	ITA pipeline	SPA pipeline	ITA LNG	SPA LNG	UK LNG	JAP LNG	KOR LNG	US LNG	US pipeline
GER pipeline		-0,83	-0,87	-0,80	-0,27	**-0,06**	0,55	-3,90	-4,39	**-0,64**	3,80
HUN pipeline	0,83		**-0,04**	**0,03**	0,56	0,77	1,38	-3,07	-3,56	**0,19**	4,63
ITA pipeline	0,87	**0,04**		**0,07**	0,60	0,81	1,42	-3,03	-3,52	**0,23**	4,67
SPA pipeline	0,80	**-0,03**	**-0,07**		0,53	0,74	1,35	-3,10	-3,59	**0,16**	4,60
ITA LNG	0,27	-0,56	-0,60	-0,53		0,21	0,82	-3,63	-4,12	**-0,37**	4,07
SPA LNG	**0,06**	-0,77	-0,81	-0,74	-0,21		0,61	-3,84	-4,33	**-0,58**	3,86
UK LNG	-0,55	-1,38	-1,42	-1,35	-0,82	-0,61		-4,45	-4,94	-1,19	3,25
JAP LNG	3,90	3,07	3,03	3,10	3,63	3,84	4,45		-0,49	3,26	7,70
KOR LNG	4,39	3,56	3,52	3,59	4,12	4,33	4,94	0,49		3,75	8,19
US LNG	**0,64**	**-0,19**	**-0,23**	**-0,16**	**0,37**	**0,58**	1,19	-3,26	-3,75		4,44
US pipeline	-3,80	-4,63	-4,67	-4,60	-4,07	-3,86	-3,25	-7,70	-8,19	-4,44	

Source: (International Energy Agency, 2016) and own calculations

12. Appendix III – ~~additional~~ Additional figures

Figure I – Correlations European prices

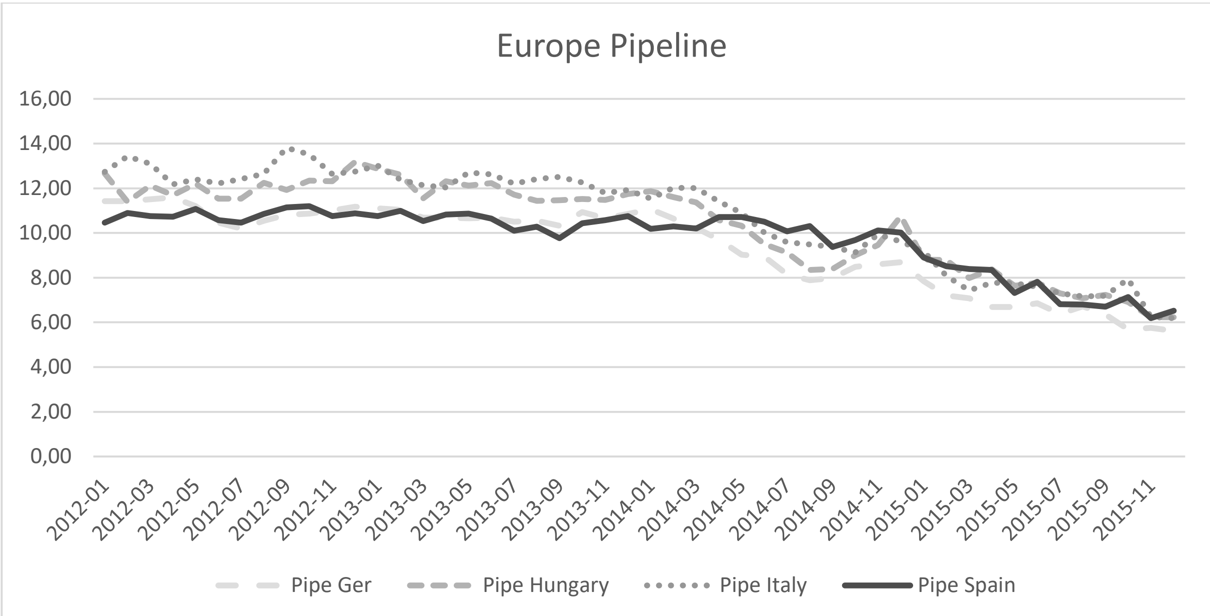
Correlations

			Pipe Ger	Pipe Hungary	Pipe Italy	Pipe Spain	LNG Italy	LNG Spain	LNG UK
Spearman's rho	Pipe Ger	Correlation Coefficient	1.000	.906**	.871**	.848**	.780**	.750**	.777**
		Sig. (2-tailed)	.	.000	.000	.000	.000	.000	.000
		N	48	48	48	48	48	48	48
	Pipe Hungary	Correlation Coefficient	.906**	1.000	.889**	.853**	.758**	.789**	.797**
		Sig. (2-tailed)	.000	.	.000	.000	.000	.000	.000
		N	48	48	48	48	48	48	48
	Pipe Italy	Correlation Coefficient	.871**	.889**	1.000	.855**	.793**	.733**	.692**
		Sig. (2-tailed)	.000	.000	.	.000	.000	.000	.000
		N	48	48	48	48	48	48	48
	Pipe Spain	Correlation Coefficient	.848**	.853**	.855**	1.000	.808**	.709**	.701**
		Sig. (2-tailed)	.000	.000	.000	.	.000	.000	.000
		N	48	48	48	48	48	48	48
	LNG Italy	Correlation Coefficient	.780**	.758**	.793**	.808**	1.000	.671**	.550**
		Sig. (2-tailed)	.000	.000	.000	.000	.	.000	.000
		N	48	48	48	48	48	48	48
	LNG Spain	Correlation Coefficient	.750**	.789**	.733**	.709**	.671**	1.000	.745**
		Sig. (2-tailed)	.000	.000	.000	.000	.000	.	.000
		N	48	48	48	48	48	48	48
	LNG UK	Correlation Coefficient	.777**	.797**	.692**	.701**	.550**	.745**	1.000
		Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.
		N	48	48	48	48	48	48	48

**. Correlation is significant at the 0.01 level (2-tailed).

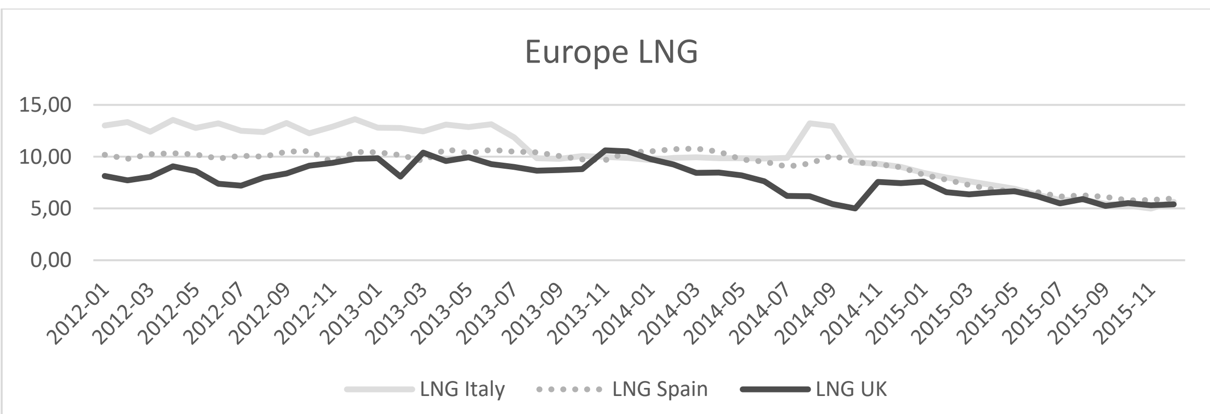
Source: own calculations

Figure II – European pipeline price development



Source: own calculations

Figure III – European LNG price development



Source: own calculations

13. Appendix IV - Abstract

This master's thesis investigates whether natural gas markets are integrated or segmented. It consists of three parts. Firstly, important characteristics, which distinguish natural gas from its substitutes are described. The major advantages are: high energy density, large reserves, less CO_2 emissions compared to oil and coal. The major disadvantage results from the difficulty to contain the gas for usage, storage and transportation. Secondly, the three most important regions regarding natural gas demand (North America, Europe and North East Asia) and their unique characteristics are presented. North America is the most liberal natural gas market on the world and produces enough gas to meet its supply. Many European countries need to import high shares of their natural gas demand. Only Norway and the Netherlands produce significant quantities. Apart from these two countries, Russia is the major source of natural gas for Europe, followed by North African and Middle Eastern exporters. The continental European markets are slowly changes regulation towards increased liberalization. In North East Asia, markets are just beginning to become more liberalized. Japan and South Korea are hugely depended on LNG imports. China's share of natural gas its energy mix is small, but growth is considerable. The country holds large, yet untapped reserves of shale gas.

Part three analyses a sample of eleven gas markets based in the aforementioned regions in three ways: Based on the concept of the law of one price, prices should be equal for identical goods. The result shows, even when accounting for transportation costs, prices are not equal. Next, a correlation analysis examines whether prices react to changing market fundamentals. Strong correlation is only found for the European market. Finally, market prices are analyzed graphically. The data indicates increasing levels of correlation towards the of the observed time-period and decreasing market prices for the European and North East Asian markets. The US market is characterized by overall low price and high price volatile. This thesis finds natural gas markets to be segmented.

14. Appendix III – Zusammenfassung

Die vorliegende Masterarbeit untersucht, ob Erdgasmärkte untereinander integriert sind. Die Arbeit besteht aus drei Teilen: Teil 1 beschreibt die Vorteile und Nachteile, die Erdgas gegenüber seinen Substituten hat. Zum einen ist Erdgas in großer Menge verfügbar, es hat eine hohe Energiedichte und es verursacht weniger CO2 Emissionen im Vergleich zu Kohle und Erdöl. Zum anderen verursacht der gasförmige Zustand höhere Aufwendungen für den Transport und die Lagerung von Erdgas. Teil 2 behandelt Nordamerika, Europa und Nordostasien. Jede dieser drei Regionen ist ein wichtiges Absatzgebiet für Erdgas. Nordamerika, insbesondere die USA haben den liberalsten Gasmarkt der Welt. Preise sind niedrig und die Produktion deckt den Verbrauch. Viele europäische Länder sind auf den Import von Erdgas angewiesen. Neben Norwegen und den Niederlanden ist Russland der wichtigste Erdgasversorger für Europa. Die Erdgasmärkte von Kontinentaleuropa sind nicht so liberal wie die USA oder das Vereinigte Königreich, aber Entwicklungen in diese Richtung sind zu beobachten. Im Gegensatz dazu stehen die Märkte in Nordostasien noch am Anfang der Liberalisierung. Japan und Südkorea sind sehr abhängig von LNG-Erdgasimporten. Der Anteil von Erdgas in Chinas Energieverbrauch ist noch gering, steigt aber kontinuierlich. Außerdem verfügt China über große Schiefergasreserven.

Der dritte Teil der Arbeit analysiert zwei Datensätze für je elf Gasmärkte in diesen drei Regionen. Basierend auf dem Konzept „the law of one price“, welches besagt, dass der Preis für zwei identisches Güter gleich sein muss, wird der erste Datensatz untersucht. Die Untersuchung ergibt, dass selbst unter der Berücksichtigung von Transportkosten die Preise nicht gleich sind. Im nächsten Schritt wird eine Korrelationsanalyse mit dem 2. Datensatz durchgeführt. Ziel ist es heraus zu finden, ob Erdgaspreise auf Marktveränderungen reagieren. Starke Korrelation wird dabei nur für den europäischen Markt festgestellt. Anschließend findet eine graphische Analyse statt. Dabei ist zu beobachten, dass die Erdgasmärkte in Europa und Nordostasien in der 2. Hälfte des Beobachtungszeitraums stärker korrelieren, und, dass die Preise in diesen Regionen sinken. Der US Markt ist hingegen stark von Preisschwankungen betroffen. Im Ergebnis wird der Erdgasmarkt als nicht integriert angesehen.