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„Shale Gas –
Studies on Environmental & Economic Impact“

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“Not Under My Backyard”

(American slogan used by Richard A. Kerr, 2010)

Intention

The intention behind this work is, to highlight two of the various aspects, which can be considered with shale gas, and analyze those in detail. In the following work, not only the environmental influence is considered, but in contrary the economic aspect, the relationship of oil and gas prices and their impact on the markets. The work is therefore divided into three broad areas: Formation of natural gas and its composition, environmental impact and economic impact.

The first part gives a comprehensive overview of the various gas forms and their specific characteristics. Particularly shale gas and its mining method, the hydraulic fracturing process, are elaborated.

The second part is about the environmental impact of shale gas and its risk, such as the influence on water safety, adequate waste water management, land use, seismic events and greenhouse gas emission. In this part my research focuses on whether or not shale gas has a negative impact on the environment and leads to major environmental problems.

The third part is about the economic effect of shale gas on the markets. In the past, oil and gas prices were proportional to each other, with the oil price always determining the gas price. The question is, whether this remains the same or if shale gas leads to a change in the relationship between oil and gas prices, and therefore to a change in the markets.

I would like to thank Dr. David Hirschmann for his comments and feedback. I am grateful for all the time he has devoted, the helpful suggestions and guidance along the way.

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Introduction

It all began in China, where the energy value was recognized first. They drilled the earliest known gas well around 211 BC. Bamboo pipelines were used for the transportation of the gas to boil water with its energy.[1] In Europe, natural gas was not discovered until 1659 in Great Britain. And even then, it was not widely-used until 1790. The United States, who nowadays are pioneers at drilling for shale gas, dug their first well in 1821. It was in Baltimore, Maryland and they used the power to lighten up the streets.

The demand for natural gas grew rapidly after World War II. Due to the fact of new developed transportation networks and storage-systems[2] it became "one of the cleanest, safest and most useful energy sources of the world and an important component of the world's energy supply, particularly for power generation."[3]

"(…) The Golden Age of Gas" as the International Energy Agency (IEA) titled a special report in 2011, started with the shale gas development. Due to new and improved technology, it is now possible to drill for it and satisfy the increasing demand with less dangerous endeavor. Shale gas is the most dynamic driver of the gas rush and the IEA predicts that in 2035, gas consumption will have increased by 50% (compared to the year 2010). This means, that the global energy consumption of natural gas will be 25%, compared to 21% today. These extreme increases of gas consumption have been especially made possible by the production of shale gas.

Even statistics are in favor of natural gas. With a R/P ratio (ratio of Resources and Production) for oil of 46.2 years worldwide, natural gas comes off well with 58.2 years. Only coal, with a P/R ratio of 118 years, is far ahead. In an informational statistic about natural gas the IEA reported in 2012 that "the globally proved reserves life index of natural gas is 64 years. The International Energy Agency (IEA) estimates in their statistics of the natural gas information

1 Speight (1993), 9
2 Speight (1993), 9
3 Bahadori (2014), 1

(2012), there are nearly 404 trillion cubic meters (tcm) (or 14,285 trillion cubic feet (tcf)) of remaining recoverable resources (including all resource categories) of conventional gas worldwide. This value is equivalent to almost 130 years of production at 2011 rates. Where Russia, Iran and Qatar together hold around half of the world's proved gas reserves."[4]

For unconventional gas the total global production is projected to rise from 13% in 2009 up to 22% in 2035. However, this is just a projection and depends on many uncertain factors like environmental regulations, political terms/issues, laws and provisions, which are set independently by the government of every single country with unconventional gas reservoirs.[5]

Not just a prediction is, that shale gas production is increasing significantly in the United States. And many countries are following this development. The cart below shows which countries have large deposits of shale gas (of 200 countries with known reserves) and are considered the "Top reserve holders":

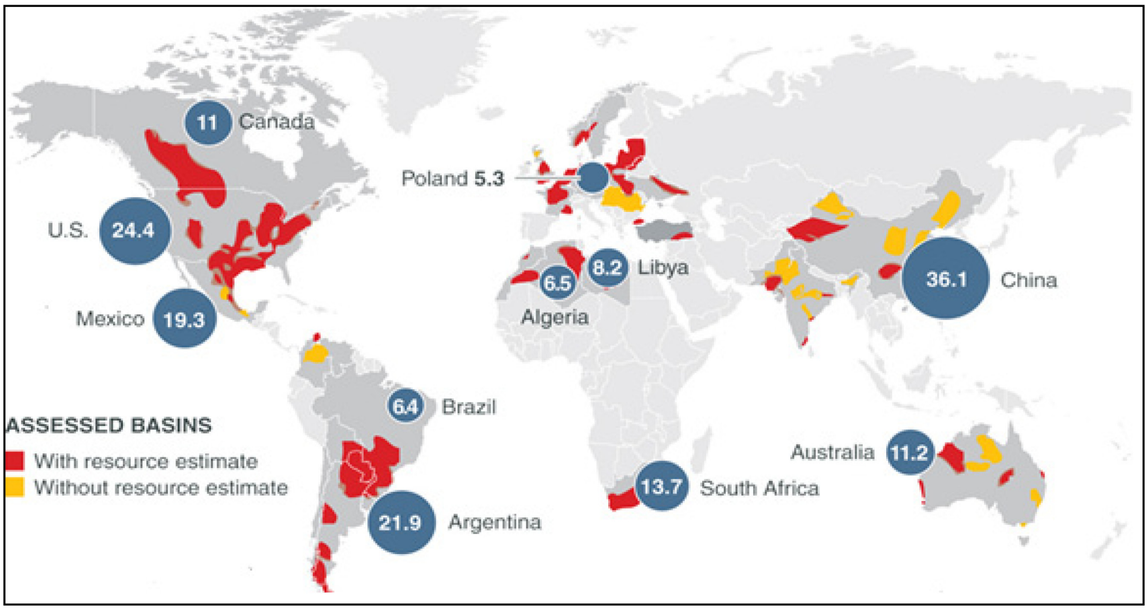

Image 0-1: EIA based on Advanced Resources International Inc data, BP, *"World shale gas reservoirs (in trillion cubic metres)"* (2013)

4 Bahadori (2014), 1
5 Bahadori (2014), 1

I. Formation of natural gas and its composition

In this part of the thesis a short introduction about the development, composition and forms of methane are given. Then, the different gas types are represented, as in figures 1-2. This is about the formation and the special properties and characteristics of each gas form. Afterwards, the hydraulic fracturing process will be explained and the chapter ends with Europe's attitude to hydraulic fracturing.

1 Formation of natural gas and its composition

Natural gas (like crude oil) is formed of buried plants and animals and it takes thousands of years of pressure and heat to convert it into fossil fuel. Due to that long development time it belongs to the non-renewable resources. In the shallower deposits (1609-3219 m (1-2 mi) below the Earth's crust), where the temperature is lower, gas is more associated with oil. Since both are fossil fuels and composed of the same material, temperature is the crucial factor in determining what is formed.[6] Natural gas was initially discovered as an unwelcome by- product of prospecting for crude oil. It is "free" trapped in multiple small zones of various naturally occurring rock formations, and it leaks out of the wells while drilling for crude oil. If this happens during the process, drilling has to stop and the workers have to wait until the unwanted natural gas is completely effused, as it is extremely flammable due to its main component

6 Bahadori (2014), 2

methane. Natural gas is mainly used for heating, as heat supplier for thermal processes for the industry, for electricity power, or as fuel for vehicles.[7]

Table of the natural gas composition:

Name	**Formula**	**Volume (%)**
Methane	CH_4	> 85
Ethane	C_2H_6	$3-8$
Propane	C_3H_8	$1-2$
Butane	C_4H_{10}	< 1
Pentane	C_5H_{12}	< 1
Carbon dioxide	CO_2	$1-2$
Hydrogen sulfide	H_2S	< 1
Nitrogen	N_2	$1-5$
Helium	He	< 0.5

Figure 1-1: Speight, *"The natural gas composition"* (1993)

Natural gas is a chemical mixture, and its composition varies widely depending on the region of where it is found. However, the main component it consists of is methane, with a percentage of around 85 or more. Reservoirs, which consist of (almost) pure methane, are called "dry". If other hydrocarbons, like ethane, propane, butane, pentanes and heavier hydrocarbons are present in natural gas, it is considered "wet". This name is due to the fact that under pressure most gases are easily liquefiable, and are called Natural Gas Liquids

7 Speight (1993), 9

(NGL).[8] During processing the mixtures of hydrocarbons need to get separated and purified immediately, because some gases are toxic or can attack the pipelines.[9]

There are three different ways methane is formed:

If the pressure of mud and sediment convert organic matter, methane is referred to as **thermogenic methane**. With higher temperatures more pure methane will be formed under the surface, while with less heat the natural gas consists also of ethane, propane, butane, pentanes and heavier hydrocarbons. This is one process how methane and natural gas are originated.[10]

Another way methane is formed, is through the transformation of organic material by tiny microorganism. This type of methane is called **biogenic methane** and it occurs at a landfill for example. With new technologies it is possible to harvest the released biogenic methane and use as energy.

The so- called **abiogenic** process is the third possibility to get **methane**. Here, the extremely deep, hydrogen-rich gases and carbon molecules may react with minerals on their way to the surface due to the absence of oxygen. The high pressure on the way up, leads then to methane production, similar to the thermogenic process.

As mentioned above, natural gas predominantly consists of methane, with minor quantities of other hydrocarbons. “The varieties of gas compositions can be broadly categorized into three distinct groups:”[11]

- Non-associated gas (or sometimes called gas well gas) appears at conventional gas fields and is formed through geological formations. It basically consists of methane or occasionally some higher boiling hydrocarbons (gas liquids). Due to the pressure it is under, it is easy to extract. Once the reservoir is open, the gas simply streams up through the wellhead, where it gets collected at the treatment plant.[12]

8 Mokhatab et.al. (2006), 4
9 Devold (2013), 16
10 Bahadori (2014), 2
11 Mokhatab et.al. (2006), 4
12 Speight (1993), 15

- Associated gas, which occurs in conventional oil fields, is produced during the drilling process for crude oil. It is a side- product due to the reduced pressure in the surface and the crude oil and natural gas need to be separated afterwards.

- Unconventional (or also called continuous) gas, which is trapped in impermeable rock, is extracted by horizontal drilling and fracturing. It can occur in the forms of tight gas, coal bed methane (coal seam gas), gas hydrates (methane hydrates) and shale gas.

  In chapter 2.2 unconventional gases are discussed in more detail.

However, it is not the composition of the gas which defines whether it is considered conventional or unconventional, but the rock types and trapping mechanisms.[13]

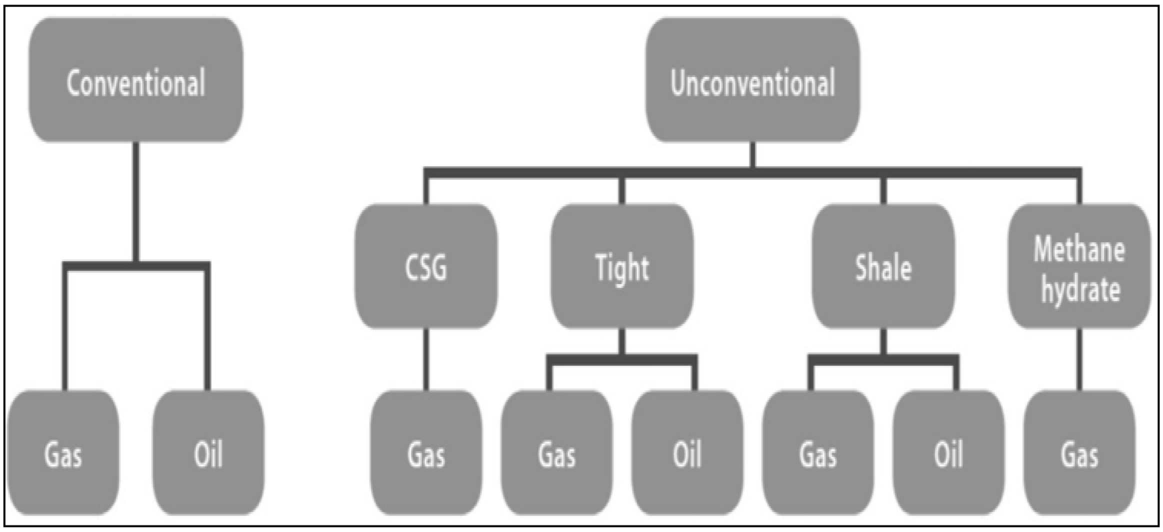

Figure 1-2: Bahadori, "*The range of conventional and unconventional hydrocarbons"* (2014)

13 Bahadori (2014), 2

1.1 Conventional gas

Conventional gas is found in sandstone and limestone formations, which are very porous and therefore easily accessible.[14] “Gas is trapped in structures in the rock that are caused by folding and/or faulting of sedimentary layers.”[15] The technique of finding gas is the same as for crude oil - the seismic technique. Through gas, the seismic waves slow down and produce a characteristic and strong reflection. For around a hundred years the focus of the industry has been on the abundant conventional gases. But before harvesting many factors need to coincide in order of a field to be developed:

First of all, there has to be a source, the ancient organic deposits. For over millions of years, high temperatures and the pressure of the overwhelming layers of earth act on it until hydrocarbons are formed. They spread out into the smallest gaps and pores of the rock and connect due to the porosity of stone. “Permeable rocks allow the migration of the hydrocarbons to travel upwards toward lesser pressure until they reach a “trap””[16] where the hydrocarbons then accumulate, as consequence of the impenetrable deposits. By drilling a vertical well into such a subsurface trap and there for using the reservoirs own energy, the way is set free for natural gas.[17]

1.2 Unconventional gas

Unconventional natural gas is mostly trapped in its source rock. Or, if it has the chance to move up, it rises until it reaches an impermeable formation. The reservoirs are spread out over large areas and consist of just a little fewer gas storages than the conventional fields. Compared to conventional gas however, its potential is far from exhausted, as it takes more effort to release the gas. It is not trapped in porous and permeable formations like conventional

14 Bahadori (2014), 2
15 Bahadori (2014), 3
16 Bahadori (2014), 4
17 Bahadori (2014), 3

gas. The gas will flow to the well only after special stimulation of the pores. Commonly, hydraulic fracturing is used as the main technique, to gain the unconventional natural gases out of the surface. “It is used to microfracture the rock around the well bore and connect the pore spaces in the rock and further enable the flow of hydrocarbons into the well bore and then to surface.”[18]

First of all, it is necessary with hydraulic fracturing to drill a vertical well to reach the required depth. Afterwards, the oriented horizontal drilling takes place through the gas- bearing rocks. It is drilled hundreds of meters into the target unit that connects the pores and allows the gas to flow through the well up to the surface. Once it is there, the transforming and conditioning process takes place, before it is transported via pipelines.

To minimize the ecological footprint on the surface, it is possible to drill many horizontal wells from just one vertical wellhead. Thereby it is easily possible to exhaust the huge areas of unconventional gas fields and extract the still extremely large existing volumes of gas over one single vertical drilling process.[19]

The boundaries between conventional and unconventional natural gas are not precisely defined. But as mentioned above, the categories of unconventional gas are: tight gas, coal bed methane, gas hydrates and shale gas and will be explained in the following chapters.[20]

1.2.1 Coal bed methane

Coal bed methane (CBM) or also called coal seam gas (CSG) is the generic term for gas that exists in underground coal seams.[21] They act as a source rock and are quite close to the surface compared to the other forms of unconventional natural gas. Unlike conventional gas that is trapped in stone and rock formations, coal bed methane is held in place by reservoir (water) pressure

18 Bahadori (2014), 6
19 Bahadori (2014), 5 f
20 Speight (1993), 16
21 Speight (1993), 16

and is gripped onto the coal grain surface.[22]

The following image (1-1) is a schematic on the production of coal bed methane. It shows, that "there are small natural fractures called "cleats" which are often filled with water within the coal seam. Natural coal seam pressure keeps methane "absorbed" or attached to the coal seam."[23]

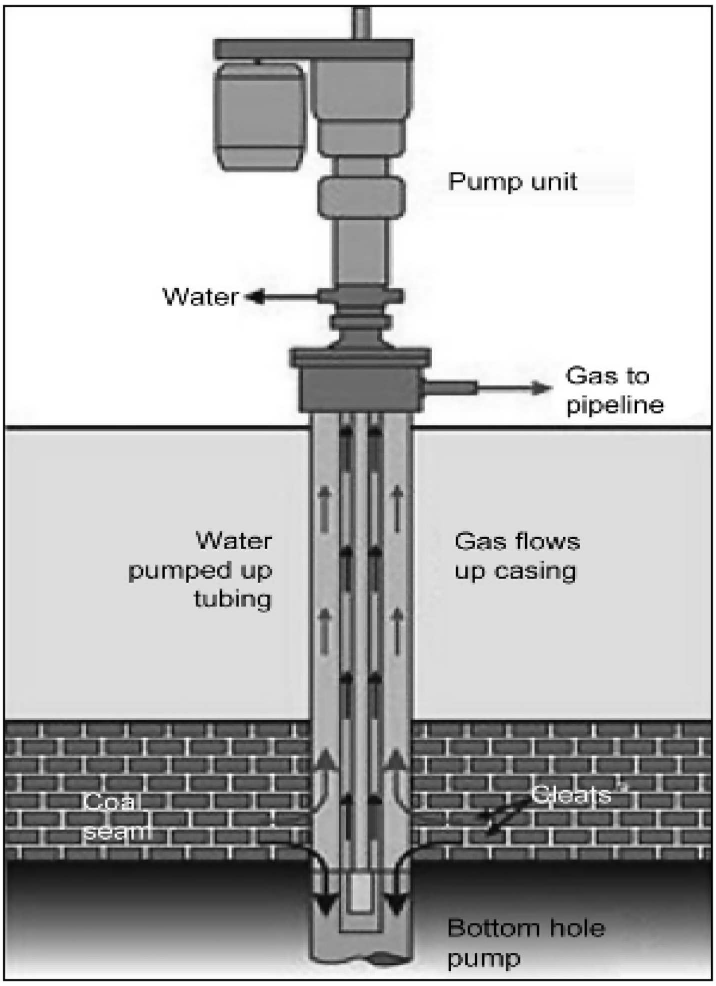

Image 1-1: Bahadori, *"Production of CBM"* (2014)

Two types can be distinguished: biogenic and thermogenic coal bed methane. As already mentioned earlier in chapter 1, for thermogenic methane

22 Mokhatab et.al. (2006), 7
23 Bahadori (2014), 11

the depth and therefore the related temperature are important. Whereas biogenic methane needs microbial activity for its formation. In the first stage of coalification, biogenic coal bed methane is formed and held in the deposit near the surface. It is generated from bacteria in organic matter and occurs in depths less than 1,000 ft, in low rank coals (lower carbon content). It is typically considered as "dry" natural gas. With lower temperatures, the generated methane is considered thermogenic coal bed methane and belongs to the "wet" natural gases. It is also usually formed during the coalification process when organic matter is buried. The matured plants and animals are buried deeper by sediment and stones and due to the higher temperatures (exceeding 50 °C) and the greater pressure in that layer of earth, it was slowly transformed into coal with large quantities of methane.[24] The methane was then absorbed onto the coal's surface, stored in the matrix of the coal and the fracture spaces of the rock (cleats), and is kept there by water pressure. “It desorbs from the micropores of the coal matrix when the hydrostatic pressure is reduced, such as the drilling of a well, and it flows through the cleats to a well bore.”[25]

“Coal has a very large internal surface area of over 1 billion square feet per ton of coal and can hold on average three times as much gas in place as the same volume of a conventional sandstone reservoir at equal depth and pressure.”[26]

The energy value of coal bed methane is higher compared to other natural gases; plus, it consists of significantly more pure methane per unit volume and doesn’t need a lot of transformation processes afterwards. That makes it very valuable for the industry and economic.[27]

24 Speight (1993), 16
25 Bahadori (2014), 10
26 Mokhatab et.al. (2006), 7
27 Mokhatab et.al. (2006), 7

1.2.2 Methane hydrate

Methane hydrate, or also known as gas hydrate, has ice-like structures located under the permafrost.[28] The methane molecule is surrounded by a cage of interlocking water molecules and is hosted just a few hundred meters under the surface. It is basically found in polar regions, where mainly the terrestrial deposits are stored or also in a marine environment.

“Methane hydrates represent a highly concentrated form of methane, with a cubic meter of idealized methane hydrate containing 0.8 cubic meter of water and more than 160 cubic meter of methane at standard temperature–pressure conditions.”[29] Methane is the predominant gas, but gases like ethane, propane and carbon dioxide can be mixed into it.

The methane can be harvested with various methods:

- Through temperature increase it can be transformed into a gaseous condition.
- With pressure relief usually arising during intersection the hydrate is exposed to atmospheric pressure, or by artificially produced clefts and cracks.
- By pumping carbon dioxide gas or heated water into the reservoir.
- Through the injection of antifreeze methanol.[30]

1.2.3 Tight gas

Tight gas (or also called tight sands gas) is found in low- permeability and low- porosity rocks. [31] Tight gas reservoirs are defined through their grade of porosity and permeability. It is referred to as tight gas if it has less than 0.1 millidarcy (mD) matrix permeability and less than 10% matrix porosity.

28 Mokhatab et.al. (2006), 4
29 Bahadori (2014), 13
30 Bahadori (2014), 9
31 Bahadori (2014), 9

Generally it exists of "dry" natural gas and requires massive hydraulic fracturing to be produced economically efficient.

The main task of drilling for tight gas is to create a long, highly conductive flow path. For stabilization reasons the propping agent is being pumped up into the wellhead therefore making the gas stream upwards. The production rate of a well will increase over time as a fact of the long endurance of the hydraulic fracturing path and the higher flow volume, which is achieved thereby.

Tight gas is found around the world, in any depth in geological basins, and is more difficult to extract than conventional gas. It has been produced for a few decades now and the process is pretty similar to that of shale gas drilling.[32] Both (shale gas and tight gas) are located generally two or more kilometers under the surface, but differ by their rock types.[33] Even if they have the same source (accumulation of sediments at the earth’s surface and within bodies of water) and both emerge in sandstone and limestone, they are considered different from each other.[34]

32 Bahadori (2014), 9
33 Bahadori (2014), 7
34 Olavarria et.al. (2013), 8

1.2.4 Shale gas

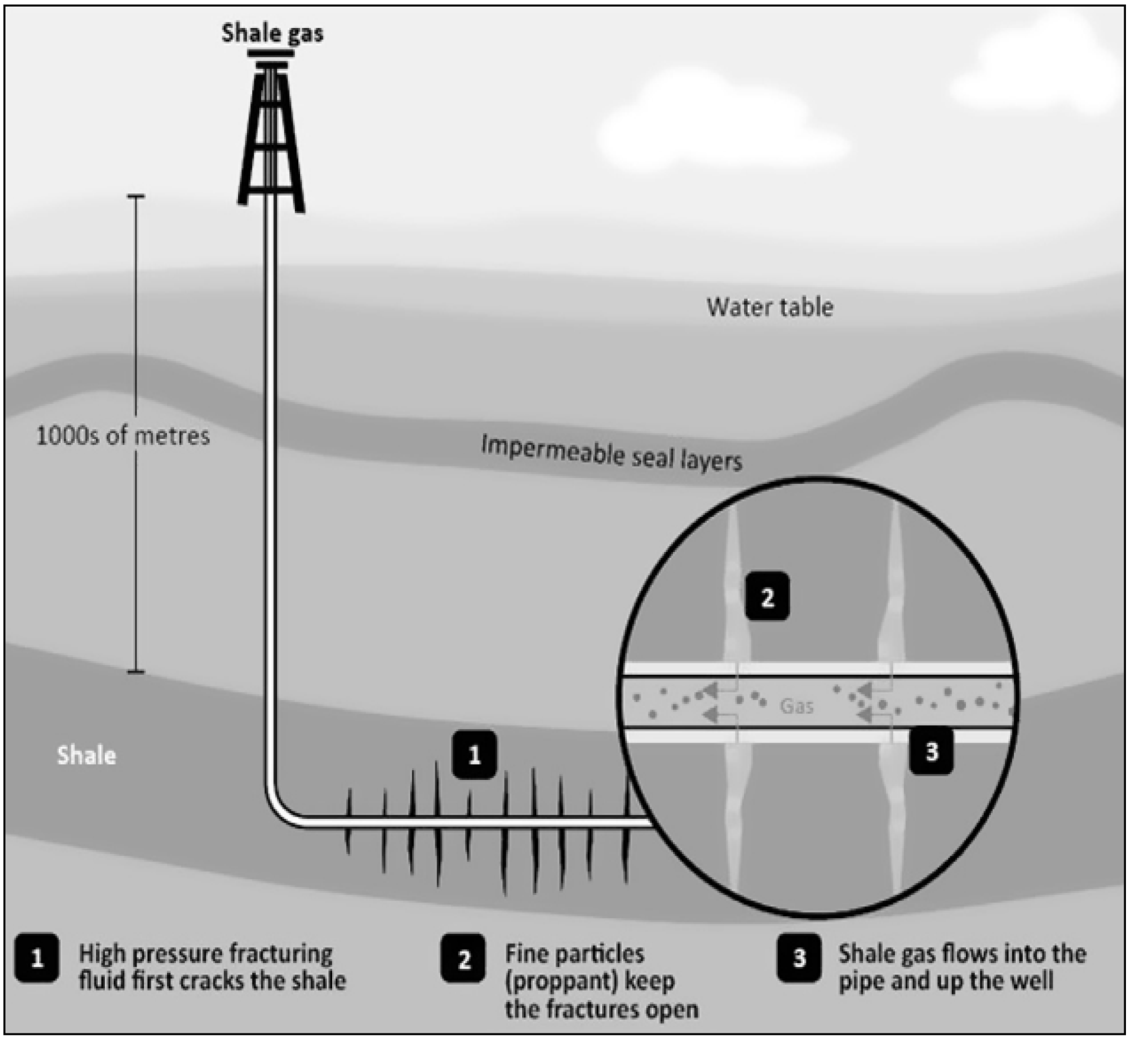

Image 1-2: Bahadori, *"Shale gas production techniques"* (2014)

The United States, the precursor of shale gas exploitation, have established a new business model with it.[35] The natural gas business with shales is extremely growing and, like tight gas, needs hydraulic fracturing for the extraction of the reservoirs, that are also the sources in this case.[36]

"Shale is a fine- grained sedimentary mudrock, comprising mostly flakes

35 Horsfield et.al. (2011)
36 Olavarria et.al. (2013), 7

of various clay minerals, and including tiny fragments of quartz, calcite, other minerals and organic material,"[37] and due to its laminate structure it has typically low permeability and low porosity so that the gas cannot escape of its formation.[38]

There are three ways to store shale gas:"

1. Absorbed onto insoluble organic matter, kerogen, that forms a molecular or atomic film.

2. Absorbed in the pore spaces.

3. Confined in the fractures in the rock."[39]

Shales commonly hold a huge quantity of natural gas. Due to the fact that the release of shale gas is more complex than of other unconventional natural gas types, it is the last natural gas form to be extracted. However, most shales will not produce natural gas and if it does, it is spread out over a large area.[40] That is why the key task is, to find a shale gas area (also known as resource plays or shale gas plays) which holds enough gas to make drilling for it economically reasonable. By horizontal multi- stage fracking a greater surface area can be exposed providing operators with larger amounts of the reservoir, than with the vertical drilling that was performed in the beginning of hydraulic fracturing.[41] "They also achieve maximization by "gas farming", meaning multiple horizontal wells are drilled perpendicular to the direction of maximum horizontal stress and stimulated with multiple hydraulic fracture stages to access the largest volume of reservoir and to intersect the maximum number of (typically) subvertical fractures."[42]

Natural fractures normally do not provide sufficient permeable pathways to produce adequate amounts to be economically profitable. With microseismic monitoring, fracture points can be identified during fracking for a profit oriented

37 Olavarria et.al. (2013), 8
38 Bahadori (2014), 7
39 Bahadori (2014), 7
40 Bahadori (2014), 7
41 Binnion (2011)
42 Bahadori (2014), 8

drilling.[43] But even then the focus is on improving the average extraction results, since shale gas wells cannot ensure consistent results, and its production rate declines exponentially over time.[44] After around 3-4 years the production rate usually stagnates at a relatively low level.[45] "Ultimate recoveries are much lower than for conventional gas fields, but completion and production technology advances are increasing recovery factors."[46]

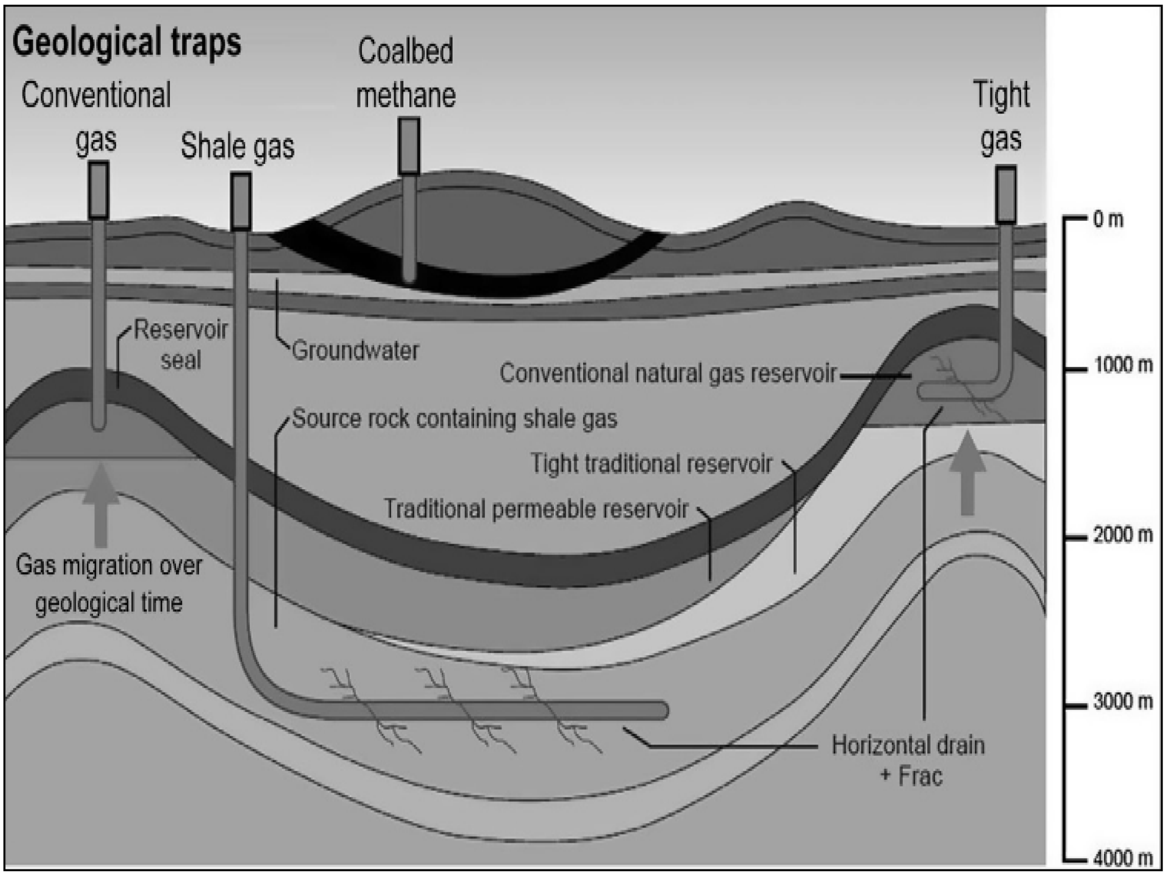

Image 1-3: Gov Australia, Department of Mines and Petroleum, *"Schematic gas accumulations"* (2013)

43 Bahadori (2014), 8
44 Binnion (2011)
45 Bahadori (2014), 8
46 Bahadori (2014), 9

1.3 Hydraulic fracturing

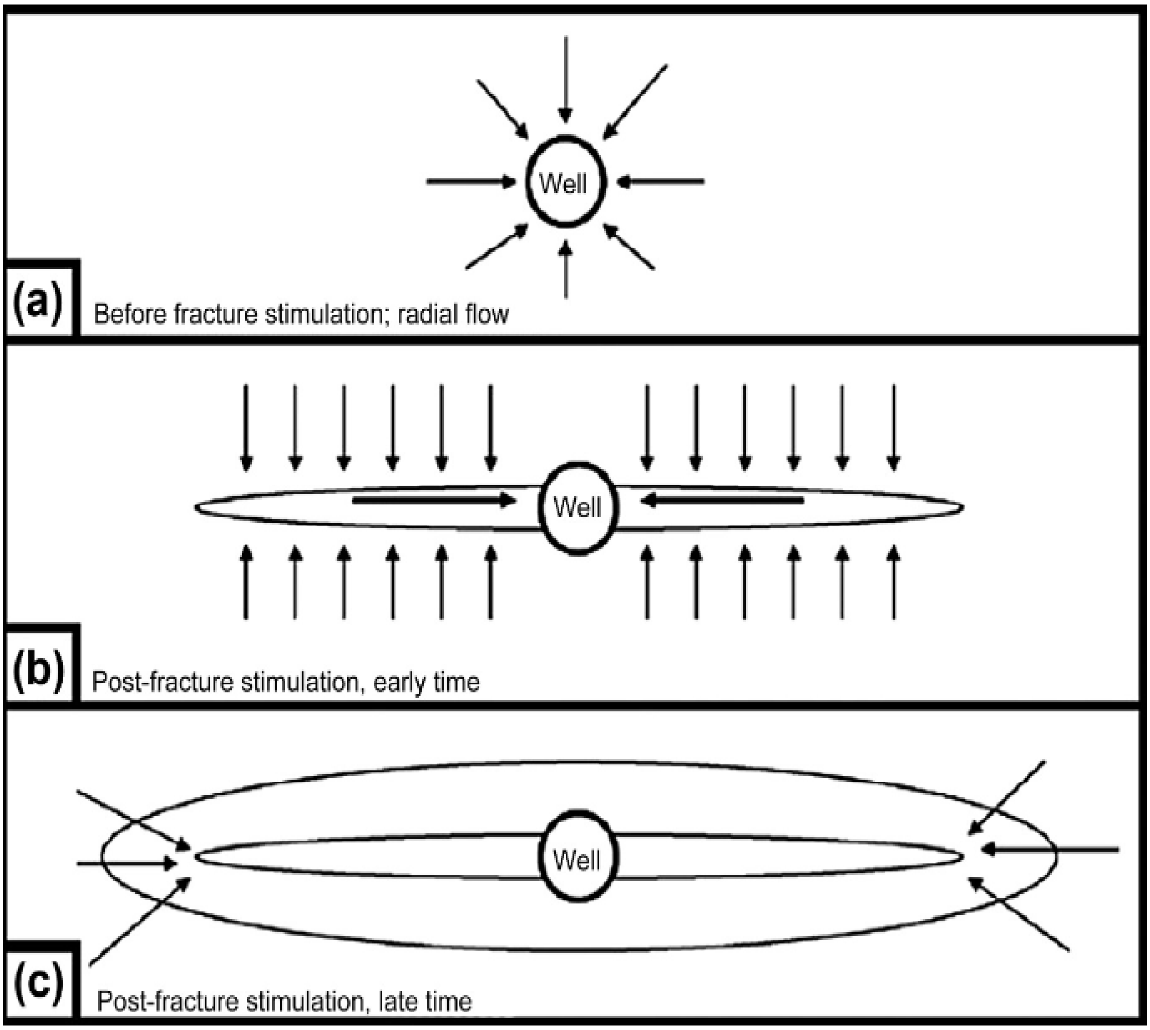

Image 1-4: Wang, J. et.al., *"Gas flow mechanism before and after fracking"* (2012)

Hydraulic fracturing, or just fracking, is a technique which is used to stimulate the productivity of a well, like pictured above (Image 1-4). And the technique isn't new. Since 1947, this conveyor technology has already been adopted to extract gas and oil resources. In its early stage, fracking was economically unattractive. Due to continuous innovative technology developments, increased energy demand and thus related price increases for energy, this has significantly changed. Today it is the prospective to gain independence from energy imports, and to achieve economic recovery.[47]

Hydraulic fracturing is a method of generating cracks in the reservoir rocks in the depth, with the aim that the stored gases or liquids flow easier and more constant to the hole and can be extracted. After well drilling, that can be up to several thousand meters deep, a viscous fluid (or pad), which usually consists of water (added with chemicals and sand), is pumped under high pressure through the hole into the deeper underground.[48] The liquid ("fracfluid"), which is inserted with the pressure of typically several hundred bars, has the function to produce cracks in the reservoir rock and thereby increase the wellbore radius. Afterwards, a propping agent is mixed into the fluid, to permanently stabilize the newly formed fractures and prevent them from closing again.

For a typical, single-stage sequenced hydraulic fracturing operation almost 2 million liters of water are used and around 200,000 kilogram of resin coated proppant for completing the process. To increase the yield, multiple additional horizontal drillings are made deep down. During these so- called slant drillings the drill head is redirected horizontally.[49] “Hydraulic fracture stimulation is only performed at the interval of gas- bearing rock. The casing in this specific zone is perforated, allowing fluids and proppants to interact with this formation of rock. Enterprises, who apply to conduct fracture stimulation, must demonstrate a comprehensive understanding of the geology and the stresses present in the subsurface rock. A range of physical tests of sample core as well as computer modeling of propagations are conducted to understand the characteristics of the rock before it is fractured. Seismic monitoring of the fracture propagation during the stimulation process can determine the extent of the fractures. Fractures are undertaken in stages to control their length and ensure there is no interaction with aquifers.”[50]

47 Habrich-Böcker et.al. (2014), 1
48 Brantley et.al. (2013)
49 Olavarria et.al. (2013), 9
50 Bahadori (2014), 15 f

1.3.1 Chemicals used in hydraulic fracturing

Fracturing fluids are normally divided into water- based, oil- based, alcohol- based, emulsions, or foam- based fluids. They must meet a number of requirements simultaneously, and need to sustain under conditions such as high temperature, pumping rates and shear rates. In order to decide which fluid entails the best results, the used technique in relation with the environment and the reservoir- type need to be taken into consideration. Typically the most commercially used fracturing fluids are gelled or foamed to keep the proppants within the fluid during the fracturing operation. The fluid is fastly pumped into the well to prevent irruption into the formation. The pressure causes to break the rock and creates artificial fractures or enlarges existing ones. Fracfluids commonly consists of 99.5% water, mixed with sand and different chemicals.[51]

Those chemicals are added for many reasons:"

- To carry the proppant
- To reduce the friction between the fluid and the pipe or casing of the well
- To stop the growth of bacteria in the well and underground intervals
- To clean the well and increase permeability
- To prevent scaling, and
- To remove oxygen and prevent corrosion of the casing."[52]

Which chemicals are permitted varies from country to country, but always need to be fully disclosed and publicly available.

Most of the fracturing fluids flow back into the wellhead (so- called "flowback water"), after the pressure is reduced. The fluids that have flowed out are collected, treated and reused for subsequent fracking or disposed of, in accordance with approved environmental management plans. However, a small part of the injected composition cannot be removed, and stays at the fractured formation in pores or trapped behind locked fractures.[53]

51 Fink (2013), 2
52 Bahadori (2014), 16
53 Fink (2013), 3 ff

1.3.2 Regulation of hydraulic fracturing

Many countries have already been doing fracking for years. But still, the threats and risks of this technology cannot widely be predicted and controlled, so that strict regulation is necessary. Permits have to be obtained for every single fracking process. Also each country individually provides a set of rules and tests which have to be fulfilled. After drilling has been started, each step needs to be documented to make sure that there is no harm for the environment and community.

According to the source 54, the local environmental departments are demanding confirmation of five main criteria, before hydraulic fracturing is approved:

- **Water management:** interaction with the subsurface water has to be kept to a minimum, which requires monitoring during the complete process. Water levels, total dissolved sediment, and general water quality must be checked before, during and after the operation, and must be made available for the public. In addition, the entire disposal process, the dump position and its method, must be made accessible to the local government and the general public.

- **Use of chemicals in hydraulic fracturing:** before starting, a list of the intended chemicals needs to be submitted to the government and community for consent.

- **Well integrity:** the government requests daily drilling reports from the operators to ensure that the “best industry standards” are used for the drilling and the harvesting of the natural gas, so that the environment and people will not suffer any harm due to it.

- **Reporting:** daily geological reports must provide information of: testing, data obtained, research and results of the fracking, as well as the length and orientation of each fracture.

- **Hydraulic fracturing Water cycle:** the following questions (provided by the U.S. Environmental Protection Agency) have to be answered before a drilling operation can start:[54]

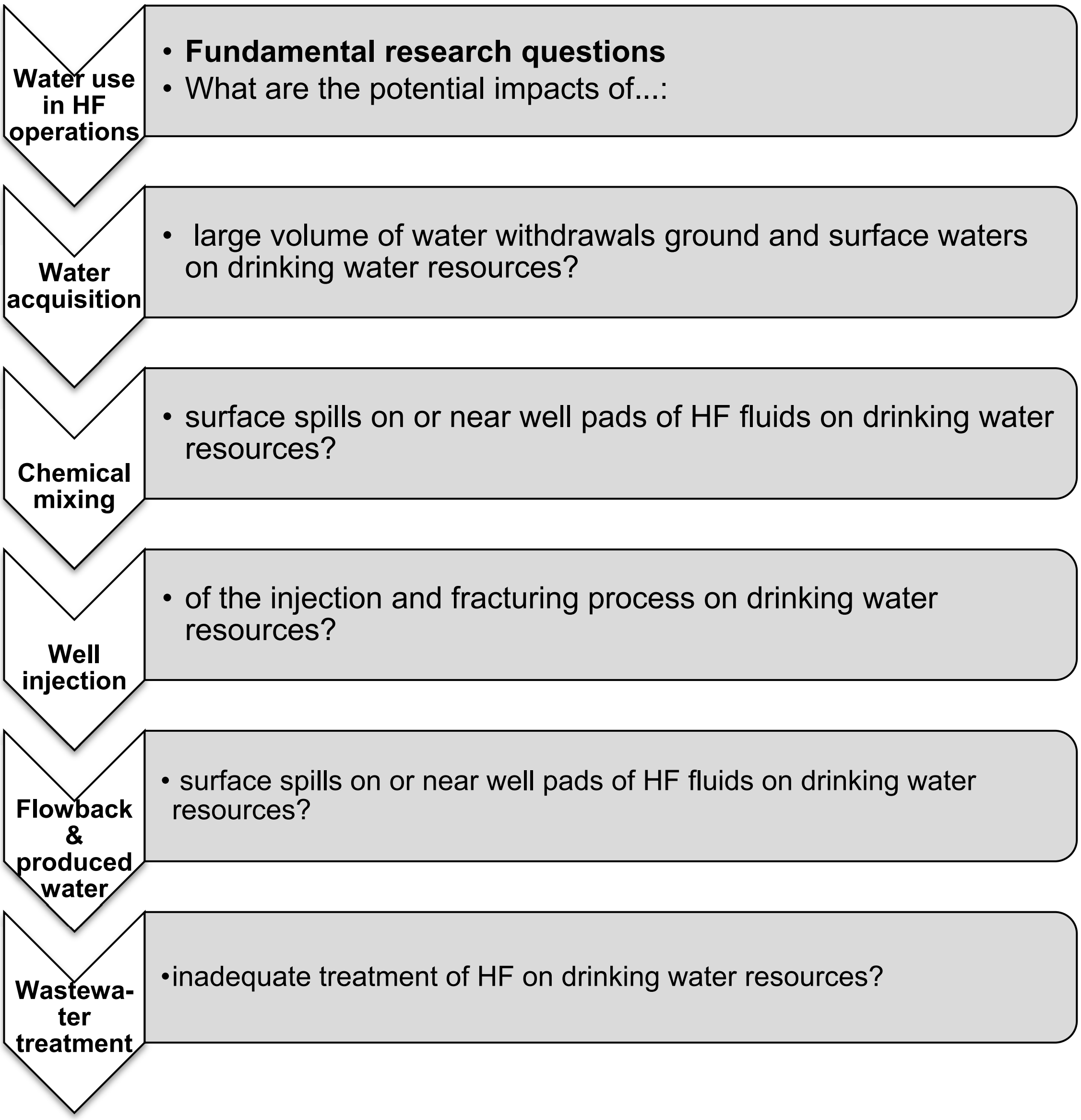

Image 1-5: EPA, *"Fundamental research question for water use in hydraulic fracturing (HF) operations"* (2014)

54 Bahadori (2014), 16

1.3.3 Hydraulic fracturing in Europe

Europe also has large shale gas reservoirs, which can be extracted. However, not all countries are as euphoric as, for example, the United States.

The figure below shows the amount of shale gas for the "top ten holders" in Europe in 2009.

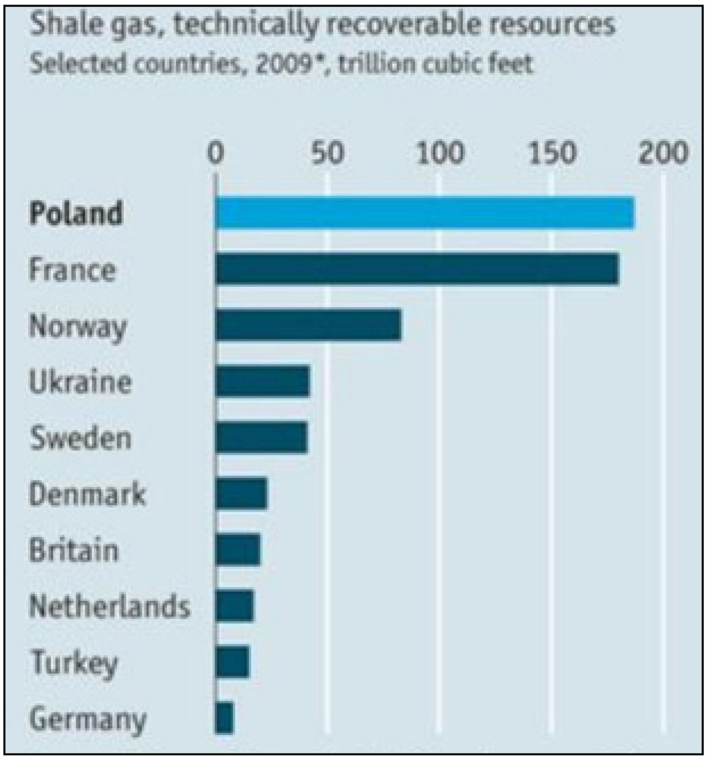

Image 1-6: US Energy Information Administration, *"Shale gas, technically recoverable resources"* (2009) *Estimate

Despite all regulation and information systems, the impact on the environment and the effects on health are neither clear nor predictable. That is why, especially in Europe, many countries have an ongoing discussion about adopting or restricting the process.

In Europe, Poland is one of the early adopters, due to great government enthusiasm and low public opposition. In contrary, France, Norway and Bulgaria have legally banned the technology at all. France argued in its decision with the lack of information and transparency, combined with the missing benefits for the local communities. Germany, the Netherland's and the United Kingdom (they stopped drilling after increased seismic activities in some regions) are still cautious and contemplating hydraulic fracturing.[55]

Austria, however, developed something called "clean fracking" or "eco fracking". The petroleum- expert Herbert Hofstätter reported in an interview for the radio station ORF Styria in March 2014, that with the new procedure shale gas can be extracted entirely without damage to the environment. He researches and works at the "Montana- University" of Leoben (Austria), and is co-founder of this new method. The hydraulic fracturing is based on purely natural materials, which means, that only natural products are used instead of chemicals. Mostly potassium carbonate will be used, which is a naturally originated salt, some starchy products, water, and specially rounded grains and sand. All of these products are 100% recyclable. The intention is, to complete and finish the field experiments in this very same year, meaning, the new method could be used already next year (2015), if nothing goes wrong. [56]

55 Boersma et.al. (2012)
56 Read at steiermark.ORF.at/news/stories/2636986/ (18.03.2014)

The following map summarizes the individual decision of each country about hydraulic fracturing in Europe:

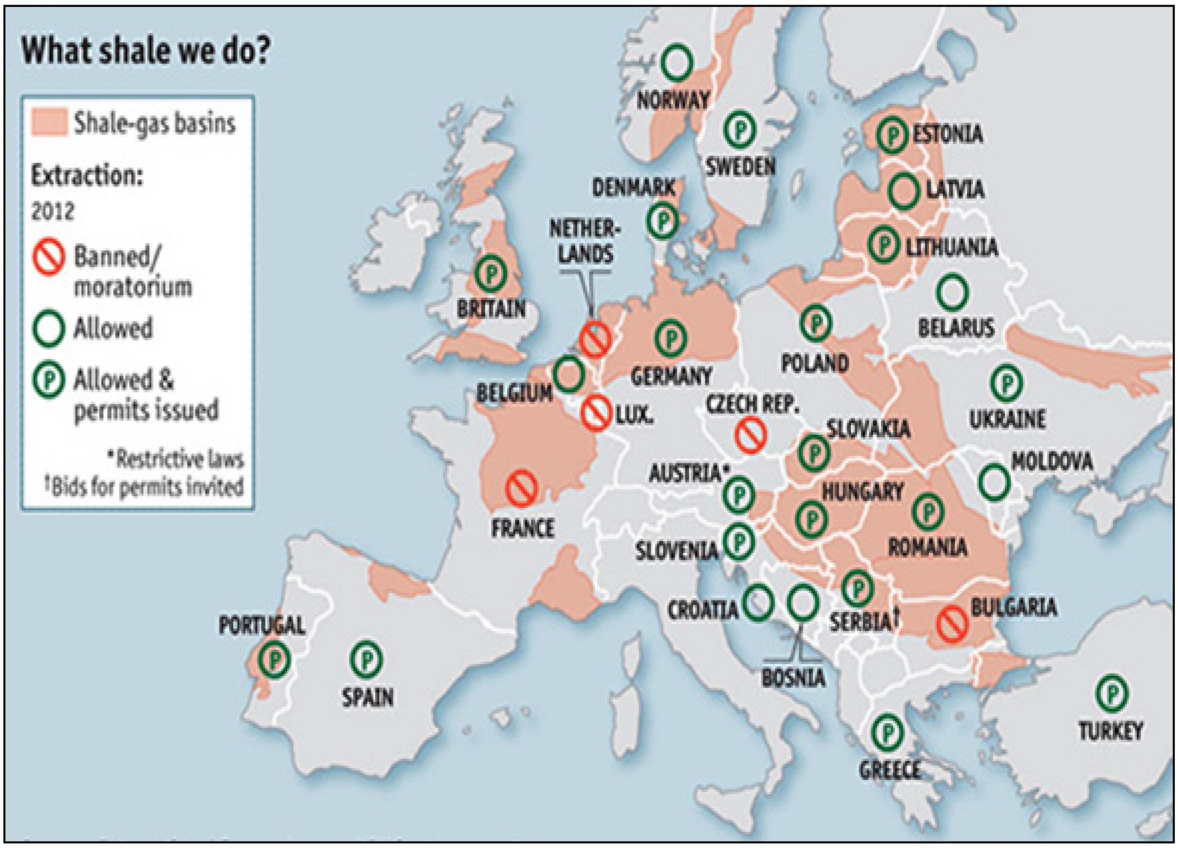

Image 1-7: IEA, KPMG, Press reports, *"What shale we do?"* (2012)

1.3.4 Transatlantic Trade and Investment Partnership (TTIP)

The Transatlantic Trade and Investment Partnership (TTIP) between the United States and Europe is a currently discussed topic in the media. This could allow energy companies to perform the controversial technology fracking in Europe. Enterprises could enforce the performance via court, even if the actual laws of the countries have restricted or even banned it. Fracking would thus come to Europe through the back door.[57] An investment protection enables companies to sue states in non- public arbitration. International corporations can sue countries for compensation in investor- state arbitration processes if they have financial losses due to, for example, passed laws for stricter environmental regulations.

Through the new technology fracking, the United States have been able to mine large amounts of gas and oil and are willing to export those, which was previously only allowed between countries with TTIP. That means, the TTIP would simplify imports and exports among the USA and Europe, and thus reduce the dependency on imports from Russia.

The arguments **pro TTIP** are, that the energy supply in Europe would be ensured and the dependency on Russia would be reduced. The exploitation through fracking would be increased to serve the growing demand and this would lead, in turn, to lower energy prices for the consumers. And, regular courts often judge biased and rather go along, the sometimes exaggerated fears, of the population about fracking instead of judging impartial.

The arguments **contra TTIP** are, that major corporations are treated more generously than regular courts would judge. The critical position of Governments in Europe against fracking could be undermined. The laws that several countries have already passed against fracking could be revoked by the TTIP. Companies, which invested in the extraction of shale gas and oil, could sue for compensation. This pressure on the countries would prevent relevant prohibitions and laws.[58]

57 Endres (2014)
58 Schulte von Drach (2014)

II. Environmental impact

This part of the master thesis is about the first research question: whether or not shale gas has a negative impact on the environment and leads to major environmental problems.

On one hand it will be discussed if shale gas is good for the climate system. And on the other hand the immediate risks and consequences to the environment due to the hydraulic fracturing process are represented in the sectors: water, land and air.

2 Climate System

An unpredictable series of energy- related disasters during the years 2010 and 2011, made shale gas an attractive alternative compared to other energy forms in the United States. Examples include the 29 coal workers dying in a mine accident in West Virginia in April 2010, the oil catastrophe at the Gulf of Mexico, or the nuclear accident in Fukushima. All these news have helped to convince the nation of the benefits of the hydraulic fracturing process. However, there are still many opponents, who place the danger to humans and the environment above the economic gainings. Especially the 2010 released movie "Gasland", produced by Josh Fox and its burning tab water is still frequently referred to, when it comes to the dangers of fracking.[59]

When the debate comes up, whether shale gas is helpful to reduce the greenhouse gas emissions or will in fact increase them, the supporter of hydraulic fracturing always come up with the argument that natural gas produces less greenhouse gas emissions than coal. However, the opposition always argues that shale gas is a powerful driver for greenhouse gas emissions, due to its methane leaks, which occur largely immediately after the fracking process.

59 Jenner et.al. (2012)

Displacing an ordinary U.S. coal plant with natural gas for generating electricity, would reduce the carbon dioxide emissions by a factor of three. A study of the Cornell University found out that during the shale gas production twice as much methane leaks out than it does during drilling for conventional gas. So, with the leakage during its further processing, transportation and distribution, shale gas basically has higher greenhouse gas emission rates than coal, "(…) due to the high warming potential of methane relative to carbon dioxide."[60]

These two statements are both true, nevertheless, they don't help to clearly testify about the pro and contra of shale gas. It is a complex topic and statements and appraisement about it depends on many different factors, as what it is compared to or the considered timescale. In the electricity sector shale gas is typically compared with coal since both are used commonly for its generation. For the timescale the question turns up: what makes sense? If climate change is only considered for the next few decades, many long- time issues could be neglected.

The two following short examples explain the dilemma: since the timescale of climate change is relatively long (around hundred years), the effect of short- term reductions, which are gained by displacing coal with natural gas, are basically minor. Whereas, when the timescales of the carbon cycle and the climate system are considered, those methane leakages aren't so dramatic, due to the short atmospheric lifetime of methane.

What remains, is the question of the effect or value of the different greenhouse gases other than the carbon dioxide. Therefore, a physical metric, called the Global Warming Potential (GWP), have been adopted to compare them. "The GWP of a greenhouse gas is defined as the time integrated global mean radiative forcing of a pulse emission of 1 kg of the gas relative to 1 kg of carbon dioxide over a specified time period, commonly one hundred years."[61] By adopting this metric into the study of the Cornell University, the scientists Robert Howarth, Renee Santoro and Anthony Ingraffea came to the conclusion, that "(...) they value a ton of methane at 105 times the values of a ton carbon

60 Schrag (2012)
61 Schrag (2012)

dioxide,"[62] (for a twenty- year timescale).

The weak point of the GWP is that it gives not really an indication to the gas, which really generates the warming. Or more precisely, only the time integral of the radiative forcing is considered at the examination. Similar defined, however, it uses the global average temperature instead of the radiative forcing: the Global Temperature Potential (GTP). It is a more efficient metric for comparing different greenhouse gases, even if the weak point is that the metric is model- dependent. Comparing those two metrics, and whatever climate model is chosen for the GTP, the values are systematically lower for short- lived gases like methane, than they would be using the GWP metric (regardless of the considered timescales). “Thus, even if shale gas production results in large methane emissions, burning natural gas is still much better for the climate system than burning coal.”[63]

The question about the timescale was analyzed in detail by the climate scientists Myles Allen et.al.. They came to the result "(...) that the peak warming in response to greenhouse gas emissions depends on cumulative greenhouse gas emissions over a period of roughly one hundred years." Several further studies proved their solution and found out as well, that the climate policy should, instead of setting emission- rate targets, turn its attention to limiting the cumulative emissions, since this is more important for the climate response to greenhouse gas emissions. The global warming could only be postponed by a couple of years, due to reduction of methane emissions and their short timescales. Compared to it, the benefits of reducing the cumulative emissions of greenhouse gases are much higher. Those are dominated by carbon dioxide which have, like mentioned earlier, long timescales and thereby make the climate policy to a century and millennia topic. However, this is an enormous problem, since politics is generally just made for the next few years. Formulating a climate change policy for the next decades is already difficult, but for the next century and further, is (almost) impossible.[64]

To sum up, testifying about shale gas and its influence on the climate change is difficult. If the shale gas boom restricts or even discontinues the

62 Schrag (2012)
63 Schrag (2012)
64 Allen et.al. (2009)

investments in renewable energies and its push into it, there is no doubt about how bad this would be for the environment and global warming. Otherwise, the comparison depends on whether it is compared with conventional gas, where it does badly, or whether with coal. Then there is usually no distinction between shale gas and natural gas, and therefore it does well. On the other hand, it depends on the timescales which will be considered. When global warming is only considered over short term, to reduce the methane emissions would be appropriate. However, long term, it is a mere drop in the ocean.

3 Water

A study on the total water consumption (extraction, processing, transport, combustion) of coal, conventional gas and shale gas in the United States, has revealed that shale gas extraction requires 50-100 times more water than conventional gas extraction. This is due to the fact that hydraulic fracturing uses more water in an additional step, the unlocking of the gas from the resource rock. However, shale gas needs less water than coal does (even if the estimations vary greatly from well to well).

Shale gas production faces three major public safety concerns related to water and groundwater:

1. The fracturing fluid could contaminate groundwater aquifers, as a result of the deeper drilling than for conventional gas.
2. Methane could seep into the water supply system. This could happen if the borehole does not completely isolate gas from soil.
3. The flow- back carries naturally occurring radioactive material up to the surface. The radiation is very low; nevertheless, it can be a threat for the workers due to the huge amounts they collect at each wellhead. It also can cause cancer if it enters the food chain through fish or water.[65]

The operators use, if possible, non- potable water and recycle as much of the flow- back as possible and reuse it in further explorations, while the engineers work steadily to improve the recycling systems and attempt to reduce the amount of water and energy each fracking operation requires.

In 2013 a team of chemical engineers of the University of Texas (USA) developed a membrane- based filtration system and managed, to produce up to 50% more water for reuse which reduces the demand for fresh water

65 Jenner et.al. (2012)

significantly.[66]

Another important topic is the management of the wastewater, which cannot be recycled. Two types of wastewater by- products are distinguished: the flow- back (fracturing fluid that returns to the surface when drilling pressure is released) and produced water (wastewater, emerged after production begin). Both contain harmful pollutants and therefore must be managed carefully to avoid harms to human health and the environment.[67] According to the source 68, the most common wastewater management options are currently:

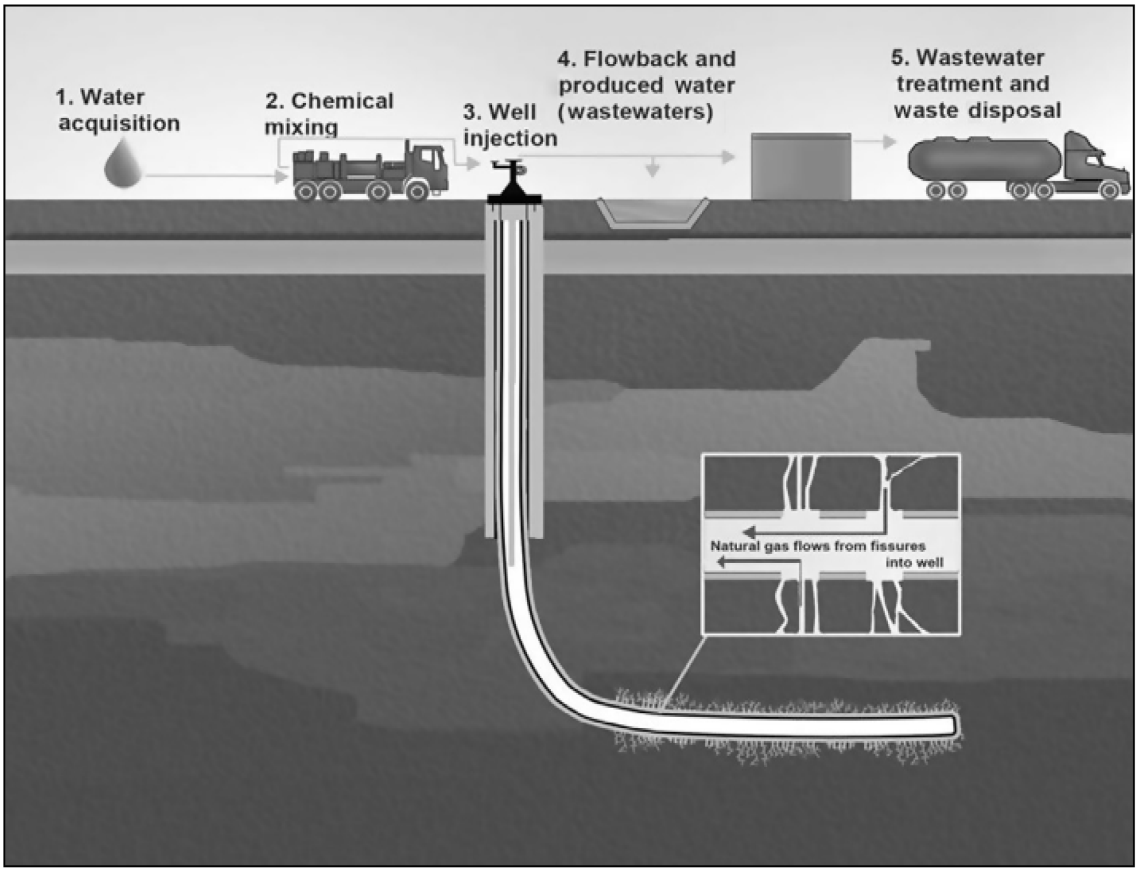

Image 3-1: EPA, Bahadori, *"hydraulic fracturing water cycle"* (2014)

66 Miller et.al. (2013)
67 Bahadori (2014), 19

Treatment and discharge to surface water

METHOD: All alternatives include treatment, since the wastewater has to be cleaned up after usage. Organic contaminants and inorganic constituents must be removed, however, the focus here is on the targeted removal of some further constituents.

RISK: Inadequate treatment (if quantities or concentrations of contaminants are too high) followed by discharge of the water may pollute surface water downstream of the discharge.

Underground injection

METHOD: Former wellheads are used as disposal wells to isolate material. It includes less treatment than the other methods and creates the least risk of wastewater contaminants being released into the environment.

RISK: It creates the risk of earthquakes, since for the fracking process small eruptions are necessary. Further, it also requires often transportation over long distances what increases the risk of accidents with the dangerous material.

Storage in impoundments and tanks

METHOD: The wastewater is stored in open tanks also called pits or in closed tanks. Tanks mostly feature a second containment, as safety factor in case of a tank rupture.

RISK: Accidental spills or mismanagement can trigger release to the environment, which could lead to contamination of nearby waters and soils.

Land application (land spreading)

METHOD: Treated wastewater or residuals, like solids and sludges, are managed through land application or landfills. Depending on their characteristics this leads to lower transportation costs for just residuals.

RISK: Rainfall and snowmelt could wash salt and chemicals away which may lead to stream or groundwater contamination.[68]

68 Hammer et.al. (2012)

4 Land

Beside the fear of water contamination or pollution through chemicals, the impact drilling has on the actual land itself must be taken into consideration. Drilling affects landforms, watersheds, habitats, soil, vegetation and biodiversity. And even if the affected land can mostly be restored, the reforestations can take up to 300 years. Already the gas exploration has caused a disruption of natural habitats, ecosystems and of indigenous species. Since the area needed for the extraction of horizontal gas is much smaller than for conventional gas, it would be preferred, however, only if just the factor land would be considered. Yet, both types result in land transformations. However, there is an unequal distribution of land useage during the lifecycle of unconventional gas (from extraction to combustion). As expected, the direct use of the land during the drilling process causes more harm to the landscape than the indirect land use, related to secondary steps in the fuel lifecycle (such as transportation infrastructure). This changes if the fuels and resources are transmitted. The development of infrastructure that will be used for transmission of both, products (pipelines for gas), and by- products (e.g. pipelines transporting water for the process), leads to the biggest effects on land usage during the gas lifecycle.

However, in the United States, the shale gas lifecycle uses less land in the exploration site than the conventional gas and coal lifecycles. The reason is that multiple horizontal wells can be drilled from a single well pad, so that fewer infrastructures are needed, which reduces surface disturbances. “Furthermore, shale gas explorations have often returned to former oil and gas rich areas, such as the “oil patch” states. Thus, the net effect of shale gas operations can be kept lower if existing land uses are subtracted.”[69]

A lifecycle analysis of coal, conventional gas and shale gas found out, that shale gas production uses the least land, followed by conventional gas and then coal as worst of the three non- renewable resources.[70]

69 Jenner et.al. (2012)
70 Jenner et.al. (2012)

5 Air

In the introduction (II.) of this second big part, the effects of the greenhouse gas emissions of coal and natural gas have already been discussed. Therefore, in this part the entire life cycle will be contemplated.

“”More gas” and “less coal” could give electric power and other delivered energy sectors a greener edge. But can gas actually be extracted, distributed and combusted at a smaller greenhouse gases footprint than coal even if the entire lifecycle is taken into account?”[71]

A study of Jenner S. and Alberto L. (2012), compares the direct (during combustion) and indirect or fugitive emissions (due to leaks earlier in the value chain) of coal, conventional gas and shale gas. On the basis of a summary of different previous studies, the emission factors for coal and natural gas and their global warming potentials enabled them to determine a conclusion about the greenhouse gas footprint. Taking into account that each greenhouse gas in the troposphere needs different time to dissolve, like already mentioned earlier, and “as consequence to the higher sensitivity of the footprint towards methane, the shale gas lifecycle has a bigger greenhouse gas footprint than the conventional gas lifecycle but a smaller one than the coal lifecycle.”[72] This is on one hand a result of the methane leakage rate of shale gas and on the other hand due to the fact that not 100% of the drilled shale gas is actually delivered to the end user. Since around 11% are used for powering well engines and other purposes and the fugitive emissions are estimated to be 1.1% for the extraction and 1.7% for the entire lifecycle.[73]

71 Jenner et.al. (2012)
72 Jenner et.al. (2012)
73 Jenner et.al. (2012)

III. Economic impact

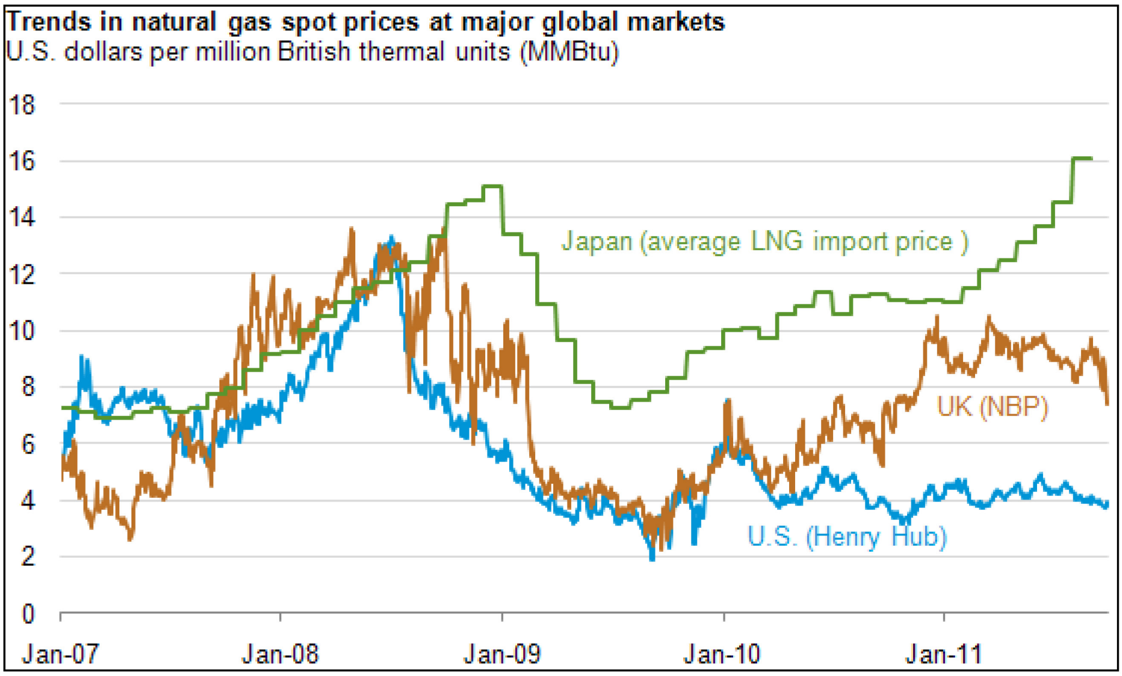

Image 5-1: EIA, "*Trends in natural gas for U.S., Europe and Japan*" (2011)

The shale gas development in the United States leads to a revolution of the American and global gas markets. Traditionally the gas contracts in Europe and Asia are linked to oil, which ensures stable, long- term contracts. The use of shale gas could stabilize the natural gas demand and the energy supply security and thereby decouple the gas contracts.

The spread between the gas prices in the U.S. and Asia is higher than ever. Europe also is more vulnerable due to the higher prices. This causes competitive disadvantages for Asia and Europe and shale gas will become a "game changer".[74]

In the following chapters, the gas and oil markets of the United States will be analyzed. It will be tested, whether the two markets decoupled due to the

74 Umbach (2013)

shale gas development, or whether they remain in an equilibrium relationship, which is largely assumed, since they are substitutes in many sectors.

The following part is about the methods which are relevant for testing the natural gas and crude oil price series for cointegration. Here, the theoretical approaches and methods are explained, which helps in understanding the later implemented tests and their interpretations. The theoretical part below is structured as:

- Unit root tests: where explicitly stationarity is defined to catch a meaning of the ADF and the KPSS test.
- VAR model: to estimate the lag length and test the residuals for autocorrelation
- Cointegration: the cointegration test is based on the Johansen test and the VECM. The exogeneity test and the LOP, which confirm the results of the cointegration test.

6 Unit root tests

In this chapter the price series are tested for a unit root. Three tests are considered: the Augmented- Dickey- Fuller test, the Kwiatkowski- Phillips- Schmidt- Shin test and the Phillips- Ouliaris test. They test for unit roots in the model and whether or not the system is stationary or non- stationary. The following explains and describes the theory while the tests are implemented in chapter 9.

6.1 Stationarity

Strict stationarity exists, if the common distribution of the random variables is invariant over time. A random variable Y_{t+1} has then the same distribution as Y_{t+1+c}, where a constant c was added. However, usually only the weak stationarity is considered, which is less restrictive.[75] The non- stationarity of time series is formally tested on the analysis of the non- stationarity of the mean value, the variance and the autocovariance. A time series is called stationary (or actually covariance- stationary) if the following three conditions are met:

(1) $\mathrm{E}(\mathrm{Y_t}) = \mu_t = \mu = \mathrm{constant}$ for all t

(2) $Var(Y_t) = \sigma_t^2 = \sigma^2 = constant$ for all t

(3) $Cov(Y_t, Y_{t+j}) = \sigma_{tj} = \sigma_j = constant$ for all t, j

The variance and the mean value must be constant in any case. However, for the covariance just the difference between the lags is needed to be constant. That means, it doesn't depend on the absolute point in time series,

75 Drobetz (2003)

the covariance between t and $t+1$ (first order lag) should be the same.[76] The autocovariance only depends on the lag length j and does not depend on the time t.

The meaning of this definition can be explained simplier by a time series which is divided into two equal intervals. Here, each individual interval should have the same mean value, the same variance and the same autocovariance. However, if there is a trend in the time series these properties of weak stationarity are destroyed and their mean values are no longer identical ($\mu_1 \neq \mu_2$). This leads on one hand to a **contempt of the mean value stationarity** (the first restriction of the weak stationarity) and on the other hand it follows a **contempt of the variance stationarity** (the second restriction of the weak stationarity) due to this. The variance measures the mean square deviation of the data points from their mean. In trend- based time series each value moves more and more away from its mean over time and leads to an increasing variance.[77]

6.2 Augmented- Dickey- Fuller test

The simple Dickey- Fuller test (DF test), introduced by Dickey and Fuller (1979) is a common way to test the null hypothesis of non- stationarity. However, it needs residuals which are not autocorrelated.[78] If the dynamic structure of the time series is including more than one lagged value, the DF equations will no longer apply, since the residuals are autocorrelated in this case. The DF test can be extended to the Augmented- Dickey- Fuller test (ADF test), in which lagged differences are absorbed by Y_t in the equations.[79]

Three different forms can be distinguished:

$$\Delta Y_t = \vartheta \, Y_{t-1} + \textstyle\sum_{i=1}^{s} \varphi_i \, \Delta Y_{t-1} + \varepsilon_t \qquad (6.1)$$

76 Winker (2010), 272 f
77 Drobetz (2003)
78 Auer et.al. (2011), 590
79 Winker (2010), 277

$$\Delta Y_t = \delta + \vartheta Y_{t-1} + \sum_{i=1}^{s} \varphi_i \Delta Y_{t-1} + \varepsilon_t \quad (6.2)$$

$$\Delta Y_t = \delta + \gamma t + \vartheta Y_{t-1} + \sum_{i=1}^{s} \varphi_i \Delta Y_{t-1} + \varepsilon_t \quad (6.3)$$

the lag length s can be determined with the Akaike- Information- Criterion (AIC) or the Schwarz- Information- Criterion (SIC).[80]

The question is now, how many of such lag terms should be added. Since the aim is the elimination of autocorrelation in the residuals, the lag length should be determined in a way, that the residuals have the property of white noise and, in particular are free of autocorrelation. Similar to the DF test, the critical t-values are taken into consideration for the decision.[81]

6.3 KPSS test

A reason why other tests, like the KPSS test, are meaningful and useful is that the DF test and the ADF test are not always suitable for strong autocorrelation due to their small explanatory power of (trend) stationary time series. In this case, the null hypothesis of non- stationarity can often not be rejected, even if it actually cannot be accepted.

The KPSS test proposed by Kwiatkowski, Phillips, Schmidt and Shin (1992) expresses the null hypothesis as stationary, contrary to the DF and ADF tests.[82]

6.4 Phillips- Ouliaris test

As the name suggests, Phillips and Ouliaris introduced this test in 1990. The PO test finds the presence of a unit root in the residuals of (cointegrating)

80 Auer et.al. (2011), 590 f
81 Drobetz (2003)
82 Winker (2010), 278 f

regressions. That is why the test could also be named Residual Based Unit Root test. It shows that residual- based unit root tests applied to the estimated cointegrating residuals do not have the usual Dickey- Fuller distributions under the null hypothesis of no- cointegration.[83]

83 Phillips et.al. (1988)

7 Vector autoregression model

In this chapter the VAR model will be introduced with some basic information. Afterwards the residuals are tested for autocorrelation.

7.1 VAR model

With the use of multivariate time series analysis it is possible to describe dynamic interdependences among price series and get a more realistic description of the reality and the behavior of time series. The multivariate or multiple time series is a vector, in which the values of each time point depend on past information and also on past information of the other variables. The variables of the system are treated symmetrically due to the fact that they influence each other equally and are therefore treated as endogenous variables.[84]

The vector autoregressive model (VAR) is the common form to handle these vector time series. One condition is, that there are no dependences between the variables, meaning that all variables are equally interdependent. This assumption applies to the price series, which will be implemented and tested in the following for cointegration.

Let y be a discrete stochastic process with T periods and a time series of $t = 1, \ldots, T$. Let y donate also the (multivariate) time series with $k = 1, \ldots, K$ as the number of variables observed. The combination is then y_{kt}, which donates the k^{th} variable of time $t = 1, \ldots, T$ and T is equal to the sample size.

The VAR model is a special form of a discrete stochastic process and can be written as:

$$y_t = v + A_1 y_{t-1} + \ldots + A_p y_{t-p} + u_t \tag{7.1}$$

84 Franses et.al. (2014), 240 f

$y_t = (y_{1t}, \dots, y_{Kt})'$ is a K- dimensional vector of the variable at time t

$v_t = (v_{1t}, \dots, v_{Kt})'$ is a K- dimensional vector of constants (intercept)

p is the lag order of past values that y depends on

A_i with $i = 1, \dots, p$ is a $K \times K$ matrix of the coefficients

$u_t = (u_{1t}, \dots, u_{Kt})$ is a sequence of random K- dimensional vectors with zero mean vector[85]

7.2 Autocorrelation in the residuals

This part is about the requirements of the residuals of the VAR model. It will be explained how to test whether these requirements are fulfilled or, how to obtain useful results of the estimations, if they are not fulfilled.

Autocorrelation exists when residuals for different observations are not independently distributed. That means, if for residuals $i \neq j$ the autocovariance $E(\varepsilon_i\ \varepsilon_j) \neq 0$. Autocorrelation of the order k describes situations, where the realization of the residual of period t depends on those of period $t - k$. The data that matches a year can be specified for monthly data with $k = 12$ and for quarterly data it would be $k = 4$. For the analysis of time series it is usually assumed that there are autocorrelated residuals, since economic variables are often auotcorrelated, forcing the residuals to be autocorrelated as well.

The examination of the existence of autocorrelation can be done in different ways. A helpful indication is a graphical representation. This is especially true for time series, as then the temporal progress of the residuals can be analyzed. If residuals with the same mathematical sign follow each other in a great number, so that an obvious structure becomes apparent, it can be assumed that an autocorrelation in the residuals exists. There are, however, also some statistical tests which can verify, whether the null hypothesis, which

85 Lütkepohl (2007), 245 f

is that the observed residuals are of a process without autocorrelation, can be accepted. The Durbin- Watson test is widely used. Unfortunately, it has many limitations. For starters, it can only be used to review autocorrelation of first order. Besides that, the test accepts no models with lagged values, which means that it is not suitable for dynamic models.

However, there are tests which allow autocorrelation with lagged values, such as the Q- statistics of Box and Pierce. Though, this test is just to check the autocorrelation of a lower order. For a higher order, the partial autocorrelation test can be used. The Breusch- Godfrey test, also known as LM statistic, is an additional alternative. However, it doesn't respond very sensitive to a dynamic model structure. The test statistic is provided by the F- statistic of the null hypothesis, the lagged residuals of a system cannot contribute to an explanation.

There are different techniques to obtain an estimation result despite the fact of autocorrelation. Primarily for autocorrelation of first order, the autocorrelated residuals can explicitly be integrated into the model. Then, numeric optimization procedures need to be used to solve the problem/equation. Unfortunately, this procedure provides no information about the actual cause of the autocorrelation. In many cases, however, economically relevant factors cause the autocorrelation, like for example, an incomplete number of variables or an unconsidered dynamic model.[86]

86 Winker (2010), 163 ff

8 Cointegration tests

Cointegration exists when two or more variables have a long- term equilibrium. When it comes to deviations in the short term, at least one variable will conform to the other(s) and restore the equilibrium.[87] This means, they cannot move apart from each other over a long time and that they have an equilibrium relationship. The time series can be considered individual as non-stationary, however the linear combinations are stationary. By applying the differences for non- stationarity, much information will get lost. That is why Engle and Granger (1987) proposed the cointegration concept.[88] It is especially useful for sample sizes which are coined of trend.[89]

Generally, cointegration can be defined for variables with different degrees of integration. If more than two variables are considered, several cointegration relationships are possible.

The simplest example of a cointegration relationship is between k non-stationary variables, which are first order integrated ($I(1)$) and difference-stationary. Given are t observations for $t = 1, \dots, T$ and k variables $Y_{1,t}, \dots, Y_{k,t}$. The variables are cointegrated if, and only if, there is a linear combination of the variables which is stationary. More precisely this means, if there are values for the parameter $\alpha_0, \alpha_1, \dots, \alpha_k$ that:

$$Z_t = \alpha_0 + \alpha_1 Y_{1,t} + \dots + \alpha_k Y_{k,t} \qquad (8.1)$$

is stationary.[90] If one variable is $I(1)$ and the other $I(0)$ they cannot be cointegrated, because a stationary variable can eventually not be expressed/explained by a non-stationary variable and vice versa.

The linear combination sort of compensates the stochastic trend of the series. A stationary linear combination also implies that two or more variables

87 Winker (2010), 269 f
88 Drobetz (2003)
89 Winker (2010), 269 f
90 Winker (2010), 282

follow a stochastic trend. Despite a stochastic trend, the series can be stationary.[91]

8.1 Multivariate cointegration process: The Johansen model

For the test of cointegration with the implementation of Engle and Granger (1987), it must be set in advance (a priori) which variable is independent and which dependent. This model can also only determine a single cointegration relationship. However, in a multivariate model (with or with more than two variables), several cointegration vectors can exist.

To solve this problem, Johansen (1991) has introduced the Maximum-Likelihood test. The test is based on the eigenvalues of a matrix, and seeks for the "most stationary" cointegration relationship.[92] Two different likelihood ratio tests can be distinguished: the Maximum Eigenvalue test and the Trace test. A simple form is a $VAR(1)$ model of order p. Then the initial equation of the Johansen model is:

$$y_t = \mu + A_1 \; y_{t-1} + \; ... + \; A_p \, Y_{p-t} \; + \; \varepsilon_t \qquad (8.2)$$

y_t is an $n \times 1$ vector of variables that are integrated of order one ($I(1)$) and the parameter ε_t is an $n \times 1$ vector of shocks/innovations. That $VAR(1)$ model can be written as:

$$\Delta Y_t = \mu + \Pi \, y_{t-1} + \sum_{i=1}^{p-1} \Gamma_{\;i} \, \Delta y_{t-1} + \varepsilon_t \qquad (8.3)$$

where

$$\Pi = \sum_{i=1}^{p} A_i - I$$ and

$$\Gamma_i = - \sum_{j=i+1}^{p} A_j$$

91 Auer et.al. (2011), 590 f
92 Drobetz (2003)

If the coefficient matrix Π has a reduced rank $r < n$, there are $n \times r$ matrices present of α and β, each with the rank r. What leads to $\Pi = \alpha \beta'$ and $\beta' y_t$ is stationary. The rank r is the number of cointegrated relationships while α are the adjustment parameters in a vector error correction model (VECM). Every single column of β represents a cointegration vector. For a given r the maximum likelihood estimator of β defines the combination of y_{t-1}. That results to the r largest canonical correlations of Δy_t with y_{t-1} (after correcting for lagged differences and deterministic variables if they exist).[93]

The rank of a matrix is determined through the number of eigenvalues which are different of zero. Therefore, the Johansen procedure is based on a test of identifying the eigenvalues dissimilar of zero of the matrix $(\Gamma - I)$. That matrix has to be ascertained by the maximum- likelihood estimation first.[94]

For testing the significance of these canonical correlations and the reduced rank due to this, the two approaches (Maximum Eigenvalue test and Trace test) can be used.

$$J_{trace} = -T \sum_{i=r+1}^{n} \ln (1 - \hat{\lambda}_i) \quad (8.4)$$

$$J_{max} = -T \ln(1 - \hat{\lambda}_{r+1}) \quad (8.5)$$

T is the sample size, n is the number of variables and $\hat{\lambda}_i$ is the i^{th} largest canonical correlation,[95] with $(0 \leq \lambda < 1)$ and in descending sequence $(\lambda_1 > \lambda_2 > \cdots > \lambda_n)$.[96]

The Trace test, tests the null hypothesis of r cointegration vectors against the alternative hypothesis of n cointegration vectors. Contrary to that, the Maximum Eigenvalue test, tests the null hypothesis of r cointegration vectors against the alternative hypothesis of $r + 1$ cointegration vectors.

The test- values are not distributed in the form chi square. The critical values for the tests are based on a pure unit root process and due to this, for a near unit root process these values no longer apply. That leads to the actual question, on how sensitive the Johansen tests are to deviations between those

93 Hjalmarsson et.al. (2007)
94 Drobetz (2003)
95 Hjalmarsson et.al. (2007)
96 Drobetz (2003)

two processes.

The Johansen model generally consists of $I(1)$ variables, while stationary variables are not really an issue and there is basically no need to pre-test the variables to establish their order of integration. For the case, that a variable is $I(1)$ instead of $I(0)$, the cointegration vector is spanned by the only stationary variable in the test. If, e.g., the Eq. (8.3) is comprised of a model in which $y_t = (y_{1,t} \quad y_{2,t})'$ where $y_{1,t}$ is $I(1)$ and $y_{2,t}$ is $I(0)$, there exists a cointegration vector which is given by $\beta = (0 \quad 1)'$. All n variables are stationary, if Π has full rank.

Since there is no need to a prior distinguish between $I(1)$ and $I(0)$, it lacks the robustness in relation to near- integrated variables. Also the sensitivity to specification errors in limited sample sizes can cause problems or, that the model is unusable for some certain procedures.

8.2 VECM

With the lag length of the VAR model it is possible to test the system with the Johansen cointegration test. First of all, the deterministic terms of the model, as constants and trends, need to be specified. Those are important effects for the asymptotic distribution of the test statistic and the empirical results differ due to it. These terms can occur inside or outside the cointegrated relationships and in the long- run or short- run dynamic. The vector error correction model ($VECM$) implies all conditions. The Johansen model which is based on the $VECM$, can be written in the following general form:

$$\Delta y_t = \alpha \begin{pmatrix} \beta \\ \mu_1 \\ \delta_1 \end{pmatrix} (Z_{t-1} \quad 1 \quad t) + \Gamma_1 \, \Delta y_{t-1} + \cdots + \Gamma_{p-1} \, \Delta y_{t-p+1} + \mu_2 + \delta_2 \, t + u_t \quad (8.6)$$

μ_i … constant

δ_i … trend

8.3 Exogeneity test

If a variable is exogenous to key parameter in the model, only a smaller set of equations need to be analyzed. This means that, the number of parameters can be reduced, which leads to more precision in forecasting.

As already mentioned, the parameter α is the adjustment coefficient and is the speed of adjustment towards equilibrium. The parameter β is the cointegration vector and indicates an equilibrium relation between the variables. For a bivariat model it represents the long- run relationship. A good explanation about the parameters α and β is of Fransen et.al.. To understand it, however, we have to start a little more at the beginning, with an independently generated bivariat model.

$$y_{1,t} + \delta\, y_{2,t} = v_t \qquad v_t = \mu_1^* + p_1\, v_{t-1} + \varepsilon_{1,t}^* \tag{8.7}$$

$$y_{1,t} + \eta\, y_{2,t} = w_t \qquad w_t = \mu_2^* + p_2\, w_{t-1} + \varepsilon_{2,t}^* \tag{8.8}$$

The interpretation of these two equations depends on p_1 and p_2 which are in the range of $0 \leq p_1, p_2 \leq 1$.

The vector autoregressive model can be expressed like:

$$\Delta Y_t = \mu + \Pi\, Y_{t-1} + e_t \tag{8.9}$$

Where μ is an intercept, $e_t = (\varepsilon_{1,t}, \varepsilon_{2,t})$ and Y_{t-1} is one period lagged (for a bivariat model). The matrix Π can be written as:

$$\Pi = \begin{bmatrix} (\eta\, p_1 - \delta\, p_2 - \eta + \delta)/(\eta - \delta) & \eta\, \delta\, (p_1 - p_2)/(\eta - \delta) \\ (p_2 - p_1)/(\eta - \delta) & (\eta\, p_2 - \delta\, p_1 - \eta_\delta)/(\eta - \delta) \end{bmatrix} \tag{8.10}$$

Three cases can be distinguished:

First, if $0 \leq p_i < 1$, for $i = 1{,}2$ and if η and δ are both not equal zero, the matrix has full rank 2.

Second, if $p_1 = p_2 = 1$, all elements of Π may be zero and the rank of Π is 0.

Third, one is the cointegration case. If $p_1 = 1$ and $0 \leq p_2 < 1$ (or vice versa) the 2×2 matrix Π can be expressed as: $\Pi = \alpha \beta'$ like mentioned earlier in the part 8.1, α and β are 2×1 matrices:

$$\alpha = \begin{bmatrix} \delta\,(1 - p_2)/(\eta - \delta) \\ -(1 - p_2)/(\eta - \delta) \end{bmatrix} \qquad \beta = \begin{bmatrix} 1 \\ \eta \end{bmatrix} \tag{8.11}$$

And the rank of the matrix Π is 1.[97]

8.4 Law of one Price

The LOP (Law of One Price) was proposed by Goldberg and Knetter (1997). They discussed, if the absolute and the relative versions of the LOP hold between the different markets. An integrated world market exists, if the LOP held for all countries for the same product. Otherwise, the absolute purchasing power parity theory held for all products among two countries.[98]

97 Franses et.al. (2014), 257 f
98 Goldberg et.al. (1997)

9 The model

The empirical part is based on the paper “Gas versus oil prices the impact of shale gas” published by Frank Asche, Atle Oglend and Petter Osmundsen at the “Energy Policy” in 2012. They discussed, what impact the shale gas production in the United States has on the European natural gas market, and whether the developments lead to a movement of the European gas prices and to a differentiation of the gas and oil price trends.

In chapter 5, Data and methodology, they break down the historical relationship of oil and natural gas prices in Europe. The differentiation of whether the growing shale gas production in the United States results in individual market changes or whether it means, that there is a huge change in the relationship of the gas and oil markets, is extremely important. That there are substantial changes in the markets is obvious, but of what dimension and context has to be examined.

9.1 Previous assumption

Their analysis is based on the European market. They took monthly observations of oil prices represented by Brent blend and gas prices at the national balancing point (NBP) in the UK, over a time period of almost fourteen years.[99] In three equations they carry out their studies:

For testing the market integration, the basic relationship is considered as follows:

$$lnp_{1t} = \alpha + b\ lnp_{2t} \tag{9.1}$$

This equation tests the long term relationship of the natural gas and oil prices (p_{1t}, p_{2t}). A logarithmic form is used, “where the parameter α is an intercept

99 Asche et.al. (2012)

which specifies the difference in level between prices. This regression constant specifies the value of lnp_{1t}, if the parameter lnp_{2t} is set equal zero. The relationship between the prices will be expressed with b."[100] So, "if $b = 0$ no relationship exists between the prices, but if $b = 1$ the prices are proportional and the relative price is constant."[101] A relationship exists under $0 < b < 1$, but gas and oil are no perfect substitutes.

The double- log model is suitable for models with constant elasticity. However it is necessary that the observed values are all greater zero, since the natural logarithm is undefined otherwise.

The second equation is the Johansen test and with the help of the vector autoregressive error correction model (VECM) it can be expressed like this:

$$\Delta P_t = \sum_{i=1}^{k-1} \Gamma_i \, \Delta P_{t-i} + \Pi P_{t-k} + \mu + e_t \quad (9.2)$$

The result ΔP_t and the endogenous variable ΔP_{t-k} represent the vector of the N prices which represents the population. The Γ_i explains the short- term dynamic, the Π matrix contains the long- term context. Π represents the matrices of $\propto$ and β $(N \times r)$ where the rank of $\Pi = 0$, $0 < N < r$, in this case of cointegration it is expressed in the form of: $-\Pi = \propto \beta'$, where $\propto$ contains the adjustment parameters and β the cointegration vectors. In the case of $\Pi = 0$, there is no cointegration and non- stationarity of $I(1)$ vanishes by taking differences. If Π has full rank N, than the P's cannot be $I(1)$ but stationary. The e_t and μ are a constant factor and a deterministic trend which can be added in the long- term context.

The final equation to get results about the cointegration of the gas and oil prices for the market, concludes the first and second equation, and is given as:

$$\begin{bmatrix} \Delta lnp_{1t} \\ \Delta lnp_{2t} \end{bmatrix} = \begin{bmatrix} A_1 \\ A_2 \end{bmatrix} + \begin{bmatrix} \propto_1 \\ \propto_2 \end{bmatrix} \begin{bmatrix} 1 & b \end{bmatrix} \begin{bmatrix} lnp_{1t-1} \\ lnp_{2t-1} \end{bmatrix} \quad (9.3)$$

100 Asche et.al. (2012)
101 Asche et.al. (2012)

The analysis of the paper includes two price series represented of the first vector of Eq. (9.3). “The intercept in Eq. (9.1) is incorporated here in parameters A_1 and A_2 depending on which variable is used on the left- hand side of Eq. (9.1). (…) It provides result whether the long- term relative price is constant or whether $b = 0$,”[102] what means a proportional price. The $\propto$ vector gives information about the exogeneity. If both, $\propto_1$ and $\propto_2$ equal zero, causality exists. If just $\propto_1$ or $\propto_2$ is equal zero, the associated price will be exogenous and will determine the other price.[103]

9.2 Literature review

Many previous papers discussed the relationship between gas and oil prices already and established that they are cointegrated. Villar and Joutz (2006) analyzed the behavior of the WTI crude oil and the Henry Hub natural gas spot prices in the short- run and the long- run. Since natural gas decoupled frequently from crude oil in the past years, the aim of their paper was to find out, if they still are related, like they had been in the past, or if this changed due to the decoupling. They used a VAR model to test for cointegration in the long- run and an error correction model for testing the short- run relationship, which allows implementing some necessary additional factors. They came to the result that the two price series still have a stable long- run cointegrating relationship. The short- run findings show that crude oil prices are weakly exogenous to natural gas prices. They also noted that the natural gas prices grow slightly faster which narrows the gap between the series over time.

Ramberg and Parsons (2012) analyzed the same price series like Villar and Joutz (2006). However, they used a more recent timeframe, until 2010 instead of 2005. What they wanted to examine was on one hand the reason for the enormous amount of unexplained volatility in the natural gas prices and on the other hand whether the cointegration relationship is stable over time.

102 Asche et.al. (2012)
103 Asche et.al. (2012)

However, previous literature, like the study of Villar and Joutz (2006), showed that the prices of natural gas are shifting up compared to the oil price, they came to the result that since 2006 the trend reversed and since 2009 they discovered another decoupling among the prices. In their model, a huge amount of the volatility of the change in natural gas prices is unaccounted. For the cointegration relationship they found out that it changed over time, which means that the historical findings are not very reliable predictors for the future.

Siliverstovs, L'Hégaret, Neumann and Hirschhausen (2005) analyzed the natural gas market for Europe, North America and Japan. They used the same tests to examine the existence of cointegration relationships between the markets which are applied in the model of this master thesis. The data set of their model are for Europe and the USA the pipeline gas, LNG and for Japan the LNG for a period from 1993 to 2004. Their findings are, that there are co-movements within the European/Japanese and the North American prices and this is confirmed by the Johansen test and its evidence of cointegration.

The study of Ahmed, Islam and Sukar (2010) is about the long- run cointegration between the oil prices and the U.S. inflation (core consumer price index). The gas price is not incorporated in that paper; however it is mentioned here to confirm that there exists (at least) a weak equilibrium relationship between the oil prices and the core consumer price index and after a shock the system moves back to that equilibrium. Their result explains why a trend can be considered in the following model.

9.3 The market of crude oil and natural gas

The oil and gas markets are quite different. For example, a world market exists for oil, while for natural gas only regional markets exist. Crude oil can be shipped easily and cheap, natural gas needs pipelines or has to be liquefied first to be shipped and regasified at the destination, which makes the transportation more expensive compared to oil. Both forms are energy carrier;

however 1 barrel of crude oil produces the same energy like 6 million Btu (British thermal unit) of natural gas.[104]

9.4 Data

Compared to the paper of Frank Asche, Atle Oglend and Petter Osmundsen, the following analysis will examine the changes and relationship of the oil and natural gas markets related to the shale gas production in the United States. Thus, the empirical analysis is based on the analysis of the paper mentioned already and the implementation and tests described above will basically be the same, only the time series and data source will be different. They used the earlier mentioned observations of the UK, with the time frame of September 1996 to March 2010, while the following analysis is based on the EIA provided prices represented by the Henry Hub Spot Prices (which is the largest of the 39 trading hubs in the U.S.) for the gas prices and the U.S. Crude Oil First Purchase Price for the oil prices. Three different timeframes had been tested: a total timeframe, a timeframe before the economic crisis and a timeframe after the economic crisis, which started in 2007. The total timeframe is running from January 1997 to June 2014. From January 1997 to April 2007 the timeframe before the crisis had been tested and from January 2009 to June 2014 it covers the time after the economic crisis. All datasets are related to the markets of the United States, with monthly (because the long- term relationship is analyzed) observations, where 210 data points and respectively 124 and 66 data points have been provided. Only the results of the tests for the total timeframe will be presented. However, in this way it is possible to compare whether the relationship changed after the shale gas boom or remained stable.

The original pricing unit for crude oil is in US- Dollar per Barrel (bbl). For natural gas it is US- Dollar per million Btu (British thermal unit). To compare the prices, they had to be transformed to US- Dollar per metric ton. For crude oil the standard conversion factor is 1 bbl = 0.136 metric tons and for natural gas the

104 Villar et.al. (2006)

standard conversion factor is 1 million Btu = 397 metric tons. Afterwards they have been transformed to logarithm to remove the scale effects.[105]

105 EIA, Annual Energy Outlook (2003)

A statistic summary of the data in log is given below, while the following two tables show the prices for crude oil and natural gas (both in USD per metric ton) for the logarithmic prices.

date	gasLT	oilLT
1.15.00: 1	Min. :-0.51083	Min. :0.09102
1.15.01: 1	1st Qu.: 0.04879	1st Qu.:1.16526
1.15.02: 1	Median : 0.38865	Median :1.86667
1.15.03: 1	Mean : 0.39149	Mean :1.73433
1.15.04: 1	3rd Qu.: 0.76547	3rd Qu.:2.43725
1.15.05: 1	Max. : 1.54756	Max. :2.86049
(Other):204		

Figure 9-1: *"Summary of the (Log) prices of natural gas and crude oil from January 1997 to June 2014"* (Sources: Henry Hub and EIA)

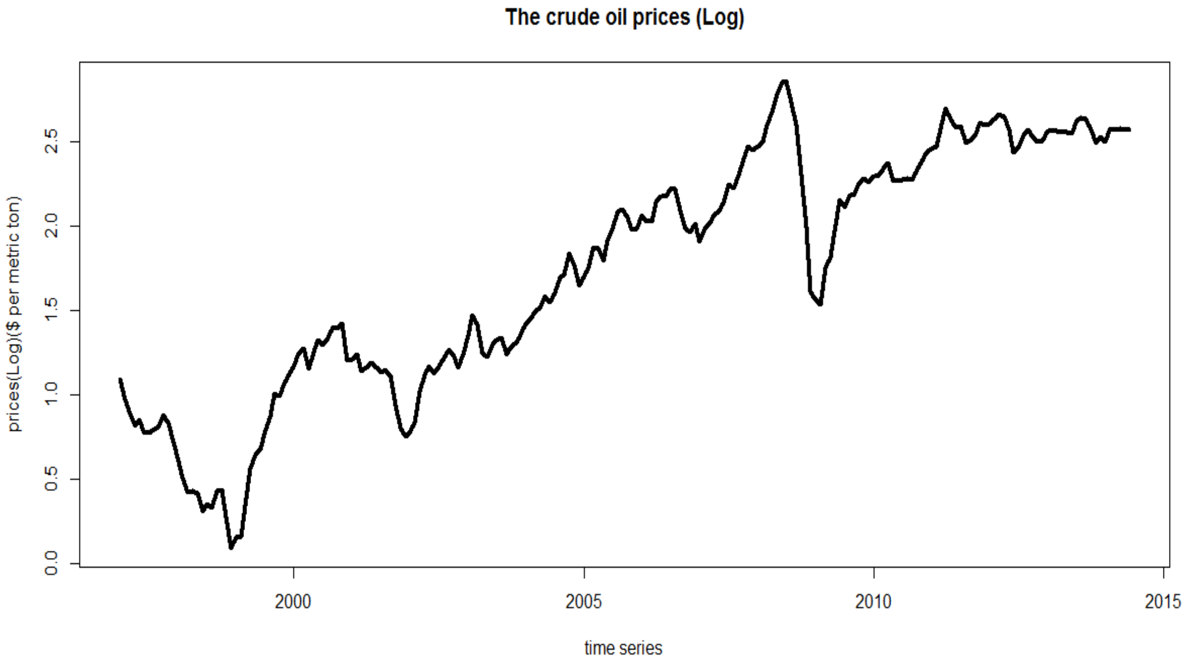

Image 9-1: *“The crude oil prices (Log) in $ per metric ton from January 1997 to June 2014”* (Sources: Henry Hub and EIA)

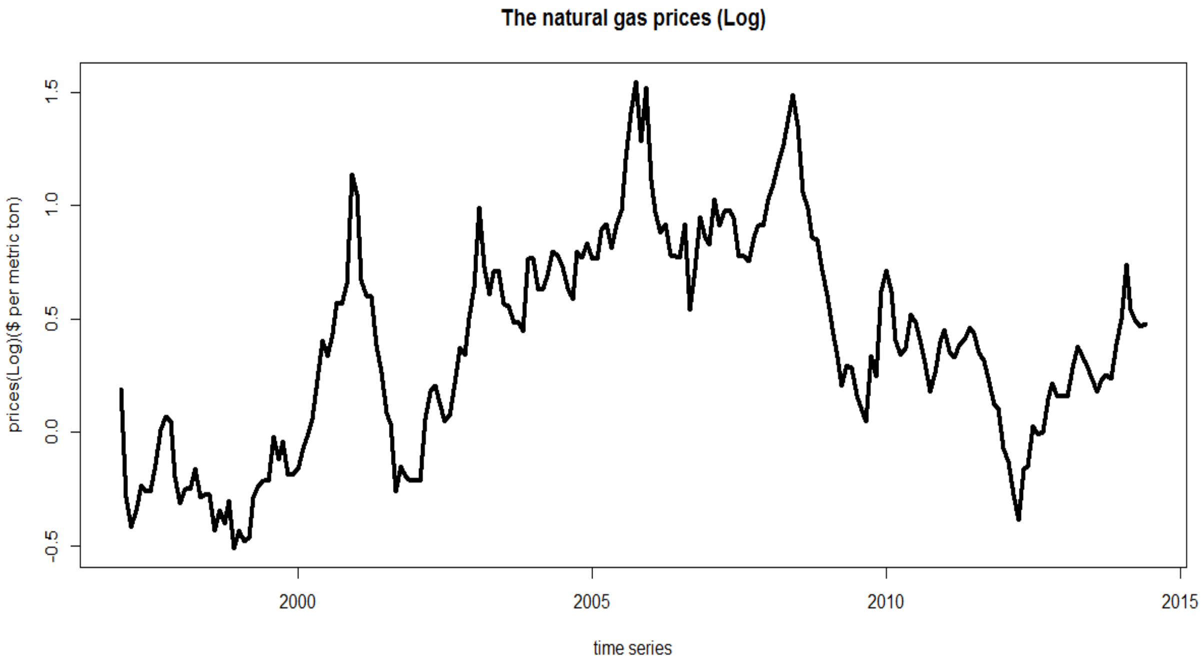

Image 9-2: *"The natural gas prices (Log) in $ per metric ton from January 1997 to June 2014"* (Sources: Henry Hub and EIA)

9.5 Unit root tests

Stationarity can be tested with the presence of unit roots. If all solutions of the vector time series are outside the unit circle, the model is said to be stationary. However, if one or more solutions are on the unit circle the time series is non- stationary. Performing different tests of the unit root test is a good method for testing the sensitivity of the conclusions, by comparing different results.[106]

The natural gas and crude oil time series in logarithms are tested for unit roots with the aim of the ADF test (for theory see chapter 6.2) and the KPSS test (see chapter 6.3), both with and without a trend. The null and alternative hypotheses are defined as:

ADF test	
H_0: non − stationary	H_1: stationary
KPSS test	
H_0: stationary	H_1: non − stationary

Figure 9-2: *"Hypotheses of ADF and KPSS test"*

106 Kunst (2006)

The following tables summarize the results of the tests in levels and first differences, with and without a trend:

Log prices in levels				
	Without trend		**With trend**	
	ADF	**KPSS**	**ADF**	**KPSS**
Crude oil	0.2945	3.8383 [a]	- 3.6401 [b]	0.2533 [a]
Natural gas	- 1.6266	1.1196 [a]	- 2.4245	0.7219 [a]

Figure 9-3: *"Unit root tests – Log prices in levels"*

Log prices 1st differences				
	Without trend		**With trend**	
	ADF	**KPSS**	**ADF**	**KPSS**
Crude oil	- 7.5974 [a]	0.0496	- 7.6244 [a]	- 0.0498
Natural gas	- 9.9938 [a]	0.0469	- 9.9826 [a]	0.0426

Figure 9-4: *"Unit root tests – Log prices 1st differences"*

[a] *Refers to rejection at the 1 per cent level. Number of lags to include in the testing procedure is determined by Akaike Information Criteria.*

[b] *Refers to rejection at the 5 per cent level. Number of lags to include in the testing procedure is determined by Akaike Information Criteria.*

Note:

critical values ADF test without trend: at 1% level -2.58, at 5% level -1.95, at 10% level -1.62

critical values ADF test with trend: at 1% level -3.99, at 5% level -3.43, at 10% level -3.13

critical values KPSS test without trend: at 10% level 0.347, at 5% level 0.463, at 2.5% level 0.574, at 1% level 0.739

critical values KPSS test with trend: at 10% level 0.119, at 5% level 0.146, at 2.5% level 0.176, at 1% level 0.216

In level, the ADF test does not reject any null hypothesis without trend and for natural gas with trend, which means the variables have a unit root and are non- stationary. It rejects the null hypothesis with trend for crude oil, what means the variables do not have a unit root and are stationary. The results of the KPSS tests in level are that the null hypothesis is stationary and is rejected for both with and without trend. This means the variables are non- stationary.

For the first differences, the ADF test rejects all null hypotheses. This means the time series are all integrated of order one ($I(1)$). The statistic values for the KPSS test are all less than the critical values, thus all null hypotheses are accepted and the series are stationary.

So, only for crude oil under the assumption of a trend the results are ambiguous. However, all other results indicate non- stationarity and integration of order one, and the number of cointegrated relationships among the variables has to be estimated. Therefore the lag order needs to be determined first.

Many previous studies have already tested the stochastic properties of crude oil and came to the result that the prices are non- stationary. Coimbra and Esteves tested in 2004 the Brent crude oil spot and future prices for a period from January 1989 to December 2003 as well as for a shorter timeframe from 1992 to 2003, and could in both cases not reject the hypothesis that the price series have a unit root. Alizadeh and Nomikos (2002) came to a similar result, when testing the weekly closing prices of WTI, Brent and Nigerian Bonny Light from January 1993 to August 2001. The long- run properties of crude oil, which have been tested by Pindyck (1999) and Krichene (2002) with annual aggregated data from 1870 to 1996, could also not reject the unit root null. Due to these solutions among many others, and despite the results of the tests here, the stationary and non- stationary price series will be tested for cointegration.

9.6 VAR model and autocorrelation

After the unit root tests, a VAR model is fitted for the two variables. Information criteria for different lag orders are commonly used for choosing the lag order p. The statistic program determined the lag order, out of a maximum of 12 lags (due to the monthly data), for the AIC with 2 lags. For the Hannan-Quinn (HQ), Schwarz Criterion (SC) and the Final Prediction Error (FPE) criteria a lag length of 2 would be chosen as well. Since there are no deviations in the result, the lag length of 2 can be assumed for the model.

	1	2	3	4	5	6
AIC(n)	-8.9922690194	-9.212211e+00	-9.205053049	-9.1696153430	-9.1680180134	-9.1391878021
HQ(n)	-8.9384920013	-9.131546e+00	-9.097499013	-9.0351727978	-9.0066869591	-8.9509682388
SC(n)	-8.8594097454	-9.012923e+00	-8.939334501	-8.8374671581	-8.7694401915	-8.6741803432
FPE(n)	0.0001243689	9.981678e-05	0.000100539	0.0001041745	0.0001043541	0.0001074253

	7	8	9	10	11	12
AIC(n)	-9.1514544931	-9.1541025557	-9.1516862320	-9.1953698864	-9.1741638088	-9.1590378449
HQ(n)	-8.9363464208	-8.9121059744	-8.8828011416	-8.8995962869	-8.8515017003	-8.8094872274
SC(n)	-8.6200173973	-8.5562358229	-8.4873898621	-8.4646438796	-8.3770081649	-8.2954525641
FPE(n)	0.0001061404	0.0001058915	0.0001061876	0.0001016955	0.0001039326	0.0001055857

Figure 9-5: *“Values for the different lag length”*

The lag length $p = 2$ returns the greatest value of the AIC and SC and these two tests are chosen since they commonly provide the most valid results. That the residuals are not autocorrelated had been tested with the Breusch-Godfrey test and the Portmanteau test. The results for the Breusch- Godfrey test are: the residuals for the $VAR(2)$ model have a p- value of 0.333 and the chi squared is 51.6546 with a df (degree of freedom) of 48. Since the p- value is higher than the significance value of 5%, the null hypothesis, no serial correlation of any order up to p, can be accepted. The Portmanteau test comes to the same result, however, the null hypothesis is that the fitted model is an adequate model and the residuals behave like white noise series. The p- value is: 0.1229 and the chi squared is 12.6923 with 8 df.

The cointegration among the residuals had been tested with the Phillips- Ouliaris test as well and the result is that there is no cointegration between the residuals. The value of the test statistic is 25.3015 and the null hypothesis, stating that no cointegration among the residuals exists, can clearly be accepted.

The test result is that a model with two lags is sufficient, in order to eliminate dynamic error specifications.

9.7 Cointegration tests: Trace test

For the Trace test the following information are required: *data set*, *lag length* estimation of the VAR model, *type* of the test for the respective statistic, *specification* of the $VECM$, *ecdet* character of what is included in the cointegration relations, *seasonal* dummies and *dummy variables.*

The data set are the logarithm oil and gas prices. The lag length has been determined with the VAR model in the chapter before (9.6) and is 2. Since the Trace test is implemented, the type 'trace' is considered and the relationship should be defined here with 'longrun', which is the appropriate form the long-term relations. There are no seasonal or dummy variables incorporated in the model. However, the ecdet character is 'trend', due to the inflation. Even if the prices, strictly speaking, do not have a rising course, there is a continuous slope of the prices conditioned by inflation. However the restriction 'trend' is responsible therefore, that the results are not significant and the null hypothesis that no cointegration relationship exists cannot be rejected.

Cointegration test				
	H_0: rank = r	Trace test	LOP [b]	Exogeneity [b]
Crude Oil	r == 0	28.35 **	8,07 (0)	3.36 (0.07)
Natural gas	r <= 1	6.02		9.77 (0.00) **

Figure 9-6: *"Cointegration tests"*

[b] *p- values in brackets.*

Note:

critical values Trace test for r == 0: at 10% level 22.76, at 5% level 25.32, at 1% level 30.45

critical values Trace test for r <= 1: at 10% level 10.49, at 5% level 12.25, at 1% level 16.26

Unrestricted cointegration vectors and adjustment speeds					
	Eigenvalues	Cointegration vectors		Adjustment coefficients	
		Natural gas	Crude oil	Natural gas	Crude oil
Natural gas	0.101791	1.000	0.392551926	-0.03999025	-0.03828331
Crude oil	0.02853883	-2.2731523	1.000	0.03922522	-0.01564441

Figure 9-7: *"Unrestricted cointegration vectors and adjustment speeds"*

The first table above (Figure 9-6) shows the results of the cointegration tests. The Johansen test, or more precisely the Trace test, had been performed. What we can see is that the rank $r == 0$, which means that no cointegration relationship among the variables exist, can be rejected. However, the hypothesis $r <= 1$, that one cointegration relationship between the time series exists, can be accepted. The oil and gas prices still have a long- run relationship, even with the increased amount of natural gas on the market. In the column of cointegration vector (Figure 9-7), the unrestricted estimate for b is -2.2731523. However, without *a prior* information it will not be possible to give an economic interpretation to the estimated cointegration vectors.[107] The test of the LOP shows, if b is significantly different from 1, the hypothesis is, that the prices move proportionally and the relative price is constant in the long term. The result is, that the hypothesis of the LOP can be rejected, so the hypothesis that the long- term price is constant can be rejected. The results of the exogeneity tests are, that the null hypothesis that oil prices are exogenous cannot be accepted. The hypothesis that gas prices are exogenous can however be rejected. This is well in accord with the often proven theory that the oil price determines the gas price, which leads to a long- term relationship. After a shock, the prices converge again and this narrow relationship is explained due to the substitute characteristic of them.

107 Wickens (1995)

Conclusion

Granger (jointly with Engle) got the Nobel Prize 2003 “for methods of analyzing economic time series with common trends (cointegration).”[108] They made it possible to test for cointegration among price series and to examine the second research question of this master thesis: Whether the oil and gas prices in the United States are still in a long- run relationship or if this has changed due to the shale gas development.

Three periods have been tested for cointegration. The first one is a total period from January 1997 to June 2014 and the results are represented in the prior chapter. The second period is before the economic crisis started, for a timeframe from January 1997 to April 2007. The third period is after the crisis from January 2009 to June 2014. Through the comparison it can be examined whether the shale gas boom leads to a change in the relationship or whether it stays stable, under consideration of the economic crisis. For all three periods the same tests were run. The result is, that in the period of 1997-2014 the price series are non- stationary and cointegration relation has existed. The analysis has shown a cointegration relation, whereas it has to be interpreted carefully since the time series are no longer stationary. What leads to the conclusion that even after the shale gas boom, natural gas and crude oil both share a long term relationship and follow a common trend. Previous analysis also came to the result that the oil and gas prices in the United States have a long- term relation, thus the result confirms well with it.

The burning tap - symbol for the fear of the deep, the fear of fracking. The United States have been the first, who drilled for shale gas and operated fracking in a grand scale. However, they produced some nightmare scenarios which were going around the world. Particularly with their (initially) less careful wastewater management and because of missing rules and monitoring of the fracking process in general, they fanned fear through occurring health problems

108 Noble prize nomination - economics (2003)

in some areas as well as environmental catastrophes.

Geologists and geoscientists, the experts, now try to release fears through better profound knowledge and enlightenment. So was the burning tap from the movie “Gasland”, triggered demonstrably not by fracking. It was naturally occurring natural gas, which exists in the upper layers of rocks and is formed, among other things, by bacteria.

In Europe as well, experts take up position. The Acatech (German Academy of Technical Sciences) and the SASEG (Swiss Association of Energy- and Geoscientist) both came to the result that the news about the fracking incidents are overstated or incorrect. The hydraulic fracturing process is controllable and from the scientific point of view, there is no reason to forbid it. This has been published at the end of September 2014 in the Copenhagen Declaration. Scientists from Switzerland, Great Britain, Scandinavia and the Netherlands worked together and Prof. Dr. Hans-Joachim Kümpel, the President of the German Federal Institute for Geosciences and Natural Resources (BGR) states: ”When critics, in connection with fracking, speak of an uncontrollable high- risk technology, from a scientific perspective this is simply wrong.”

Despite all of it, some risk remains. The drilling technology *may* trigger earthquakes and *may* contaminate ground water, or it *may* destroy whole tracts of land - so the question remains: Do we really want to risk it?[109]

109 Frey (2014)

Figures

Images

References

[1] Ahmed, S.M., Islam, A.M., Sukar, A. (2010), *The Long- Run Co-integration Analysis between Oil Prices and U.S. Inflation*, Volume 10 Issue 2, Journal of Financial and Economic Practice

[2] Alizadhe, A.H., Nomikos, N.K. (2002), *Cost of carry, causality and arbitrage between oil futures and tanker freight markets*, Paper presented at the IAME 2002 Conference

[3] Allen, R.M., Frame, D.J., Huntingford, C., Jones, C.D., Lowe, J.A., Meinhausen, M., Meinhausen, N. (2009), *Warming Caused by Cumulative Carbon Emissions towards the Trillionth Tonne*, Nature 458 (7242) 1163-1166

[4] Asche, F., Oglend, A., Osmundsen, P. (2012), *Gas versus oil prices the impact of shale gas*, Energy Policy 47 (2012) 117-124, Energy Policy

[5] Auer, B., Rottmann, H. (2011), *Statistik und Ökonometrie für 4 Wirtschaftswissenschaftler*, Gabler, Wiesbaden

[6] Bahadori, A. (2014), *Natural Gas Processing*, Elsevier, Waltham (USA)

[7] Binnion, M. (2011), *How the technical differences between shale gas and conventional gas projects lead to a new business model being required to be successful*, 31 (2012), Marine and Petroleum Geology, 3-7

[8] Boersma, T., Johnson, C. (2012), *The Shale Gas Revolution: U.S. and EU Policy and Research Agendas*, Volume 29, Number 4 (2012), Review of Policy Research

[9] Brantley, S., Meyendorff, A. (2013), *The Facts on Fracking*, March 13 (2013), The New York Times

[10] Coimbra, C., Esteves, P.S. (2004), *Oil prices assumptions in macroeconomic forecasts: should we follow futures market expectations?*, OPEC Review 28, 87-106

[11] Department of Mines and Petroleum (2013), *Petroleum Fact Sheet – Gas Resource Types*, Government of Western Australia

[12] Devold, H. (2013), *Oil and gas production handbook*, ABB, Oslo

[13] Drobetz, W. (2003), *Nichtstationarität und Kointegration: Eine Einführung*, Universität Basel (WWZ)

[14] Endres, A. (2014), *Kommt Fracking durch Freihandel?,* 6. März 2014, Zeit Online – Wirtschaft

[15] Engle, R., Granger, C. (1987), *Co-Integration and Error Correction: Representation, Estimation, and Testing*, Volume 55, Number 2 (Mar, 1987), Econometria

[16] Fink, J. (2013), *Hydraulic Fracturing Chemicals and Fluids Technology*, Elsevier, Waltham (USA)

[17] Franses, P.H., van Dijk, D., Opschoor, A. (2014), *Time Series Models for Business and Economic Forecasting*, Cambridge University Press, Cambridge (UK)

[18] Frey, A. (2014), *Angst vor der Tiefe*, 31. Oktober/1./2. November, Nr. 251, Süddeutsche Zeitung

[19] Goldberg, P.K., Knetter, M.M. (1997), *Goods Prices and Exchange Rates: What Have We Learned?*, Vol. XXXV (September 1997) pp. 1243-1272, Journal of Economic Literature

[20] Habrich-Böcker, C., Kirchner, B., Weißenberg, P. (2014), *Fracking- Die neue Produktonsgeografie*, Springer-Gabler, Wiesbaden

[21] Hammer, R., VanBriesen, J. (2012), *In Fracking's Wake: New Rules are Needed to Protect Our Health and Environment from Contaminated Wastewater*, D: 12-05-A, Natural Resources Defense Council

[22] Hjalmarsson, E, Österholm, P. (2007), *Testing for Cointegration Using the Johansen Methodology when Variales are Near- Integrated*, IMF Working Paper WP/07/141, International Monetary Fund

[23] Horsfield, B., Schulz, H.M. (2011), *Shale gas exploration and exploitation*, 31 (2012) 1-2, Marine and Petroleum Geology

[24] Jenner, S., Lamadrid, A. (2012), *Shale gas vs. coal: Policy implications from environmental impact comparisons of shale gas, conventional gas, and coal on air, water, and land in the United States*, 53 (2013) 442-453, Energy Policy

[25] Johansen, S. (1995), *Likelihood- based Inference in Cointegrated Vector Auto- regressive Models*, Oxford University Press

[26] Krichene, N. (2002), *World crude oil and natural gas: a demand and supply model*, Energy Economics 24, 557-576

[27] Kunst, R. (2006), *Ökonomische Zeitreihenanalyse - Teil 2*, University of Vienna and Institute for Advanced Studies Vienna

[28] Lütkepohl, H. (2007), *New Introduction to multiple time series analysis*, Springer Verlag, Berlin Heidelberg

[29] Miller, D., Huang, X., Lee, A., Agnihotri, D., Hayes, T., Paul, D., Freeman, B. (2013), *Fouling-resistant membranes for the treatment of flowback water from hydraulic shale fracturing: A pilot study*, Volume 437, 15 June 2013, Journal of Membrane Science, 265-275

[30] Mokhatab, S., William, P., James, S. (2006), *Handbook of Natural Gas Transmission and Processing*, Elsevier, Burlington (USA)

[31] Olavarria, L., Jaimes, D., Mata, G., Cull, A., Mendis, J., Yoon, J., Martinez, C.,Harvie, A., Litton, K., Kwok, F., Li, B., Gonzalez, S., Vicioso, C., Koster, W., Schoevaars, M., Kozlowski, A., Ash, M., Baines, T., May, C., Nicholson, B., O'Brien, E., Lewis, E. (2013), *Energy, Shale gas handbook*, Norton Rose Fulbright

[32] Phillips, P.C.B, Ouliaris, S. (1988), *Asymptotic Properties of Residual Based Tests for Cointegration*, No. 847-R, Cowles Foundation for Research in Economics at Yale University

[33] Pindyck, R.S. (1999), *The long- run evolution of energy prices*, Energy Journal 20, 1-27

[34] Ramberg, D.J., Parsons, J.E. (2012), *The Weak Tie Between Natural Gas and Oil Prices*, Vol. 33 No. 2, The Energy Journal

[35] Schrag, D. (2012), *Is Shale Gas Good for Climate Change?,* Daedalus – the Journal of the American Academy of Arts & Sciences, Vol. 141, No. 2 pages 72-80, Cambridge

[36] Schulte von Drach, M. (2014), *Europas riesiger Energiehunger*, 13. August 2014, Süddeutsche Zeitung Online – Politik

[37] Siliverstovs, B., L'Hégaret, G., Neumann, A., von Hirschhausen, C. (2005), *International market integration for natural gas? A cointegration analysis of prices in Europe, North America and Japan*, Energy Economics 27 (2005) 603-615

[38] Speight, J (1993), *Natural Gas: A Basic Handbook*, Gulf Publishing Company, Houston (USA)

[39] Umbach, F. (2013), *The unconventional gas revolution and the prospects for Europe and Asia*, Springer Verlag, Berlin Heidelberg

[40] Villar, J.A., Joutz, F.L. (2006*), The Relationship between Crude Oil and Natural Gas Prices*, EIA – Office of Oil and Gas

[41] Wang, J., Holditch, S., McVay, D. (2012), Effect of gel damage on fracture fluid cleanup and long- term recovery in tight gas reservoirs, J Nat Gas Sci Eng, 9:108-118, Elsevier

[42] Wickens, M.R. (1995), *Interpreting cointegrating vectors and common stochastic trends*, Journal of Econometrics 74 (1996) 255-271, Elsevier

[43] Winker, P. (2010), *Empirische Wirtschaftsforschung und Ökonometrie*, Springer Verlag, Berlin Heidelberg

Appendix: Abstract

The master thesis gives an overview about shale gas and its impact on the environment and on the oil and gas markets in the United States. Shale gas is classified as unconventional gas. It is located in a depth of 3000 m and lower, and the reservoirs keep large amounts of methane. It is mined through hydraulic fracturing (or just fracking), a special process in which high pressure generates cracks in the rocks, so that the gas can flow up to the surface. When horizontal drilling is used, starting from one borewell, the reservoirs within a radius of several kilometers can be mined. Like the other fossil forms (oil, coal and conventional natural gas) which are produced already for many decades, the production of shale gas and its further consumption influences the environment as well. The environmental impacts of shale gas on air, water and land are discussed. For air the greatest impact is due to the methane leaks, which occurs especially right after the drilling. For water, the chemicals used in the fracking process, are the biggest problem. However for the factor land, in comparison to coal and conventional gas, the harm is minor, as a result of the horizontal drilling process. At the end, the oil and gas markets in the United States will be analyzed. The study is based on the prices of crude oil and natural gas for three different periods of time. The first period is considering around 17 years and represents the relationship for the total timeframe before and after the economic crisis. The second period is around 10 years and represents the relationship before the economic crisis had been. The third period is covering the time after the crisis and is around 5 years long. Based on these three timeframes it is determined whether there is still a long term relationship between the resources, or whether the relationship changed due to the shale gas development in the United States.

Appendix: Zusammenfassung

Diese Masterarbeit gibt einen Überblick über Schiefergas und seine Umweltauswirkungen und die Auswirkungen auf die Öl und Gas Märkte in den Vereinigten Staaten. Schiefergas ist als unkonventionelles Gas eingestuft, welches sich in einer Tiefe von 3000 m und tiefer befindet und in dessen Reservoirs große Mengen an Methan vorkommen. Gefördert wird es durch Hydraulik Fracturing (oder auch nur Fracking genannt), welches ein spezielles Verfahren ist, bei dem durch hohen Druck Risse im Gestein entstehen, welche das Gas freisetzen, so dass es an die Oberfläche fließen kann. Da horizontal gebohrt wird, können von einem Bohrloch ausgehend die Reservoirs in einem Umkreis von mehreren Kilometern abgebaut werden. Wie auch bei den anderen fossilen Energieformen (Öl, Kohle und die unkonventionellen Erdgasformen) die bereits seit vielen Jahrzehnten abgebaut werden, beeinflusst die Förderung von Schiefergas und sein späterer Verbrauch die Umwelt. Diese Umweltauswirkungen durch Schiefergas auf Luft, Wasser und Boden werden in dieser Arbeit genauer analysiert. Für „Luft“ entstehen die größten Auswirkungen aufgrund der Methanlecks, die vor allem direkt nach der Bohrung auftreten. Der Flowback und seine Entsorgung stellen die größte Gefährdung für die Gewässer und auch für das Grundwasser dar. Während die Auswirkungen für das eigentliche "Land" auf dem gefrackt wird eher gering sind, im Gegensatz zur Förderung von Kohle und konventionellem Gas, da die horizontalen Bohrungen weniger Fläche benötigen.

Am Ende werden die Öl und Gas Märkte in den Vereinigten Staaten analysiert. Dies basiert auf den Preisen für Rohöl und Erdgas, für drei unterschiedliche Zeitperioden. Einmal wird der totale Zeitraum von rund 17 Jahren betrachtet, der die Beziehung vor, nach und während der Wirtschaftkrise darstellt. Dem gegenüber stehen die Zeiträume vor der Wirtschaftskrise von rund 10 Jahren und nach der Krise von rund 5 Jahren. Es wird dadurch ermittelt, ob noch immer eine langfristige Beziehung zwischen den Ressourcen vorhanden ist, oder ob sich das Verhältnis aufgrund der Schiefergasvorkommen in den Vereinigten Staaten geändert hat.

Appendix: R code

```
#library
install.packages("urca")
library(urca)
install.packages("AER")
library (AER)
install.packages("lmtest")
library(lmtest)
install.packages("tseries")
library(tseries)
install.packages("vars")
library(vars)

#data (timeframe: Total=T: January 1997 to June 2014)
setwd("C:/R program/Data")
getwd()
PricesLogTotal<-read.csv("GasOilPricesLogTotal.csv",header=TRUE,sep=";",dec=".")
attach(PricesLogTotal)
dataLT<-cbind(gasLT,oilLT)
summary(PricesLogTotal)

#plot Log prices
gasLTplot<-ts(PricesLogTotal$gasLT,start=c(1997,1),frequency=12)
plot(gasLTplot,main="The natural gas prices (Log)",lwd=4,ylab="prices(Log)($ per metric
ton)",xlab="time series")

oilLTplot<-ts(PricesLogTotal$oilLT,start=c(1997,1),frequency=12)
plot(oilLTplot,main="The crude oil prices (Log)",lwd=4,ylab="prices(Log)($ per metric
ton)",xlab="time series")

#ADF test, with trend  #AIC selected
gasLT.adf<-ur.df(gasLT,selectlags="AIC",type="trend")
summary(gasLT.adf)
oilLT.adf<-ur.df(oilLT,selectlags="AIC",type="trend")
summary(oilLT.adf)
```

```
#ADF test, without trend
gasLT.adf<-ur.df(gasLT,selectlags="AIC",type="none")
summary(gasLT.adf)
oilLT.adf<-ur.df(oilLT,selectlags="AIC",type="none")
summary(oilLT.adf)

#KPSS test, with trend (type=tau)
gasLT.kpss<-ur.kpss(gasLT,type="tau",lags="short")
summary(gasLT.kpss)
oilLT.kpss<-ur.kpss(oilLT,type="tau",lags="short")
summary(oilLT.kpss)

#KPSS test, without trend (type=mu)
gasLT.kpss<-ur.kpss(gasLT,type="mu",lags="short")
summary(gasLT.kpss)
oilLT.kpss<-ur.kpss(oilLT,type="mu",lags="short")
summary(oilLT.kpss)

#AFD test, first difference, with trend
dgasLT<-diff(gasLT)
dgasLT
dgasLT.adf<-ur.df(dgasLT,selectlags="AIC",type="trend")
summary(dgasLT.adf)
doilLT<-diff(oilLT)
doilLT.adf<-ur.df(doilLT,selectlags="AIC",type="trend")
summary(doilLT.adf)

#ADF test, first difference, without trend
dgasLT<-diff(gasLT)
dgasLT
dgasLT.adf<-ur.df(dgasLT,selectlags="AIC",type="none")
summary(dgasLT.adf)
doilLT<-diff(oilLT)
doilLT.adf<-ur.df(doilLT,selectlags="AIC",type="none")
summary(doilLT.adf)
```

#KPSS test, first difference, with trend

```
dgasLT<-diff(gasLT)
dgasLT.kpss<-ur.kpss(dgasLT,type="tau",lags="short")
summary(dgasLT.kpss)
doilLT<-diff(oilLT)
doilLT.kpss<-ur.kpss(doilLT,type="tau",lags="short")
summary(doilLT.kpss)
```

#KPSS test, first difference, without trend

```
dgasLT<-diff(gasLT)
dgasLT.kpss<-ur.kpss(dgasLT,type="mu",lags="short")
summary(dgasLT.kpss)
doilLT<-diff(oilLT)
doilLT.kpss<-ur.kpss(doilLT,type="mu",lags="short")
summary(doilLT.kpss)
```

#Phillips- Ouliaris test

```
PhillipsOuliaris.T<-ca.po(cbind(gasLT,oilLT),demean="none",lag="short",type="Pz",tol=NULL)
summary(PhillipsOuliaris.T)
```

#Cointegration test (TRACE test, EIGENVALUE test)

```
Prices.trace.T<-ca.jo(cbind(gasLT,oilLT),K=2,ecdet="trend",spec="longrun",type="trace")
summary(Prices.trace.T)
Prices.eigen.T<-ca.jo(cbind(gasLT,oilLT),K=2,ecdet="const",spec="longrun",type="eigen")
summary(Prices.eigen.T)
```

#VAR select

```
yT=cbind(gasLT,oilLT)
VARselect(yT,type="both",lag.max=12,season=NULL,exogen=NULL)$selection
VARselect(yT,type="both",lag.max=12,season=NULL,exogen=NULL)$criteria
```

#test for uncorrelated residuals; PT=Portmanteau test / BG=Breusch-Godfrey test

```
varT<-VAR(yT,p=3,lag.max=12,type="none",season=NULL,exogen=NULL)
serial.test(varT,lags.pt=12,type="PT.asymptotic")
serial.test(varT,type="BG",lags.bg=12)
```

```
#restriction on alpha (exogeneity)
A<-matrix(c(1,0),nrow=2,ncol=1)
alpha.restr<-alrtest(Prices.trace.T,A,r=1)
summary(alpha.restr)

#restriction on alpha (exogeneity)
A<-matrix(c(0,1),nrow=2,ncol=1)
alpha.restr<-alrtest(Prices.trace.T,A,r=1)
summary(alpha.restr)

#restriction on beta (LOP)
H1<-matrix(c(1,-1,0,0,0,1),c(3,2))
beta.restr<-blrtest(Prices.trace.T,H1,r=1)
summary(beta.restr)
```

Appendix: Curriculum vitae

Lisa Sicklinger (BA)

<u>Studies</u>

Since 3/11	M.Sc. Business Administration at the University of Vienna • International Energy Management • Supply Chain Management
10/06-3/11	B.A. Business Administration at the THW of Nuermberg • Human Resource Management • Environmental Management • Supply Chain Management • Production, Distribution & Transport
3/06-9/06	Environmental Engineering at the HAW of Hamburg

<u>School</u>

9/99-7/05	High School

<u>Interruption of Studying</u>

10/13-2/14	Work and Travel / Australia, New Zealand
4/12-9/12	Mercedes- Benz / New Jersey (USA) • Parts Logistics
2/08-8/08	BMW AG / Regensburg (Germany) • HR department