Universitetet i Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

MASTER THESIS

Study programme / specialisation: Industrial Economics	The spring semester, 2023 Open / Confidential

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Thesis title: ***Drivers of natural gas price divergence between NBP and TTF in 2022***

Credits (ECTS): 30p

Keywords:

Natural gas price, trading hubs, Europe, The Netherlands, The United Kingdom, LNG, pipeline, storage

Pages: 75

Stavanger, 15.06.2023

Preface

The master's thesis is the final result of work carried out in the spring of 2023 at the Department of Security, Economics and Planning at UiS. Both authors have their main profile in Investment and Finance and Project Management, and technical specialization in mechanical engineering. Aforementioned professional specialization has created motivation to study how various fundamental factors affect the gas price in the British and European sector.

Working on the master's thesis has above all been educational and engaging, as well as providing excellent training in working with an extensive project. Hopefully the thesis will enrich the subject area and provide a foundation for further analysis of the topic.

The authors would like to extend a big thank you to supervisor Atle Øglend for good guidance. As well as Harald Olsnes and Bjørn Marius Larsen at Aker BP for useful input and for taking the time to answer questions and provide access to data.

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June 2023, Stavanger

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Abstract

The European gas market has undergone substantial transformations and fluctuations in recent years, resulting in a decoupling in natural gas prices between trading hubs in 2022. Specifically, the Title Transfer Facility (TTF) in the Netherlands and the National Balancing Point (NBP) in the United Kingdom experienced large deviations. Utilization of liquefied natural gas (LNG) as a supplement to pipeline imports has increased significantly after discontinuation of gas trade between Europe and Russia. The European gas market experienced constraints in supply and demand due to various factors, leading to elevated prices. The United Kingdom encountered a significant storage capacity crisis, necessitating the export of surplus natural gas to the Netherlands.

The study of the natural gas market implemented a combination of qualitative and quantitative methodologies, including the utilization of Vector Auto-Regression (VAR) models, correlation-, cointegration-, and Granger causality analysis.

As Europe sought to replace the Russian gas supply with LNG, the Netherlands' relatively low LNG import capacity hindered the country to fully exploit the expanded use of LNG. Furthermore, pipeline maintenance on the Netherlands' connections to Norwegian gas, coupled with the surplus gas in the UK, resulted in capacity constraints on the direct pipeline connection between NBP and TTF. The fundamental economic theory of supply and demand demonstrated how the shortage of supply in the Netherlands generated higher prices for natural gas in the country. The exhaustion of storage facilities in the UK contributed to limits on arbitrage, causing downward price spikes in the NBP compared to TTF, as predicted by storage theory. Data analysis revealed that although the European gas market traditionally functioned as a highly integrated and efficient market, it became disjointed and less efficient in 2022, thereby increasing market predictability.

The study's outcome was accordant to economic theories and findings from the conducted analysis. The findings emphasize the necessity for diversified natural gas supply sources, adequate storage capacity, and efficient transportation infrastructure to ensure a reliable and sustainable gas supply in Europe. In practical terms, the analysis results can potentially assist energy traders and analysts in making more informed decisions regarding gas contracts. By monitoring gas flow through connecting pipelines and analysing storage levels, they can make more accurate predictions about future price movements and adjust their trading strategies accordingly.

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Abbreviations

ADF – Augmented Dicky Fuller

AIC - Akaike Information Criterion

BBL – Balgzand Bacton Line

BCM – Billion cubic metres

BEIS - Department for Business, Energy and Industrial Strategy

BIC - Bayesian Information Criterion

IEM – Internal Energy Market

EU ETS – European Union Missions Trading System

FPE - Final Prediction Error

IDE - Integrated development environment

LNG – Liquid natural gas

LOP – Law of One Price

NBP – National Balancing point

OECD - Organization for Economic Co-operation and Development

OLS - Ordinary Least Squares

RSS – Residual Sum of Squares

TTF – Title Transfer Facility

UK – United Kingdom

UK ETS – United Kingdom Emissions Trading System

VAR – Vector Autoregression

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1

Introduction

The summer of 2022 has been the most volatile season ever in European energy markets. The European Union imported 83% of its natural gas in 2021, with 40% coming from Russian pipelines. However, following Russia's invasion of Ukraine, gas imports from Russia to Europe were greatly reduced. As a result, energy costs internationally skyrocketed (European Commission, n.d.). The consumption of gas by the 27 countries in the European Union in 2021 was 412 bcm (412 trillion litres), with the primary uses of gas being for power generation, household heating, and industrial processes. Heating homes is a significant use of gas, with more than 30% of households in the EU utilizing gas for this purpose (European Council, 2023).

By 2027, the European Union intends to completely phase out the use of natural gas from Russia (European Council, n.d.). To compensate for this decline in supply to the EU, there has been a notable increase in imports of liquified natural gas (LNG), primarily from the United States. This has resulted in abnormally high gas prices and has led Europe into the most severe energy crisis ever experienced (European Commission, n.d.). Another significant shock occurred when there were explosions, that resulted in ruptures and gas leaks, in both the Nord Stream 1 and 2 pipelines (Tsygankova et al., 2022).

A vital objective of the EU's energy union strategy is to ensure that all member states have access to liquid natural gas markets. This objective recognizes that LNG has the potential to enhance the diversity of gas supply and bolster energy security throughout the EU. Countries that have access to LNG import terminals and liquid gas markets in Europe are now better prepared to withstand potential gas supply disruptions, compared to those reliant on a single gas supplier (European Commission, n.d.).

The many different factors and world events affecting the European gas market in recent years have had a very interesting result on the market itself. The gas prices between the different markets have changed drastically. Prices have risen dramatically in all of Europe, but even more interestingly, there has been large deviations between the different gas trading hubs (Refinitiv, n.d.a).

1.1 Problem Description

The gas market in Europe has been greatly influenced by unforeseen events the last couple of years. Unpredictable geopolitical conflicts arose, in addition to the Covid-19 pandemic, and was followed by a volatile market situation in Europe. During April 2022, the UK NBP gas prices experienced a significant discount of over 30 €/MWh compared to the TTF prices in Netherland. Usually, the adjacent hubs trade within a narrow range of 1-2 €/MWh (Refinitiv, n.d.a).

The thesis aims to:

- ***Analyse the European gas market to find possible drivers of the gas price deviation between NBP and TTF in 2022.***

The first part consists of analysing the European gas market to identify the drivers of gas price deviations, using both qualitative and quantitative data. The two central trading points for gas, NBP and TTF respectively, will be used to analyse the European market situation. Following the results of the research, the second part of the study involves a discussion on possible drivers to the deviation and how future gas markets may unfold.

1.2 Limitations

The focus of the thesis is exclusively on the European gas market. The TTF and NBP trading hubs were used to asses the market in Europe, as they are the most commonly used trading hubs in the UK and continental Europe. The research question touches upon reasons for higher gas prices in Europe, but focuses on the divergence between NBP and TTF. Other European hubs such as PVB (Spanish hub) and PEG (French hub) have also experienced discount in gas price regarding to TTF, but NBP has been used as reference point (Essajee, 2022).

1.3 Structure of Thesis

The structure of the report is intended to enhance the credibility and appeal of the thesis. The report comprises several chapters, each of them serving a specific purpose in the research process.

The background chapter constitutes the second section of the report and is devoted to contextualizing the study by providing an overview of the natural gas markets and trading in the Netherlands and the UK. This chapter is instrumental in establishing the relevance and importance of the research question that will be addressed in the following chapters.

The third chapter is dedicated to presenting the theoretical framework that underpins the study. Specifically, this section provides a summary of the economic concepts and theories that are relevant to the research. Theoretical considerations form an essential component of the research, as they enable the formulation of hypotheses and the identification of key variables that will be examined in subsequent chapters.

The methodology chapter follows the theoretical framework and describes the research methods and techniques used in the study. This chapter provides a detailed account of how the research question is addressed, the construction of variables, and the statistical techniques utilized in the analysis.

The data chapter constitutes a crucial section of the thesis report, as it presents the empirical data used in the research, including the selection of data sources. The data is displayed in various formats, including tables and plots, to facilitate the interpretation of results and the identification of patterns and trends.

The analysis chapter is the section where the results of the quantitative analysis are presented. The chapter provides a detailed account of the statistical techniques employed and the findings obtained.

The discussion chapter follows the analysis chapter and aims to provide a critical evaluation of the results obtained in the previous sections. Specifically, this chapter combines the quantitative results with the qualitative information presented in the background chapter, integrating the economic theory.

The report concludes with a final chapter dedicated to summarizing the main findings of the study and outlining the implications of the research. Additionally, this chapter highlights the limitations of the study and suggests avenues for future research.

2

Background

2.1 Production of Natural Gas

Natural gas is a fossil fuel predominantly comprised of methane, a colourless and odourless gas. It is typically extracted from subterranean reservoirs that are frequently found adjacent to oil deposits via drilling procedures. It serves as an energy source for various purposes, such as heating homes, generating electricity, and propelling vehicles. Additionally, it plays a significant role in industrial processes, including the manufacturing of fertilizers and chemicals (Turgeon and Morse, 2023).

Natural gas plays an essential role in the global energy mix and is sourced from numerous locations worldwide. The preeminent natural gas producers are the United States, Russia, Iran and China, which collectively contribute to over fifty percent of the world's natural gas production. Furthermore, noteworthy natural gas producing nations include Qatar, Canada, Australia, Saudi Arabia, Norway, and Algeria. It is worth noting that the location of natural gas production constitutes a critical element of the global energy landscape as it affects natural gas market dynamics regarding price, supply, and demand (Pistilli, 2022).

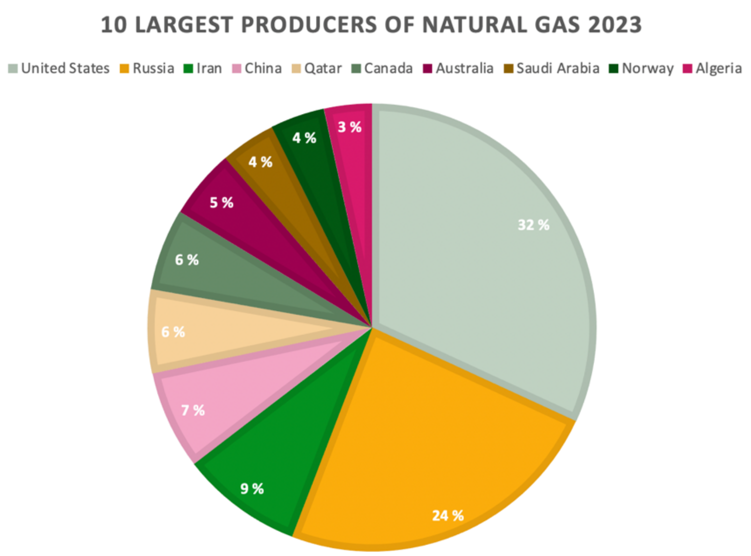

Figure 1. Each countries percentage of the total production from top 10 producers.

2.2 Transportation of Natural Gas

The energy source is transported in several forms depending on the distance travelled and the volume to be transported. The most common methods of transportation are through pipelines or via LNG (METGroup, 2020).

2.2.1 ***Pipeline***

Natural gas pipelines can extend for thousands of kilometres and constitute a critical element of the energy infrastructure. The network of pipelines facilitates secure and effective transportation of natural gas from the production site to end-users. These pipelines, typically composed of steel, are subterranean and follow the terrain contours to minimize ecological impacts. Compressor stations play a pivotal role in maintaining requisite gas pressure for pipeline traversal, while metering and regulating stations govern gas flow and pressure. Additionally, safety measures are installed along the pipeline to avert mishaps and curtail environmental consequences. A well-maintained pipeline system enables natural gas transportation over vast distances, offering a reliable and cost-effective energy source for a diverse range of applications. The use of gas pipelines is an important factor in meeting supply and demand for several countries. If there where to appear constraints on the pipelines, meaning that a country needs more supply than the maximum capacity of the pipeline, this could create shortage of supply (METGroup, 2020).

2.2.2 ***Liquefied Natural Gas***

LNG is natural gas cooled down to -162 degrees Celsius. At this temperature natural gas becomes liquid, which is advantageous, because its volume is reduced by up to 600 times. LNG can therefore be stored and transported more easily and to greater effect than with regular natural gas. This makes it easier to reach more remote locations and to provide more energy to larger regions. LNG can be transported around the world and across continents by special refrigerated transport ships (Equipe GNPW Group, 2021).

LNG is an excellent substitute for conventional fuels, like diesel, gasoline and ethanol. This is because it contributes to environmental sustainability by considerably reducing CO2 emissions and also reducing fuel costs (Equipe GNPW Group, 2021). The primary component of LNG, methane gas, has an air flammability range of 5% to 15%. This results in it being even more efficient than propane. LNG cannot ignite, making it safer than in its gaseous form (Freshteam, n.d.).

Figure 2. LNG Terminals in the UK.

The UK's LNG import terminals are shown in figure 2. There is two at Milford Haven in Wales: Dragon and South Hook, and there is also Isle of Grain in the south-east of England. According to the "Department for Energy Security & Net Zero" the combined regasification capacity in the UK is 48 bcm per year in 2022 (Andrewes and Mettrick, 2023).

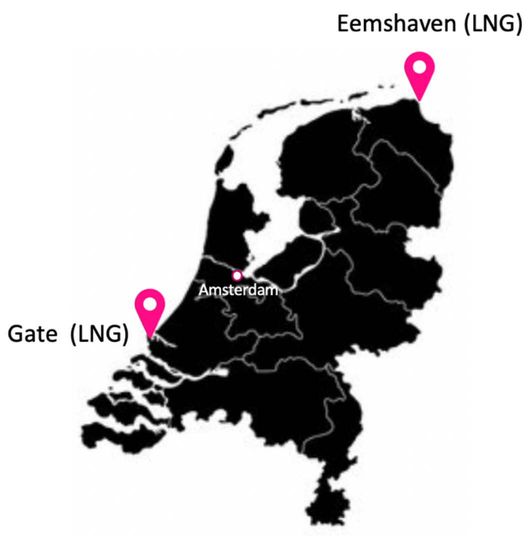

Figure 3. LNG terminals in the Netherlands.

The Netherlands' LNG import terminals are shown in figure 3. The largest LNG terminal in the Netherlands is called Gate in Rotterdam, which has a capacity of 16 bcm and is expected to be expanded to 20 bcm by 2025. The second LNG terminal is Eemshaven, which was built in 2022 to cut the Netherlands dependencies on Russian gas, has a capacity of 8 bcm (Reuters, 2023b).

The LNG import terminals are used for regasification, which is the process of reheating LNG to covert it back into a natural gas state. The regasification capacity is the maximum amount of LNG converted to gas within a certain time period and is determined by the technology and design of the LNG terminals (Eikens, 2021).

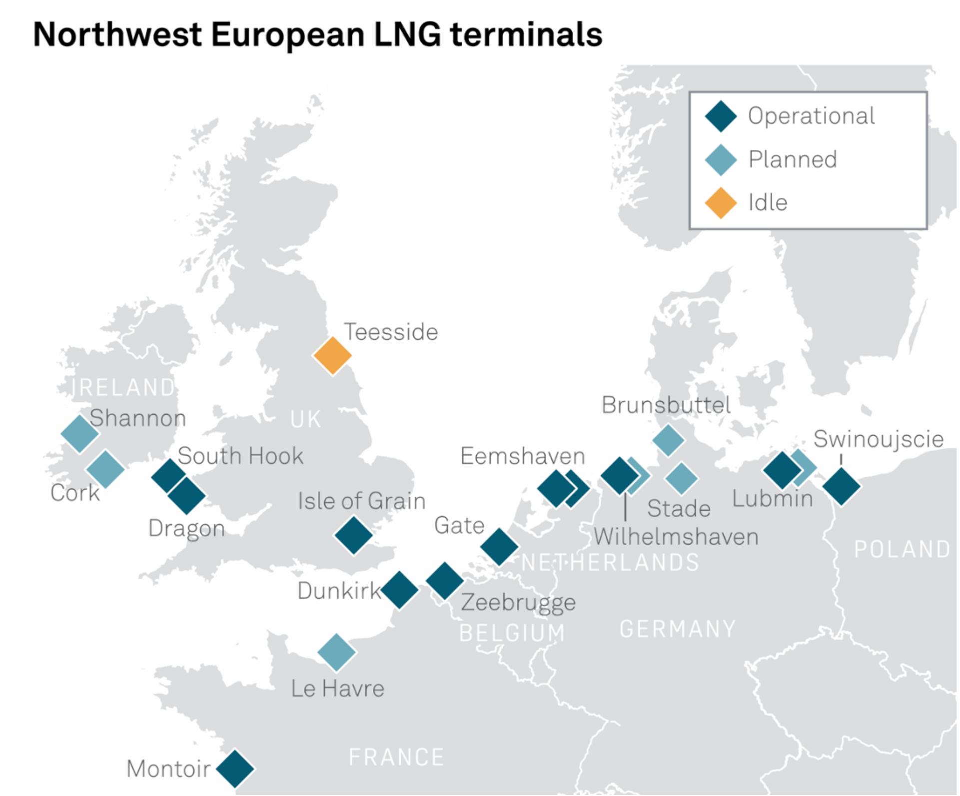

Figure 4. Northwest European LNG Terminals (S&P Global Commodity Insights, 2023).

There is an estimated volume of 7,177 trillion cubic feet (203,230 bcm) of proved reserves of gross natural gas in the world. At the current consumption rates, this would mean the LNG will last for around 200 years. Due to new techniques and low-cost methods for unconventional gas extraction there will be a surplus of LNG reserves for the foreseeable future (SHV ENERGY, n.d.). Figure 4 shows both the operational as well as the planned

LNG terminals in Northwest Europe, as of January 2023. The number of planned LNG terminals indicate that LNG is going to be an even more significant part of the future European gas market.

2.3 Gas Situation in The Netherlands/Europe

The gas market in Europe is highly developed and liberalized, enabling gas suppliers to sell gas to consumers across borders (METGroup, 2020). In 2021, the Netherlands imported 6 bcm of Russian pipeline gas, which constituted for approximately 13% of the country's total gas supply. After the gas trade between Russia and Europe was discontinued, the Netherlands faced a huge challenge meeting its gas demand (Elijah, 2023).

The Netherlands, alongside the other EU member states, ceased its import of Russian gas following the Russian invasion of Ukraine. To be able to compensate for the loss in gas supply, Europe sought to utilize more LNG. The Netherlands facilitated an expansion to the import capacity of its Gate terminal, which added 4 bcm of interruptible capacity (Elijah, 2023). An additional regasification terminal in Eemshaven was also commissioned in September 2022, adding another 8 bcm to the country's maximum capacity. This means that the Netherlands had a maximum regasification capacity of 24 bcm per year at the end of 2022. (Reuters, 2023a) In 2023, the Dutch government announced plans to further increase LNG regasification capacity to a total of 30 bcm by 2026, aiming to further reduce its reliance on fossil fuel imports from Russia (Elijah, 2023).

The increase in regasification capacity does not necessarily imply that the Netherlands has fully offset the loss of Russian pipeline supplies. The higher LNG imports were also necessary to compensate for the decline in pipeline supplies. In parts of 2022, Norway, which surpassed Russia as the primary gas supplier to Europe, due to the conflict in Ukraine, had to significantly reduce its gas exports to Germany due to extensive maintenance activities. This led to more Norwegian gas being exported to the UK, creating further constraints to the Netherlands gas supply (Buli, 2022). Additionally, not all the LNG arriving at Dutch terminals is used for domestic consumption, as a portion is regasified and exported to Germany and Belgium (Elijah, 2023).

2.3.1 ***The Groningen Gas Field***

The Netherlands has, since they discovered the huge Groningen gas field in 1959, been relying on this as their main source of natural gas and have historically been an exporter of the resource. The size of the field was estimated to be 2800 bcm. The discovery of the Groningen field did greatly improve the economy of the country and helped make The Netherlands a leading country within the natural gas industry (Van Loo, 2018). The field was for a long time one of Europe's main sources of domestic gas supply, but because of reoccurring earthquakes and seismic activity, production had to be lowered gradually. The Dutch has planned a complete shutdown of the Groningen field by 2026, even though there has been pressure to keep operating the field because of the Russian invasion of Ukraine (Szabo, 2023).

Since production from the Groningen field has been gradually lowered over a long period, the closure of the field does not significantly affect the TTF prices and are not considered as supply shock to the markets, according to Dr. Amin Shokri at GECF. The share of the Groningen gas field represented about 2% of the total volume of traded natural gas in TTF Hub. This small percentage has been replaced by other supplies from the market, like LNG and pipeline gas (Shokri, n.d.). The Netherlands in 2022 relies on the many smaller natural gas fields owned by the country, as well as importing natural gas from Europe (Zaken, 2022).

2.3.2 ***TTF***

The Title Transfer Facility (TTF) serves as the virtual trading point for natural gas in the Netherlands. Due to the country's central location in Europe, abundant natural gas reserves, and strong connections, the country has emerged as the primary hub for natural gas exports on the continent. The Netherlands has developed an extensive pipeline infrastructure that enables the transportation of gas across the country and beyond, establishing TTF as one of the most significant trading centers in Europe for futures, physical trades, and exchange trades. Similar to the transatlantic benchmark, Henry Hub in the US, TTF is widely used by traders as a reference for natural gas prices (Spilker, 2019).

The Netherlands benefits from its favorable location near residential and industrial customers in Germany, France, Belgium, and Luxembourg, which provides it with a competitive advantage. Furthermore, its pipeline connectivity with Norway and the United Kingdom, via the North Sea, further strengthens its position. The investments made in the natural gas pipeline infrastructure have yielded positive results, enabling the TTF market to function efficiently, irrespective of whether the Netherlands is a net exporter or importer. By effectively utilizing its existing infrastructure, the country maintains its prominent position in both scenarios (Spilker, 2019).

The volume of gas traded through TTF surpasses the combined total of all other continental European gas trading platforms. Each day, more than 100 gas dealers and financial parties participate in the exchange of substantial gas volumes on the virtual platform. TTF owes its success to its facilitation of gas trading and its commitment to forging new connections with other networks. Furthermore, TTF operates transparently and provides cross-border transportation capacity (Gasunie, n.d.).

*2.3.3 **European Storage***

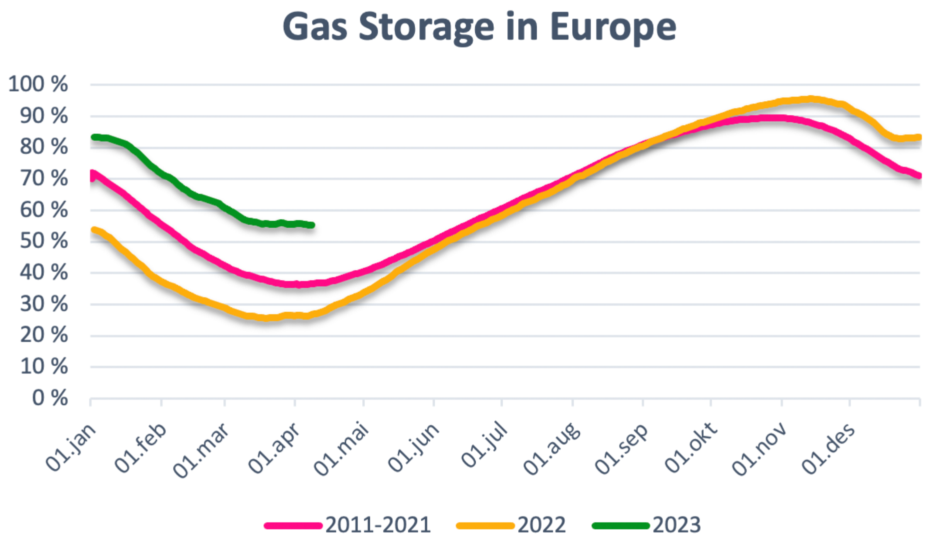

Figure 5. European gas storage levels in 2022 and 2023 compared to 2011-2021 average.

Following the conflict in Ukraine, European countries raced to reduce their reliance on Russian gas, which resulted in large spikes in the natural gas prices in Europe. In March 2022 the storage levels were at 26%, quite low compared to the 2015-2021 average. However, European gas storage levels filled up during the latter part of 2022, signalling positive news for gas supplies amidst the ongoing energy crisis. The significant increase in gas reserves is attributed to the region's push for storage expansion in anticipation of high demand, especially during the winter season. The boost in gas stocks is expected to cushion the impact of potential supply chain disruptions or unexpected demand surges. The storage levels in Europe will end winter of 2023 between 45-61%. This average of 55% surpasses the previous record of 54% in 2020. Overall, the current gas storage levels in Europe offer a measure of stability and confidence in the security of energy supplies (Taaffe-Maguire, 2023).

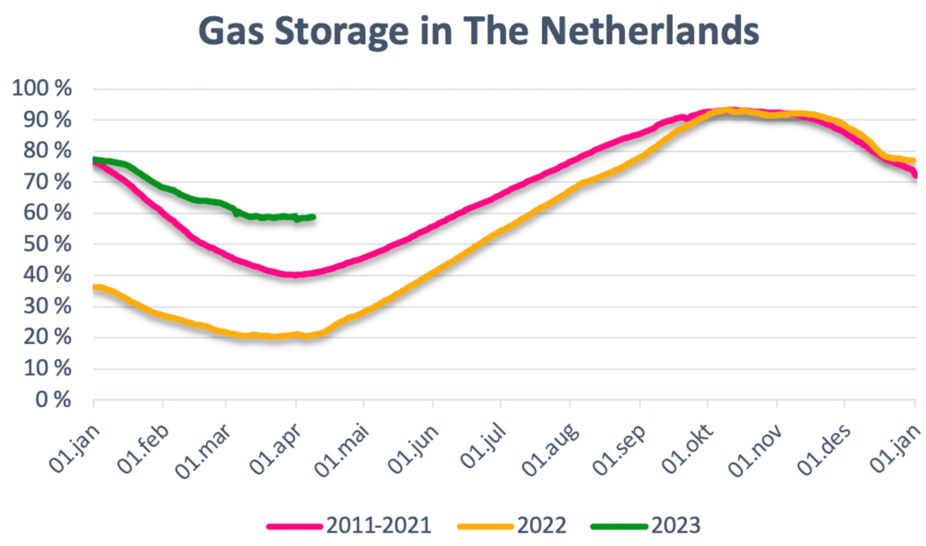

Figure 6. The Netherlands' gas storage levels in 2022 and 2023 compared to the 2011-2021 average.

In comparison to the entirety of Europe, the gas storage situation in the Netherlands exhibited a similar trend but was marked by notably lower levels in 2022. Specifically, during March 2022, the gas storage level in the Netherlands reached a mere 20%, in contrast to the overall European average of 26%. Analogous to the overall European context, the gas storage situation in the Netherlands began to stabilize during the latter part of the year and the storage levels for the year 2023 have surpassed the average recorded over the past decade (Refinitiv, n.d.c).

2.4 Gas Situation in the UK

The drop in Russian oil and natural gas exports to Europe, resulting from Russia's invasion of Ukraine in late February 2022, has also driven up gas prices in the UK. The Office for National Statistics reported that UK natural gas prices rose by almost 96% between July of 2021 and July of 2022. Deutsche Bank's analysis predicted that annual consumer price inflation for gas and electricity in the UK would soar to an average of around 80% in 2022 (Cooban, 2022).

The UK has traditionally been self-sufficient in gas up until the early 2000s and were actually a small gas exporter. However, production declined as old fields got depleted, but demand has not. The UK has maintained a status of being a net energy importer since 2004. (Andrewes and Mettrick, 2023). Despite not being a significant exporter of natural gas, the

UK engage in the re-exportation of natural gas to the continent through both pipeline networks and liquefied natural gas terminals, contingent upon prevailing market conditions. This suggests a degree of flexibility in the country's natural gas trade, allowing for potential adjustments in response to market dynamics and demands (EIA, 2022).

As of 2021, the UK's offshore gas production was 31.15 bcm and provided around 43% of UK's total gas needs (EIA, 2022). This makes natural gas the second-largest source of energy in the United Kingdom after oil, accounting for approximately 34.8% of the country's total energy consumption. The rest of the gas came from various countries, with Norway, Qatar, the USA and Russia contributing the most (BEIS, 2022).

In 2022, a significant surge in imports, made a new annual record high. This notable increase of 10 percent to 2021 can be largely attributed to the unprecedented levels of LNG imports. Norway emerged as the primary supplier of pipeline imports, while the pipelines connecting the UK to Belgium and the Netherlands witnessed a significant decline in imports, primarily due to their increased usage for exporting purposes (Department for Energy Security & Net Zero, 2023).

2.4.1 ***NBP***

The National Balancing Point, commonly known as NBP, is a virtual trading platform for the sale of UK gas supplies. All gas within the national transmission system is priced at NBP gas levels, optimizing trading (Powerstar, n.d.). The National Gas Transmission system forms the fundamental infrastructure of the UK's energy system and ensure the efficient distribution of gas across all regions of the nation according to demand (National Gas, n.d.). The NBP gas market enables broad participation, from various stakeholders, to buy and sell natural gas, allowing prices to be set for same day delivery, day-ahead, months, quarters, summers, winters and annual contracts (Powerstar, n.d.).

The NBP serves as both the price and delivery point for the ICE natural gas futures contracts. As a result, it exerts a substantial impact on the pricing of natural gas futures in the UK and various regions of Western Europe. The physical transportation of gas within the system falls under the purview of National Grid, while buyers and sellers solely bear responsibility for the quantities of gas entering or leaving the NBP system, without any involvement in the transportation process (Powerstar, n.d.).

2.4.2 ***Brexit***

After the UK's withdrawal from the EU on January 1, 2021, there have been several changes in terms of gas trading in the UK. One significant change is the introduction of a new UK Emissions Trading System (UK ETS) to replace the EU Emissions Trading System (EU ETS), which the UK was previously a part of. The UK ETS operates independently of the EU ETS, has its own rules and regulations for emissions trading, and is designed to help the UK achieve its climate change goals by putting a price on carbon emissions and incentivizing businesses to reduce their greenhouse gas emissions (Ralston, 2021).

Another change is that the UK is no longer a part of the Internal Energy Market (IEM), which was established by the EU to promote the free flow of electricity and gas across member states. This means that the UK's gas trading market is now separate from the EU's market and gas trading between the UK and the EU is now subject to new rules and regulations. This includes the UK's new energy trading system, which requires companies trading gas across borders to register with the UK energy regulator, Ofgem. The UK has also introduced new customs procedures for the import and export of gas, which can impact the flow of gas between the UK and the EU (Rahman, 2021).

The changes made in terms of gas trading after Brexit have created a new regulatory environment that businesses must navigate in order to continue trading gas between the UK and the EU. Despite the impact on the UK economy, reports suggests that Brexit does not appear to be a significant factor in the energy crisis in 2022 (Cooban, 2022).

2.4.3 ***UK Storage***

The UK has traditionally had relatively low storage capacity for natural gas compared to other European countries, as displayed in figure 7. High storage capacity was not needed, because the country had gas fields in the north-sea able to cope with demand rises quite easily. Traditionally this would have kept less than a month's worth of storage (Refinitiv, n.d.c). That however did decrease in 2018 with the decommissioning of the "Rough Gas storage facility", which had a capacity of about 2.8 bcm (Offshore-mag, 2022).

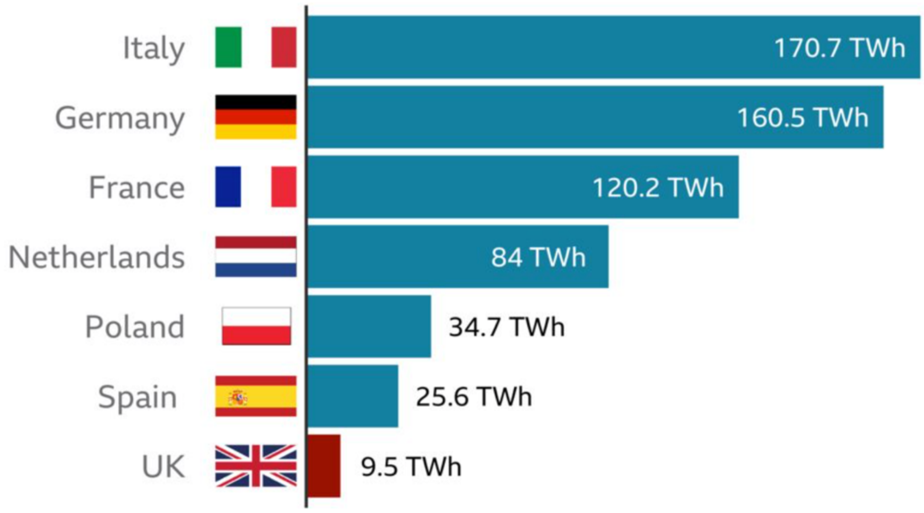

Figure 7. UK's storage capacity compared to other European countries (Peachey, 2021).

In 2022 the "Rough gas storage facility" re-established some of its capacity, raising UK storage capacity by 50% (Centrica, 2022). However, the UK continues to exhibit some of the lowest natural gas storage capacities in Europe, with a mere 9 days of storage as opposed to Germany's 89 days, France's 103 days, and the Netherlands' 123 days, should all gas supplies disappear. In spite of that, the Rough Facility's flexibility enabled the storage of less expensive natural gas in anticipation of winter 2022 (Mavrokefalidis, 2022).

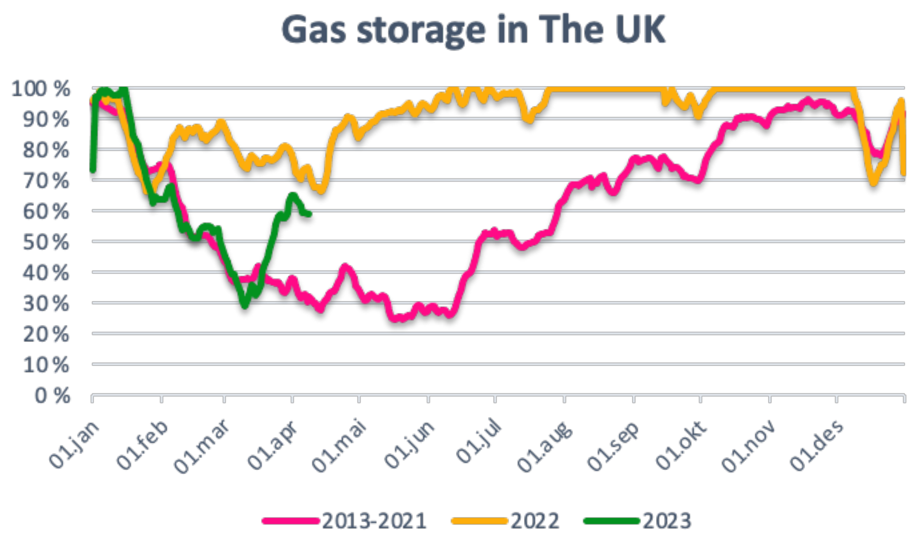

Figure 8. European gas storage levels in 2022 and 2023 compared to the 2011-21 average.

Gas storage in the UK was close to 100% during large parts of 2022, as shown in figure 8. Even though the storage was full, the limited capacity of the UK resulted in a continued need for natural gas in the country (Refinitiv, n.d.c). Nonetheless, natural gas storage remains a vital aspect of ensuring energy security and stability in both the UK and Europe, and focused endeavours are being undertaken to enhance storage capacity in the UK to maintain consistent supply and demand dynamics (American Gas Association, 2016).

2.5 Gas Flow and Market Connections

Gas traders buy and sell gas on a spot basis and through long-term contracts, with prices mainly determined by market conditions such as weather, gas storage levels, and the availability of gas supplies. The UK has become increasingly reliant on imported gas in recent years, as domestic gas production has declined, leading to an increase in gas imports from Europe. Resulting in a more interconnected gas market between the UK and Europe. The trade of natural gas is vital for both entities, providing a reliable source of energy and maintaining the competitiveness of the gas market in Europe (Donnarumma, 2022).

By linking the gas markets in the UK and continental Europe a critical pathway for the transportation of natural gas is established, enabling market participants to access a broader range of gas supply sources and trading opportunities. This connection, in turn, enhances the fluidity of gas trading across these markets and reinforces energy security in the region (Parliament UK, n.d.).

Europe has a highly developed and interconnected natural gas market that comprises of a vast network of pipelines and LNG terminals. The continent has several significant pipelines that connect different regions. The Interconnector, BBL pipeline and the Langeled pipeline are important natural gas pipelines connecting the UK and continental Europe (Entsog, n.d.b).

2.5.1 ***LNG***

In 2021, before the Russian invasion, Spain had the fourth largest LNG regasification capacity in the world with around 62 bcm. The UK and France is also high on this list having the seventh and eight highest LNG regasification capacity, respectively worldwide. The UK having a capacity of 49.2 bcm and France having a capacity of 34.7 bcm (Aizarani, 2023). The Netherlands in comparison only had a regasification capacity of 12 bcm, leaving the TTF gas market vulnerable compared to the other large European markets (Global Energy Monitor, 2023). The Netherlands did make improvements to their regasification capacity, but was already far behind its peers, and could not take advantage of LNG in the same way when the Russian export to Europe suddenly stopped (Reuters, 2023b). As is seen in figure 9, the Netherlands did import significantly smaller amount of LNG than the UK in the period 2020-2023.

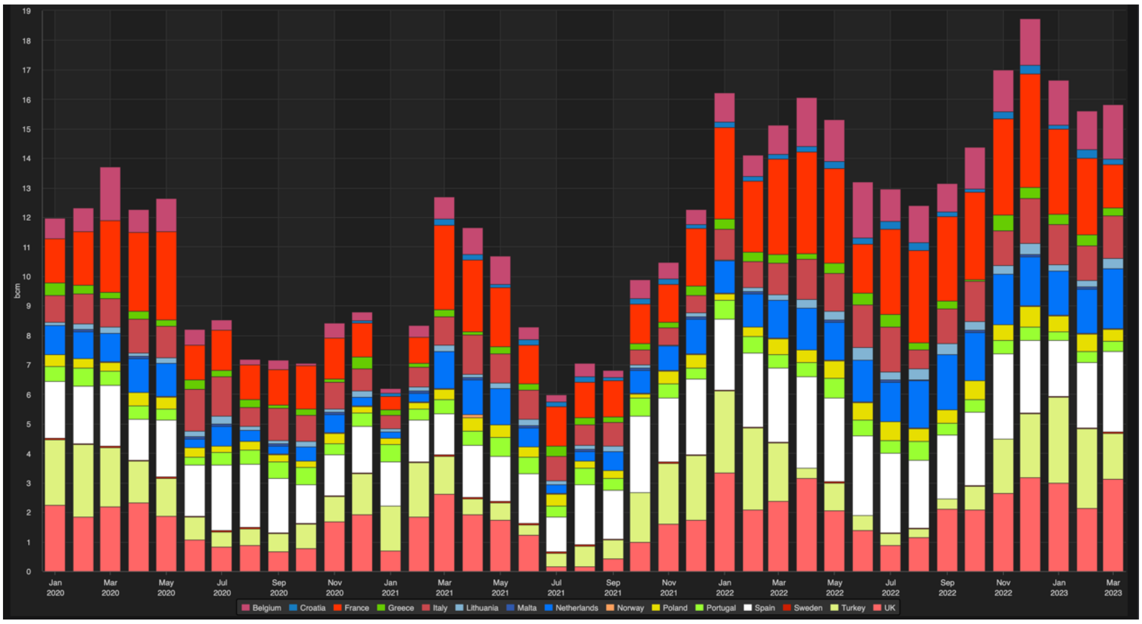

Figure 9. LNG imports by country 2020 – 2023 (Refinitiv, 2023).

Following the sudden extreme demand for LNG in Europe, import restrictions emerged throughout North-Western Europe due to limited regasification capacity. As a result of these limitations, spot prices for LNG cargoes significantly dropped to large discounts to TTF (Essajee, 2022).

2.5.2 ***BBL***

Figure 10. BBL pipeline between the UK and the Netherlands (Entsog, n.d.b).

The BBL pipeline serves as a crucial link connecting the NBP to the TTF. The BBL pipeline is directly connected to the NBP through a gas interconnection facility at Bacton, enabling the import capacity of 494 GWh natural gas per day into the UK from the TTF. The pipeline was established in 2006 and runs 235 km, exporting gas from the continent to the UK. It is directly connected to the TTF through the Balgzand interconnection point, and from 2019 the pipeline was upgraded to facilitate export of 168 GWh natural gas per day from the UK to the Netherlands (BBL Company, n.d.).

2.5.3 *The Interconnector*

Figure 11. Interconnector between the UK and Belgium (Entsog, n.d.b).

The Interconnector pipeline functions as a vital link between the gas networks of the UK and continental Europe, facilitating the import and export of natural gas based on prevailing market conditions and supply availability. It runs from Bacton in the UK to Zeebrugge in Belgium and possesses an export capacity of 20 bcm per year for the UK and an import capacity of 25.5 bcm per year for the UK. This bidirectional capability enables the pipeline to contribute towards balancing the gas supply and demand between the two regions, thereby ensuring a more stable and reliable gas supply. Additionally, the Interconnector pipeline serves as an important instrument for enhancing market efficiency and competitiveness by enabling market participants to access a wider range of gas sources and capitalize on price differentials between the two regions (Fluxys, 2023).

2.5.4 ***Langeled***

Figure 12. Langeled pipeline between the UK and Norway (Entsog, n.d.b).

The Langeled pipeline has played a central role in the European energy landscape since its completion in 2006. Spanning a distance of 1166 kilometres from Nyhamna in Norway to Easington in the United Kingdom. Its capacity to transport 70 million cubic metres of natural gas per day makes it a vital component of Europe's energy infrastructure, contributing significantly to the stability of natural gas supply and demand across the continent (Gassco, n.d.).

According to the data from the UK's Department for Business, Energy and Industrial Strategy (BEIS), the pipeline imported 36.34 bcm of natural gas in 2021, accounting for around 63% of the UK's total natural gas imports that year. This shows how important the connection to Norway is for the UK (BEIS, 2022). The Langeled pipeline have been providing a direct and reliable connection between the two countries and reducing the need for gas to be transported by ship or other means. With demand for natural gas expected to continue to increase in the coming decades, the pipeline is likely to remain an important part of the European energy landscape for many years to come (Asche, Osmundsen and Sandsmark, 2006).

3

Theory

The theory chapter provides a basis for understanding the mechanisms that drive the phenomena under investigation. The present study utilizes established economic theories as a lens through which to analyse and interpret the empirical findings related to the natural gas market. Specifically, the theoretical framework employed in this study draws upon principles of supply and demand, market efficiency, and the role of storage in energy markets. These theories are essential to understanding the dynamics of natural gas markets and provide a framework for identifying the drivers of price deviation between NBP and TTF.

3.1 Supply and Demand

The theory of supply and demand constitutes a fundamental concept in economics that provides an explanation of how the prices of goods and services are established in a market economy that operates without any interventions. This principle is based on two interrelated forces, namely supply and demand (Whelan and Msefer, 2003).

The concept of supply refers to the volume of goods or services that manufacturers are willing and able to sell at a given price. The law of supply asserts that as the price of a commodity increases, the quantity supplied of that commodity will increase, holding other factors constant. In contrast, as the price of a commodity decreases, the quantity supplied of that commodity will also decrease (Whelan and Msefer, 2003).

The concept of demand refers to the amount of a product that consumers are willing and able to purchase at a particular price. The law of demand posits that as the price of a product increases, the quantity demanded of that product will decrease. Conversely, as the price of a product decreases, the quantity demanded of that product will increase (Whelan and Msefer, 2003).

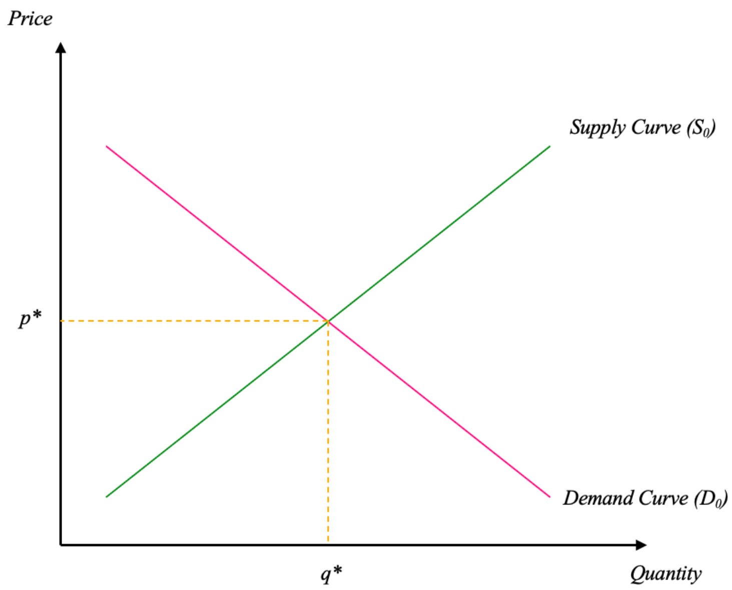

Figure 13. Illustration of supply and demand principle.

The equilibrium price and quantity of a good or service in the market are determined by the intersection of the supply and demand curves. If the price of a good or service is below the equilibrium level, there will be an excess demand that will lead to a shortage, resulting in a price increase until the equilibrium level is reached. Conversely, if the price of a good or service is above the equilibrium level, there will be an excess supply that will lead to a surplus, causing the price to decrease until the equilibrium level is attained (Whelan and Msefer, 2003).

Changes in supply and demand can result in shifts in the respective curves, leading to alterations in the equilibrium price and quantity. For example, an increase in consumer income can trigger an increase in demand, which in turn can cause a rise in the equilibrium price and quantity. On the other hand, a decrease in production costs can lead to an increase in supply, resulting in a decline in the equilibrium price and an increase in the equilibrium quantity (Whelan and Msefer, 2003).

Various factors influence the supply and demand of natural gas, including the level of natural gas reserves, the cost of production, availability of storage, transportation and distribution infrastructure, price of natural gas relative to other commodities, the level of economic activity, weather conditions, government policies, environmental regulations, and geopolitical events (Eia, 2016).

The intersection of the supply and demand curves determines the equilibrium price and quantity of natural gas in the market. If the supply of natural gas surpasses the demand, there will be an excess supply leading to a price reduction until it reaches the equilibrium level. Conversely, if the demand for natural gas is higher than the supply, there will be an excess demand that leads to a price increase until it attains the equilibrium level. The factors creating fluctuations in supply and demand are therefore also affecting the price levels of natural gas significantly. (Eia, 2016).

3.2 Storage Theory

Storage theory is a theoretical framework that seeks to explain the relationship between current and future prices of commodities, with the objective of understanding the dynamics of supply and demand for these goods. The theory is based on the premise that producers and consumers can store commodities, such as oil, wheat, or natural gas, to smooth out fluctuations in supply and demand over time (Williams and Wright, 2005).

At the core of storage theory is the intertemporal pricing condition, which postulates that the price of a commodity today should equal the sum of its expected future price and the cost of storage. This principle acknowledges that the decision to store a commodity is contingent on both the expected future price and the cost of storage, and these factors influence the current price. The intertemporal pricing condition model:

$$\frac{1}{1+r}E_t(P_{t+1}) = P_t + m(I_t)$$

$\frac{1}{1+r}$ represents the market discount factor. $\mathrm{E_t}(\mathrm{P_{t+1}})$ is the expected next period spot price given all available information. $\mathrm{P_t}$ is the current spot price. $\mathrm{m}(\mathrm{I_t})$ shows the marginal inventory cost given inventory level $\mathrm{I_t}$ (Williams and Wright, 2005).

Additionally, storage theory emphasizes the concept of limits to arbitrage, which refers to the constraints that traders may encounter when trying to exploit price discrepancies between different markets over time. These limits may arise due to transaction costs, capital constraints, or information asymmetries, among other market frictions. The presence of limits to arbitrage may result in persistent price differentials, which may reflect disparities in storage costs, transportation expenses, or other factors. When there are limits of arbitrage, the intertemporal pricing condition does not hold. If there is a stock-out, there is no reason why the condition should hold. This is also true in the situation where the storage capacity is full. Both cases would lead to a volatile market situation, where a stock-out would lead to an upwards price spike, and a full storage capacity situation would lead to a downwards price spike (Williams and Wright, 2005).

In essence, the interplay between the intertemporal pricing condition and limits to arbitrage shapes the price dynamics of stored commodities. For instance, if the expected future price of a commodity exceeds the current price plus storage costs, this creates an incentive for traders to purchase the commodity and store it until the future price is realized. However, the presence of limits to arbitrage may impede traders from fully capitalizing on this arbitrage opportunity, leading to persistent price differentials and opportunities for profit for other traders who can overcome these limitations (Williams and Wright, 2005).

3.3 Market Integration

Market integration refers to the situation were identical products, that flow between different markets, should in theory have the same price. This would indicate a perfect market integration and that the "law of one price" (LOP) holds. The LOP states that for an identical product, the price differences between two locations and/or the difference in quality should be equal to the transport costs (Asche, Osmundsen and Tveterås, 2000).

Natural gas as a commodity should in theory be bound to "the law of one price" when looking at the UK and the Netherlands market. Natural gas is a near identical commodity in between the two countries. The transportation cost, between the two markets, appears when transporting natural gas through the BBL pipeline (Asche, Osmundsen and Tveterås, 2000).

The natural gas market in Europe, more specifically the UK and the Netherlands, has in recent history been a strongly integrated market. Large price deviations are rare and the difference in price reflects the cost of transport and quality differences. The integration of trading hubs and pipeline systems between the UK and the Netherlands has greatly improved the fluidity of gas trading between the countries (Asche, Osmundsen and Tveterås, 2000).

Market integration model:

$$\ln(P_{it}) = \beta_0 + \beta_1 * \ln(P_{jt}) + \epsilon_{it}$$

The relationship describes the level of market integration when the prices change immediately. β_0 is a constant that describes the transportation costs and quality differences. β_1 shows the relationship between the two prices P_{it} and P_{jt}. If $\beta_1 = 0$, there is no market integration, because there is no relationship between the prices. If $\beta_1 = 1$, the LOP holds and there is a perfect market integration, as mentioned above. In relation to natural gas markets, this is consistent with the two sources of natural gas being perfect substitutes in the markets. If $0 < \beta_1 < 1$, this is consistent with imperfect substitutes. The error term ϵ_{it} is a representation of how trustworthy the estimates are. The larger the error term is, the less uncertain the estimates are (Asche, Osmundsen and Tveterås, 2000).

3.4 Efficient Market Hypothesis

The concept of market efficiency pertains to the degree to which prices incorporate all available information. According to the efficient markets hypothesis (EMH), financial markets are highly efficient, implying that opportunities for generating excess returns through investment strategies are limited. The EMH asserts that all publicly available information is rapidly and accurately factored into security prices, leaving little room for investors to capitalize on informational asymmetries. The speed with which product prices adjust to new information serves as a gauge of market efficiency. In other words, the efficiency of a market can be assessed based on how rapidly prices incorporate available information. Consequently, while it may be possible to achieve market returns through passive index investing, attempts to outperform the market are unlikely to be successful if the market is efficient (Downey, 2023).

Some proponents of the EMH argue that markets for commodities such as natural gas are efficient due to the large number of participants and the availability of information, which leads to market prices quickly reflecting all available information (Downey, 2023). Concerning natural gas, there could arise certain market inefficiencies from external factors, such as geopolitical events, which can impact natural gas prices and lead to inefficiencies in the market. For inefficiencies to emerge due to external factors it is likely to be in extreme events where an unpredictable situation has a large impact on the market (Bricout et al, 2022).

4

Methodology

Methodology refers to the set of techniques, procedures, and tools used to conduct research, make decisions, or solve problems in a systematic and rigorous way. It involves various steps, such as formulating and selecting appropriate methods for collecting and analysing data, sampling, interpreting results, and addressing ethical concerns and potential biases. A well-designed methodology is crucial for obtaining accurate and valid findings and advancing knowledge in a given field. In this chapter the methodology used to answer the research questions is presented (Dalland, 2007).

4.1 Quantitative and Qualitative method

In this research, a quantitative and qualitative method was employed. Quantitative research is a type of empirical research that is based on the collection and analysis of numerical data. It involves the use of statistical tools and techniques to examine the relationship between variables and to test the significance of the findings. All analysis conducted to solve the research problem was completed in the statistical software R-studio. The quantitative approach allows for a more systematic and objective analysis of the data and helps to reduce the potential for researcher bias. Furthermore, quantitative research is often used in economics and finance to study the behaviour of financial markets, the impact of policies, and to forecast future outcomes (Dalland, 2007). By using a quantitative method, the research aimed to provide a rigorous and objective analysis of the natural gas market and to test the hypotheses that was formulated based on economic theory.

To delve further into the topic, a qualitative approach was opted for, with the intention of sourcing information from specific channels, professionals and document analysis. In gathering data, two types were differentiated: primary and secondary data. Primary data is sourced directly from the origin, by means such as observations, questionnaires, or interviews. Conversely, secondary data is gathered by others, and it is vital to employ credible sources (Sundbye and Nisted, 2017).

To acquire information, both primary and secondary data were selected. Aker BP gas negotiators and analysts was involved in delivering primary data. For the purpose of meeting knowledge requirements surrounding the research problem, acquiring external data sources, in other words, secondary data was deemed necessary.

4.2 VAR-Analysis

Auto-regressive models are a type of time series models used in statistical analysis to predict future values of a time series based on past observations (Prabhakaran, 2019). The Vector Auto-Regression (VAR) model extends the standard auto-regressive model to capture the linear interdependencies among multiple time series variables (Stock and Watson, 2015). The main reason for creating VAR-models in this study was to be able to conduct further analysis on the time series.

To be able to create a functioning VAR-model it is required that all the time series data is stationary, meaning that characteristics like mean and variance do not change over time (Hyndman and Athanasopoulos, 2018). If the data is found to be nonstationary, it is made stationary by differencing the time series until it becomes stationary (Prabhakaran, 2019). The quantitative data used in the study were found to be non-stationary and were differentiated once. All the time series became stationary after one differentiation, and the series lengths were reduced by one. The stationary time series could then be interpreted in VAR-models.

When creating a VAR-model, it is necessary to test how many lags are optimal for the data used (Prabhakaran, 2019). The default maximum lag is 10, so this is what was used as a limit for the number of lags in the analysis. A VAR-model model assumes that the current value of each variable depends on its own past values as well as the past values of other variables in the system (Prabhakaran, 2019).

The VAR-model can be represented as follows:

$$Y_t = c + A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_p y_{t-p} + e$$

Where Y_t is a vector of k variables at time t. $A_1,\ A_2,\ \ldots,\ A_p$ are $k\ x\ k$ matrices of coefficients, p is the order of the VAR model. c is a vector of constant terms and e is the vector of errors (Stock and Watson, 2015).

The coefficients in the VAR-model capture the strength and direction of the relationships between the variables. The future values of the time series variables can be predicted by estimating the coefficients (Hyndman and Athanasopoulos, 2018).

The VAR model has many applications in economics, finance, and other fields where multiple time series are available for analysis. It is widely used in forecasting and policy analysis to estimate the effects of changes in economic variables on other variables in the system (Hyndman and Athanasopoulos, 2018).

The VAR analysis was carried out in three steps:

1. Test data for stationarity (**adf.test** function)
2. Finding the optimal lag (**VARSelect** function)
3. Estimation of a VAR (**VAR** function)

4.2.1 ***Step 1. Dickey-Fuller test:***

As aforementioned, in VAR analysis it is necessary to check if the datasets used are stationary. It is possible to check for stationarity by using a unit root test. A unit root is a characteristic of a non-stationary time series in which the series has a root that is equal to 1. This means that the series has no tendency to return to its mean after being perturbed, and therefore exhibits a trend or drift over time. A unit root test is used to determine whether a time series has a unit root, and thus is non-stationary. The Augmented Dickey-Fuller test is one of the most commonly used unit root tests and was the preferred method to check the datasets for stationarity in this study (Verma, 2021).

This is a statistical significance test, which means that the test will result in accepting a null hypothesis or rejecting the null hypothesis to accept an alternative hypothesis. The result of the test will give a P-value, which determines if the null hypothesis is to be rejected or accepted. A general rule used is if the P-value is greater than 0,05 the null hypothesis fails to be accepted, and the dataset will be non-stationary (Verma, 2021).

To perform the *ADF* test, an autoregressive model of the time series is estimated. The null hypothesis, that the series has a unit root, is tested against the alternative hypothesis, that the series is stationary. The test statistic is computed as the t-ratio of the coefficient on the lagged difference of the series. The t-ratio measures how many standard errors the coefficients are away from 0. Critical values, which depend on the sample size and the number of lags included in the model, are used to compare the ADF test statistic (Verma, 2021).

The ADF test, however, is not without limitations. It assumes that the errors in the autoregressive model are serially uncorrelated and normally distributed, which may not hold in reality. Additionally, the ADF test is sensitive to the selection of the lag length, and varying lag lengths may produce different results. Thus, when using the ADF test, it is crucial to carefully consider its assumptions and limitations (Rtmath, 2020).

4.2.2 ***Step 2. Optimal lag***

In VAR analysis, "lag" refers to the number of past observations of each variable that are considered in the model. Choosing the appropriate lag is important for accurately predicting the outcome (Prabhakaran, 2019).

To find the optimal lag the *VARSelect* function was used. It takes a time-series dataset as input and returns the optimal lag order based on either the Akaike Information Criterion (AIC), the Bayesian Information Criterion (BIC), or the Final Prediction Error (FPE) criteria. It is common to use the AIC as the optimal lag criterion, therefore the AIC was prioritized in this study. The *VARSelect* function performs a grid search over a range of lag orders to find the optimal lag order that minimizes the selected information criterion. It is possible to specify the maximum lag order to search over, using the *lag.max* parameter. As mentioned, the default maximum lag is 10 (Crane.r “vars”, 2018).

4.2.3 ***Step 3. VAR-analysis***

The *VAR* function takes a time-series dataset as input and estimates a VAR-model with a specified lag order. The function allows the user to specify various options, including the type of constant term to include in the model, the estimation method, and whether to include exogenous variables. The *VAR* function estimates a VAR by utilizing Ordinary Least Squares (OLS) per equation. This involves estimating each equation in the VAR-model separately using OLS regression (Crane.r “vars”, 2018).

OLS regression is a statistical method for estimating the parameters of a linear regression model. In OLS regression, the goal is to estimate the values of the coefficients of a linear equation that best fits a set of data points. A general form of a linear regression equation:

$Y = a + bx + e$

The OLS regression method estimates the values of the coefficients a and b that minimize the sum of the squared errors, between the observed values of y and the predicted values of y, based on the linear equation. The OLS method assumes that the error term is normally distributed, with a mean of zero and constant variance. To estimate the values of the coefficients a and b, the OLS method calculates the residual sum of squares (RSS), which is the sum of the squared differences between the observed values of y and the predicted values of y based on the linear equation. The OLS method then estimates the values of a and b that minimize the RSS (XLSTAT, 2017).

In the VAR-analysis, each equation is estimated separately using OLS regression, with the lagged values of the variables and any exogenous variables included as predictors. The resulting estimated coefficients can be used to analyse the dynamic relationships among the variables in the model and to make predictions about future values of the variables (Stock and Watson, 2015).

The VAR function returns an object that contains the estimated coefficients, the residuals, the estimated covariance matrix, and other diagnostic statistics (Package 'vars' VAR Modelling, 2018). The estimated coefficients can be used to analyse the dynamic relationships among the variables in the model and to make predictions about future values of the variables. The residuals and diagnostic statistics can be used to assess how well the model fits and to identify any potential issues with the model specification (Stock and Watson, 2015).

4.3 Causality Test

The *causality* function is used to test for Granger- and instantaneous causality between variables in a VAR-model (Package 'vars' VAR Modelling, 2018). Granger causality is a statistical concept that is used to determine if one time series is useful in predicting another time series (Aptech, 2021). Instantaneous causality refers to the causal relationship between variables that occurs at the same time, without any lag. In other words, it is the direct impact of one variable on another variable in the same time period (Norrulashikin, Yusof and Kane, 2016).

The causality function takes a fitted VAR-model and a lag order as inputs and returns a matrix of test statistics and p-values for each pairwise Granger causality test. The function tests whether the past values of one variable help predict the current values of another variable, after controlling for the past values of both variables. The causality test help to identify the direction of causality between the variables. However, it is important to note that Granger causality tests do not prove causation, and the results should be interpreted with caution (Aptech, 2021).

Granger causality tests were used on the VAR-models, to test how the time series influences each other. The returned P-value was interpreted to see if there was Granger causality indicated between the time series. P-values indicate the strength of the signal present in the effect of lagged prices on current prices. It is typical for there to be lower significance in differentiated prices, given the inherent difficulty in predicting price changes. A lower P-value corresponds to a stronger effect. The utilization of the standard deviations in the Granger causality analysis allows for the computation of the significance of the causality test, thereby establishing the relevance of these figures to the ongoing analysis.

Two causality tests are implemented when using the causality function in R-studio. The first is a F-type Granger causality test and the second is a Wald-type test that is characterized by testing for nonzero correlation between the error processes of the cause- and effect-variables. For both tests the vector of endogenous variables y_t is split into two subvectors y1t and y2t with dimensions (K1 × 1) and (K2 × 1) with K = K1 + K2 (Cran.r "vars", 2018). For the rewritten VAR(p):

$$[y_{1t}, y_{2t}] = \sum_{i=1}^{p} [\alpha'_{11,i}, \alpha'_{12,i} | \alpha'_{21,i}, \alpha'_{22,i}][y_{1,t-i}, y_{2,t-i}] + CD_t + [u_{1t}, u_{2t}]$$

The null hypothesis states that the subvector y1t does not have a Granger-causal effect on y_{2t}, which is represented as $\alpha_{21,i} = 0$ for $i = 1, 2, \ldots, p$. The alternative hypothesis states that there exists at least one α_{21},i that is not equal to zero, where $i = 1, 2, \ldots, p$ (Cran.r "vars", 2018).

The null hypothesis for instantaneous causality is defined as H0: $C\sigma = 0$. C is a matrix of size $\left(N \times \frac{K(K+1)}{2}\right)$ with rank N, which selects the relevant co-variances of u_{1t} and u_{2t}. σ represents the vectorization of the covariance matrix Σu (Cran.r "vars", 2018).

The Wald test statistic exhibits an asymptotic distribution that converges to a chi-square distribution with N degrees of freedom. When conducting the Granger causality test, it is advisable to employ a robust covariance-matrix estimator to account for heteroskedasticity. This can be accomplished by utilizing the argument *vcov*, which can accept either a precomputed covariance matrix or a function capable of extracting the covariance matrix (Cran.r "vars", 2018).

4.4 Correlation Test

The correlation of NBP and TTF gas prices is computed with the *cor* function. Correlation is a statistical concept that evaluates the possible linear association between two continuous variables. It is measured by a statistic known as the correlation coefficient, which ranges from -1 (perfect negative correlation) to +1 (perfect positive correlation), with 0 indicating no correlation. A positive correlation coefficient indicates that the variables have a direct relationship, while a negative correlation coefficient indicates an inverse relationship. The strength of the relationship can vary from weak to strong, with the coefficient approaching -1 or +1 indicating a stronger correlation (Mukaka, 2012).

4.5 Cointegration Test

In this study cointegration analysis was used to compare the gas market prices in Europe. To conduct the cointegration test on the different time series, the function *ca.jo* was utilized. The *ca.jo* function uses the Johansen cointegration test to analyse the time series. Cointegration refers to the long-term relationship between two or more non-stationary variables. As mentioned, a time series is stationary if the mean, variance and autocorrelation do not change over time. A set of non-stationary variables is said to be cointegrated if there exists a linear combination of them that is stationary. This means that even though the individual variables may exhibit a trend over time, their combination is stable and does not exhibit any long-term systematic patterns (Engle and Granger, 1987). To find a possible linear combination for the non-stationary time series, the following equation was studied:

$$\beta Y_t = \beta_1 y_1 + \beta_2 y_2 \sim I(0)$$

Where Y_t is the time series which is to be modelled, y_1 and y_2 are the time series which may have a linear relationship with Y_t. β, β_1, β_2 represent the respective weight assigned to each variable. If the variables have a linear combination that is integrated to order 0 (denoted as $I(0)$), which means that the combination is stationary, the time series are cointegrated. (Aptech, 2020)

After conducting the cointegration test, the trace statistic, which measures the maximum eigen value test statistics across different cointegrating relationships, are compared to the critical value for the desired significance level. If the trace statistic is greater than the critical value, the test is indicating evidence of cointegration. (Aptech, 2020)

Cointegration is an important concept in time series analysis because it makes it possible to model the long-term relationship between variables and to account for the possibility of spurious regression. In a spurious regression, two or more non-stationary variables may appear to be strongly correlated over time, even though there is no meaningful relationship between them. Cointegration helps to avoid spurious regression by identifying the existence of a long-term relationship between variables (Ericsson and Hendry, 2019).

4.6 Evaluation of Selected Methodology

In research, the quality of information collected is of utmost importance. Two essential concepts used to describe data quality are validity and reliability. Validity is an indication of the extent to which collected data are pertinent and appropriate for addressing the research problem. Reliability, on the other hand, refers to the consistency and accuracy of the data collected. Hence, researchers should minimize potential errors to collect reliable data (Dalland, 2007).

When conducting research for the thesis, it was essential to ensure data accuracy and reliability to eliminate uncertainties. The methodology primarily used to gather data involved obtaining information from professionals or quantitative data from secure sources. All information was cross-checked with other sources to enhance the reliability and validity. The authors consider the collected information reliable due to the secure data collection methods used. Furthermore, regular contact with the advisors ensured that questions could always be answered.

All sources and theories utilized in the study were approached with caution, recognizing the inherent limitations and ongoing debates surrounding them. Within this context, the Efficient Market Hypothesis theory has been subject to discussion regarding its applicability and effectiveness. Critics have raised valid concerns about the assumptions and constraints embedded within the EMH, prompting a critical evaluation of its suitability in explaining real-world financial markets. Acknowledging this scholarly discourse, this thesis embraces a cautious approach in utilizing the EMH as a theoretical framework. While recognizing its value in understanding market efficiency, this study remains open to alternative viewpoints and potential refinements that may account for the intricacies and complexities present in actual market dynamics. By adopting a measured perspective, this research aims to strike a balance between acknowledging the contributions of the EMH and considering alternative perspectives to enhance the accuracy and validity of the analysis. (Downey, 2023).

Additionally, it is essential that the analysis conducted demonstrates a high level of reliability to ensure the accuracy and validity of the findings. The results of the conducted analysis possess a degree of unreliability, warranting caution in their interpretation. It is crucial to acknowledge that these findings have been used solely as a guiding framework for the study, rather than as conclusive evidence. While these results provide some directional insight, their limitations and potential sources of bias necessitate caution when drawing definitive conclusions. Therefore, additional research and comprehensive validation of these findings are imperative to ensure the robustness and reliability of the conclusions.

5

Data

In order to address the research questions numerical data was needed for conducting statistical analyses. The data used is from Refinitiv, (Refinitiv, n.d.a) a global provider of financial market data and BBL Company (ENTSOG, n.d.a), the operating company of the BBL pipeline.

Logarithmic data were used as they are favoured over nominal data in economic and financial analysis. They better capture proportional changes over time by reflecting percentage changes rather than absolute changes, which is important for financial time series data that tend to exhibit large fluctuations. (Murphy, 2021)

When implementing the different analysis in the study, the data has been divided into three sample series.

1. Full sample, data from 2008-2023
2. Early sample, data from 2008-2020
3. Late sample, data from 2021-2023

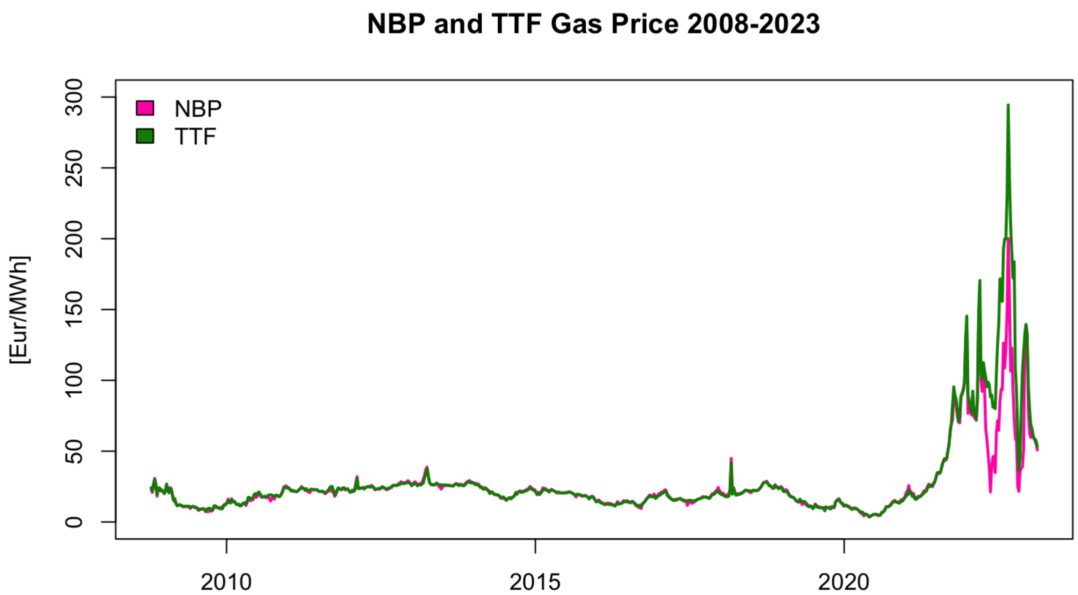

Figure 14. NBP and TTF day ahead gas prices from 2008 to 2023.

The data is divided into three, because the graphed time series data in figure 14 clearly shows that there is a change to the price trends in year 2021. It can be observed that the prices have remained relatively stable from 2008 until 2020. However, a notable upswing was experienced in both prices in 2021, with a substantial deviation between the two occurring in the following year. Nevertheless, as of 2023, the prices appear to have stabilized once more. The temporal pattern of price movements in the depicted period may provide valuable insights into the underlying dynamics of the natural gas market, as well as the potential factors contributing to the observed fluctuations. It is therefore interesting to analyse the situation before and after the decoupling.

5.1 Day Ahead Prices

Historical day-ahead prices from NBP and TTF was gathered from Refinitiv. Day-ahead prices in the gas market refer to the prices at which natural gas is traded for delivery on the following day in wholesale markets. The prices are established via a competitive bidding process, wherein gas producers, traders, and suppliers submit offers to sell or purchase natural gas for the next day. The market operator subsequently matches these offers to attain an optimal combination of supply and demand at the lowest possible cost (Nord Pool, 2020).

Market participants in the gas industry rely on day-ahead gas prices to inform their supply and demand requirements for the next day. For instance, gas-fired power plants may utilize day-ahead prices to determine the quantity of gas they need to purchase to generate electricity on the subsequent day. Similarly, gas distributors and suppliers may utilize day-ahead prices to establish the amount of gas they must acquire to satisfy the demand of their customers (ScienceDirect, 2014).

Analogous to electricity markets, day-ahead gas prices are critical in facilitating the efficient functioning of the gas market, as they provide market participants with information about the supply and demand balance, enabling them to make informed decisions regarding gas trading activities. Day ahead prices within gas trading act as a crucial benchmark for gas market participants to mitigate their risks and make informed trading decisions (Downey, 2023).

The gathered day ahead prices will be adequate estimations for the historical spot prices for the NBP and TTF and will therefore be considered eligible for use in the market analysis. The data obtained is a weekly price from year 2008-2023. In general, weekly average prices may be less suitable for indicating the typical value of a sample. However, it is appropriate to use mean values in the analysis as daily fluctuations in gas prices may occur. It is the general deviations between TTF and NBP over time that are of interest for the research problem. Daily fluctuations in data analysis can produce undesirable effects in estimations and lead to erroneous assessments.

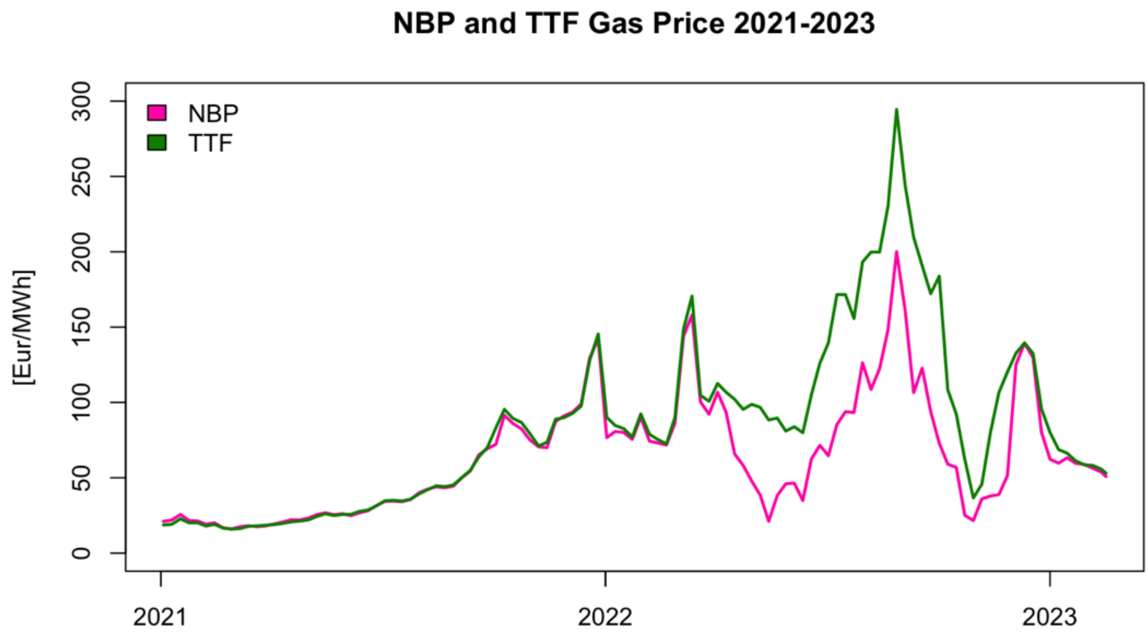

Figure 15. NBP and TTF day ahead gas price from 2021 to 2023.

The presented plot illustrates the price developments of NBP and TTF in 2021-2023. As depicted, in 2022, the NBP price exhibits a substantial discount compared to TTF. During autumn of that year, both prices reach a record high for the period, but NBP remains lower than TTF. Towards the end of 2022 and the start of 2023, both prices experience a downward trend, leading to a vanishing deviation between the two prices.

5.2 BBL Flow Data

Since there is such a divergence between the NBP and TTF prices in 2022 it would be interesting to analyse the direct gas flow connection between the two markets, being the BBL pipeline. Both the entry and exit flow data was gathered from the BBL company, the operator of BBL pipeline. The earliest data found was from late 2015. (ENTSOG, n.d.a)

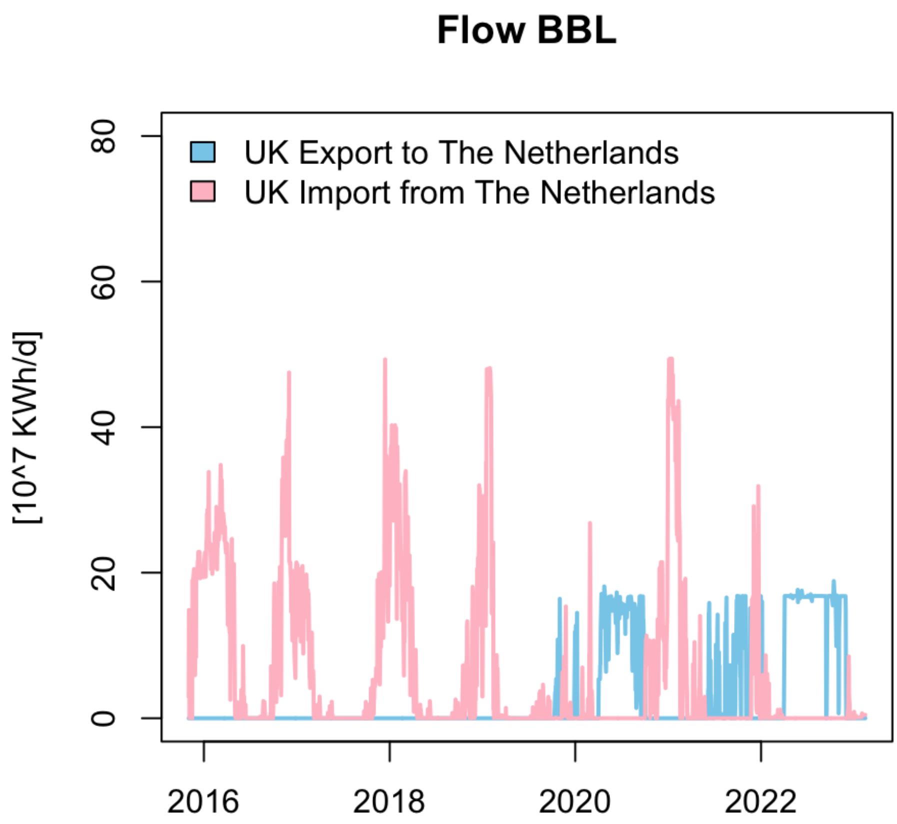

Figure 16. BBL pipeline flow from 2015 to 2023.

The data from 2015 to 2019 exhibits that the BBL pipeline functioned one-directionally, transmitting natural gas from Europe to the United Kingdom. However, the data subsequent to 2019 displays that the flow of natural gas through the pipeline has become bidirectional, indicating exports from the United Kingdom to the Netherlands as well. The capacity for natural gas transportation from the Netherlands to the United Kingdom exceeds the capacity of the pipeline in the opposite direction. Figure 16 displays the UK import flow and the UK export flow through the BBL pipeline. The flow is measured in 10^7 kWh/day.

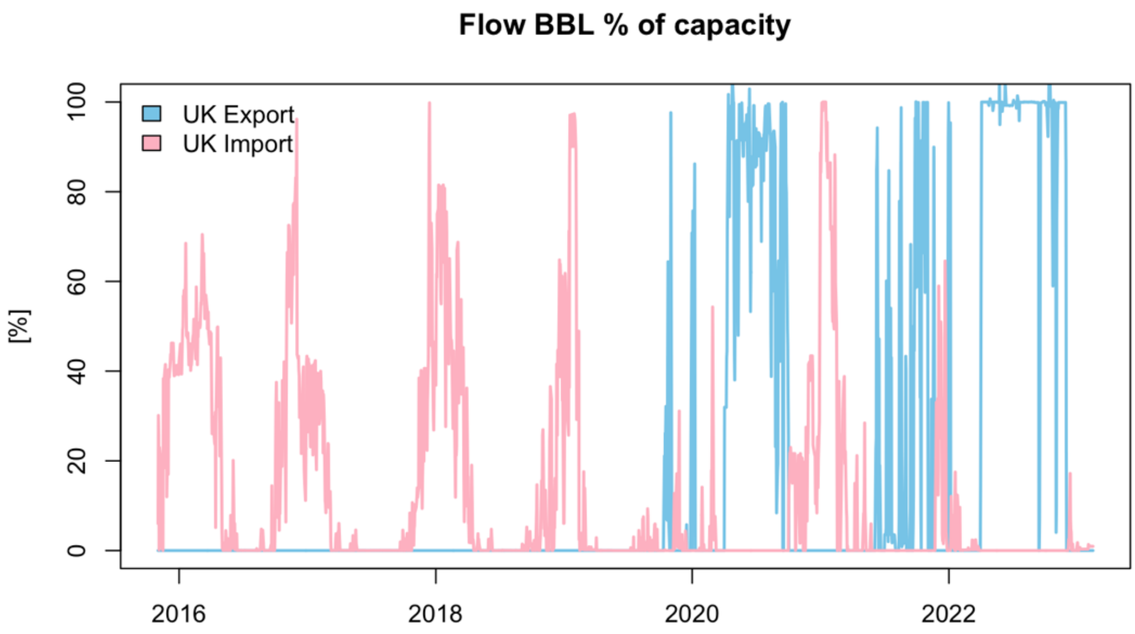

Figure 17. BBL pipeline flow from 2016 to 2023 – percentage of capacity.

The presented plot in figure 17 illustrates the percentage of capacity at which the BBL pipeline operated from 2015 to 2023. The data shows that natural gas has not been transported from the Netherlands to the UK at its maximum capacity for an extended period. On the other hand, exporting natural gas from the UK to the Netherlands has more often operated at full capacity, as evidenced by the plot. Specifically, in the year 2022, the pipeline ran at full capacity for an extended period, indicating that demand for natural gas from the UK to the Netherlands was high during that time.

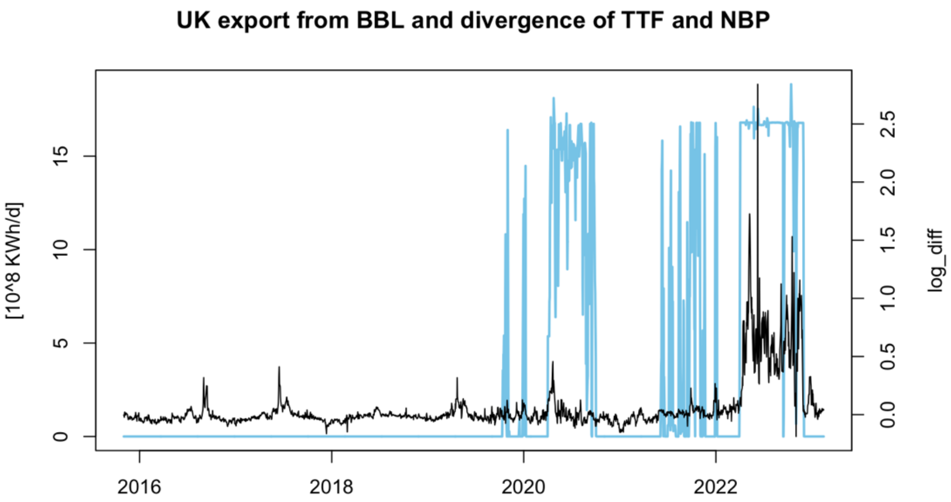

Figure 18. UK export trough BBL pipeline compared to deviation in NBP and TTF prices from 2016 to 2023.

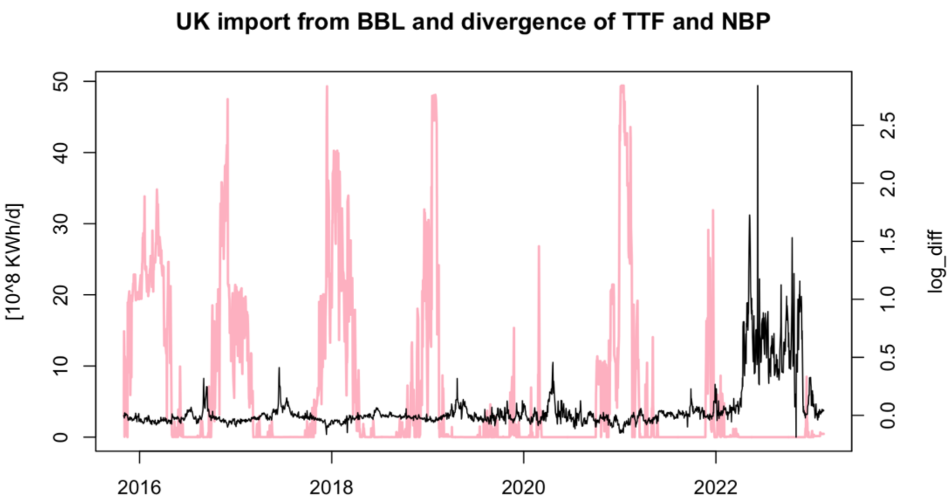

Figure 19. UK Import trough BBL pipeline compared to deviation in NBP and TTF prices from 2016 to 2023.

Figures 18 and 19 display the flow of gas through the BBL pipeline compared to the price deviation between NBP and TTF. Specifically, when there is a high level of gas import to the UK, there is little divergence, but tends to be followed by an increased price difference between NBP and TTF after time delay. When there is gas exported from the UK to the Netherlands, the price difference between NBP and TTF is generally wider.

5.3 Storage

The presented plot displays storage levels of natural gas in Europe, the UK, and the Netherlands from 2019 to 2023. The storage data was gathered from GIE AGSI via Refinitiv (Refinitiv, n.d.c). To ensure a clear overview of the data, fluctuations have been mitigated by calculating average weekly values. Preceding the time period with significant price deviations, the data suggests that each year had two extreme points, one minimum and one maximum. In 2021, all storage levels dropped to their respective minimum points for the studied period. The low storage levels persisted for several months before all countries were able to build their natural gas storage levels. However, in late 2021, an abnormality occurred as the UK's storage levels did not follow the trend observed in the Netherlands and Europe. For the majority of 2022, the UK had full or near-full storage levels, while the Netherlands and Europe experienced significantly low storage levels.

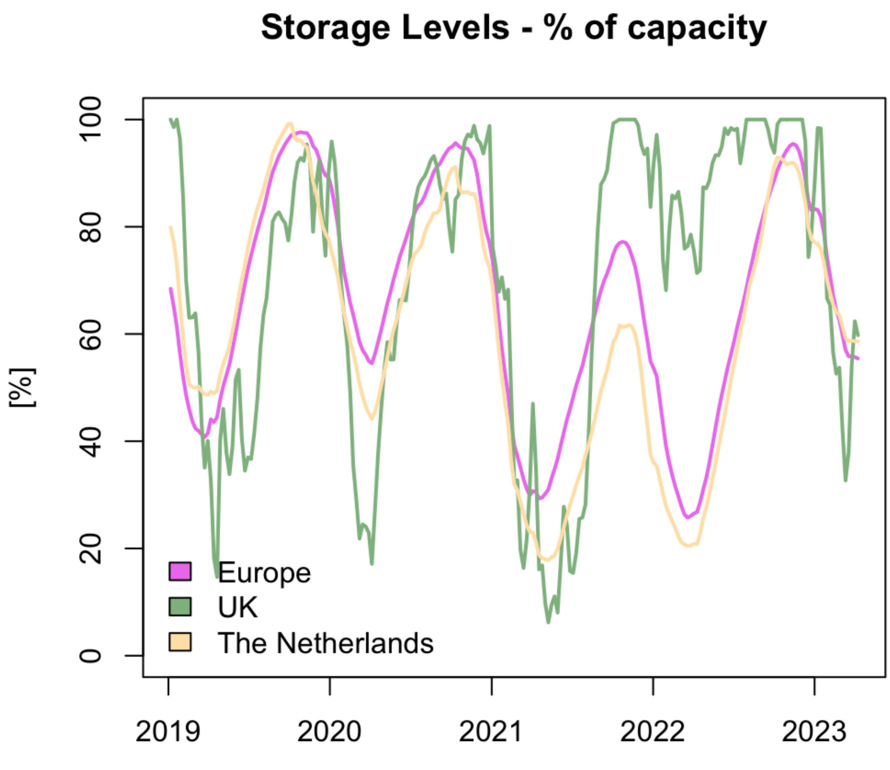

Figure 20. Storage levels in Europe, the UK and the Netherlands.

6

Analysis

This part of the study was based on the analysis of quantitative data. The first part concerns the gas prices from the NBP and TTF, to understand the European market situation both historically and in recent years. The second part aims to understand if the gas prices are useful in predicting gas flow in the BBL pipeline or vice versa, utilizing the price difference between the NBP and TTF as the first data set and the flow of the BBL pipeline as the second dataset.

The analysis was performed across the three distinct time periods to facilitate meaningful comparisons. This approach allows for a comprehensive examination of the data by capturing potential variations and trends over time. Given that the complete sample encompasses two significantly different trends, interpreting the results becomes challenging. Consequently, to enhance precision and mitigate the impact of divergent trends, the results obtained from the sub time periods will be given greater consideration. By focusing on these specific subsets, a more precise and nuanced understanding of the underlying dynamics can be attained, contributing to a more robust interpretation of the findings.

The following analysis will be conducted:

- VAR
- Granger causality
- Corelation
- Cointegration

6.1 Natural gas prices

6.1.1 VAR 2008-2023

	2008-2023			
	TTF		NBP	
Lag	Estimate	Std.error	Estimate	Std.error
TTF_log.l1	0,014	0,064	0,089	0,077
NBP_log.l1	0,104	0,052	-0,024	0,064
TTF_log.l2	-0,154	0,064	0,207	0,077
NBP_log.l2	0,113	0,053	-0,221	0,064
TTF_log.l3	0,071	0,066	0,275	0,081
NBP_log.l3	-0,051	0,055	-0,161	0,067
TTF_log.l4	-0,242	0,067	-0,172	0,081
NBP_log.l4	0,206	0,055	0,207	0,067
TTF_log.l5	-0,073	0,067	0,036	0,082
NBP_log.l5	0,024	0,056	-0,096	0,068
TTF_log.l6	-0,088	0,067	-0,160	0,082
NBP_log.l6	0,050	0,055	0,032	0,067
TTF_log.l7	-0,064	0,064	-0,098	0,078
NBP_log.l7	0,009	0,052	0,038	0,063
TTF_log.l8	0,130	0,064	0,080	0,077
NBP_log.l8	-0,169	0,052	-0,166	0,063
Const	0,001	0,003	0,001	0,004

Figure 21. Important metrics from the VAR model for TTF and NBP (2008-2023).

Figure 21 displays the results derived from the VAR models for the NBP and TTF gas prices. For period 2008-2023 the optimal lag vas 8. The combination of estimated coefficients and standard deviations help to understand the dynamics and volatility of NBP and TTF prices. The positive coefficients indicate a positive association between lagged values and current/future values, suggesting some degree of predictability. However, the negative coefficients highlight the possibility of counterintuitive relationships in certain instances. The standard deviations provide insights into the variability and uncertainty of the data points, indicating the level of volatility in TTF and NBP prices during specific periods.

6.1.2 Granger Causality Test 2008-2023

2008-2023	
Null hypothesis	P-value
TTF do not Granger-cause NBP	7.819e-06
NBP do not Granger-cause TTF	6.873e-05

Figure 22. Granger causality metrics (2008-2023).

The VAR-model was used to implement a Granger causality test. For TTF-NBP, the test returned a p-value of 7.819e-06, which suggests that the causal relationship between the two prices is strong. For NBP-TTF, the test returns a p-value of 6.873e-05, which like the prior test, infer a strong causal relationship. These results suggest that both NBP gas price and TTF gas prices are useful in predicting each other in this period. That would mean that there is bi-directional Granger causality between the time series when using full sample from period 2008-2023.

6.1.3 Correlation 2008-2023

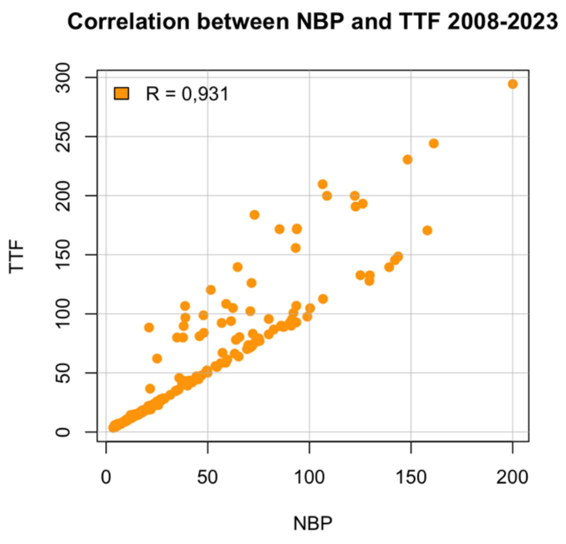

Figure 23. Correlation plot (2008-2023)

The correlation coefficient R=0.931 was calculated for the full sample period, indicating a strong positive correlation between the variables. However, this strong correlation is mainly due to the first period, as the second period shows a deviation from this trend.

6.1.4 *Cointegration Test 2008-2023*

```
           test 10pct  5pct  1pct
r <= 1 |   5.28  7.52  9.24 12.97
r = 0  |  31.40 17.85 19.96 24.60
```

Figure 24. Values of teststatistic and critical values of cointegration test 2008-2023.

In the cointegration test, the null hypothesis R equals 0, implies zero cointegrated relationships in the data. The test statistic value obtained from this analysis is 31.40, which exceeds the significance levels of 1%, 5%, and 10%. This result leads to rejection of the null hypothesis, indicating the presence of at least one cointegrating relationship during the period of 2008-2023.

Furthermore, for the alternate hypothesis $R \leq 1$, the test statistic 5.28 is found to be lower than the critical value. As a consequence, the null hypothesis is failed to be rejected. Thus, the results suggest that there is at most one cointegrating relationship in the system. In light of these findings, it can be concluded that cointegration is present in the data, implying that a long-term relationship exists between the variables.

6.1.5 *VAR 2008-2020*

	2008-2020			
	TTF		NBP	
Lag	Estimate	Std.error	Estimate	Std.error
TTF_log.l1	-0,005	0,098	0,157	0,108
NBP_log.l1	-0,059	0,089	-0,204	0,098
TTF_log.l2	-0,085	0,098	0,057	0,108
NBP_log.l2	0,036	0,089	-0,119	0,098
TTF_log.l3	-0,064	0,098	0,104	0,108
NBP_log.l3	0,101	0,089	-0,038	0,098
Const	-0,001	0,003	-0,001	0,003

Figure 25. Important metrics from the VAR model for TTF and NBP (2008-2020).

Figure 25 displays the results derived from the VAR models for the NBP and TTF gas prices. For period 2008-2020 the optimal lag vas 3.

6.1.6 ***Granger Causality Test 2008-2020***

2008-2020	
Null hypothesis	P-value
TTF do not Granger-cause NBP	0.4153
NBP do not Granger-cause TTF	0.5572

Figure 26. Granger causality metrics (2008-2020).

The VAR-model was used to implement a Granger causality test. For TTF-NBP the test returns a p value of 0.4153, which suggests that there is a weak causal relationship between the prices. For NBP-TTF the test returns a p value of 0.5572, which similar to the prior test suggests that there is a weak causal relationship between the prices. The Granger causality test infers that both NBP gas price and TTF gas price are not useful in predicting one another. That is, there are weak signs of causality detected between the time series between 2008-2020.

6.1.7 ***Correlation 2008-2020***

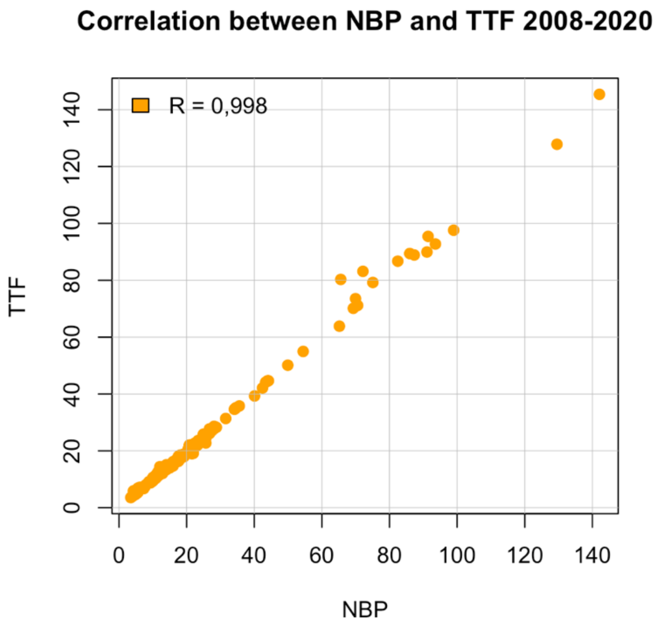

Figure 27. Correlation plot (2008-2020).

The results of the correlation analysis conducted on the time series data of NBP and TTF from the period of 2008 to 2021 reveal a strong positive correlation of 0.998. This indicates that the two variables exhibit a tendency to vary in a consistent manner, whereby an increase or decrease in one variable is accompanied by a corresponding increase or decrease in the other. Furthermore, the close proximity of the correlation coefficient to the maximum value of 1 signifies a high degree of association between the two variables, as can be seen from the corresponding plot.

6.1.8 ***Cointegration Test 2008-2020***

```
          test 10pct  5pct  1pct
r <= 1 |  2.17  7.52  9.24 12.97
r = 0  | 60.04 17.85 19.96 24.60
```

Figure 28. Values of test statistic and critical values of cointegration test 2008-2020.

In the cointegration test, the null hypothesis R equals 0, implies zero cointegrated relationships in the data. The test statistic value obtained from this analysis is 60.04, which exceeds the values of significance levels 1%, 5%, and 10%. This result leads to rejection of the null hypothesis, indicating the presence of at least one cointegrating relationship during the period of 2008-2020.

Furthermore, for the alternate hypothesis $R \leq 1$, the test statistic 2.17 value is found to be less than the critical value. Consequently, the hypothesis is failed to be rejected. Thus, the results suggest that there are at most one cointegrating relationship in the system. Considering these findings, it can be concluded that cointegration is present in the data, implying that a long-term relationship exists between the variables.

6.1.9 ***VAR 2021-2023***

	2021-2023			
	TTF		NBP	
Lag	Estimate	Std.error	Estimate	Std.error
TTF_log.l1	0,215	0,135	0,083	0,191
NBP_log.l1	0,137	0,093	0,096	0,131
TTF_log.l2	-0,124	0,127	0,386	0,180
NBP_log.l2	0,000	0,093	-0,358	0,131
Const	0,006	0,015	0,004	0,022

Figure 29. Important metrics from the VAR model for TTF and NBP (2021-2023).

Figure 29 displays the results derived from the VAR model for NBP and TTF gas prices. For period 2021-2023 the optimal lag vas 2.

6.1.10 ***Granger Causality Test 2021-2023***

2021-2023	
Null hypothesis	P-value
TTF do not Granger-cause NBP	0.07632
NBP do not Granger-cause TTF	0.3351

Figure 30. Granger causality metrics (2021-2023).

The VAR-model was used to implement a Granger causality test. For TTF-NBP the test returns a p value of 0.07632 P, indicating that there is a somewhat strong causal relationship between the prices. For NBP-TTF the test returns a p value of 0.3351, which suggests that the causal relationship between the prices is weak. Thus, the p-value analysis indicates a stronger predictive power of TTF over NBP in 2021-2023.

6.1.11 *Correlation test 2021-2023*

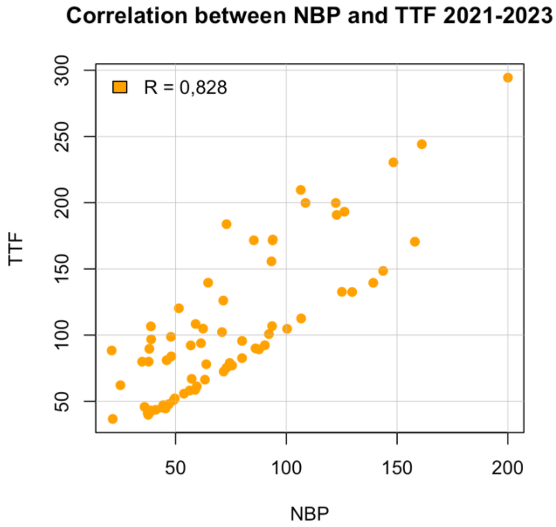

Figure 31. Correlation plot (2021-2023).

The results of the correlation analysis conducted from the period of 2021 to 2023 reveal a positive correlation of 0.828. As in the previous period, this indicates that an increase or decrease in one variable is accompanied by an increase or decrease in the other. However, the correlation coefficient is lower and indicate a weaker relationship between the prices, a trend that is also visually evident from the corresponding plot.

6.1.12 *Cointegration test 2021-2023*

```
          test 10pct  5pct  1pct
r <= 1 |  3.01  7.52  9.24 12.97
r = 0  | 15.77 17.85 19.96 24.60
```

Figure 32. Values of test statistic and critical values of cointegration test (2021-2023).

In the cointegration test, the null hypothesis R equals 0, implies zero cointegrated relationships in the data. The test statistic value obtained from this analysis is 15.77, which falls short of the significance levels of 1%, 5%, and 10%. That is, the null hypothesis is failed to be rejected, indicating no presence of a cointegrated relationship during the period of 2021-2023. The findings conclude that a long-term relationship does not exist between the variables in this period.

6.2 BBL

This Granger causality analysis uses flow data from the BBL pipeline and the logarithmic price difference between NBP and TTF. Data is used to analyse if the difference in natural gas price between TTF and NBP is useful in predicting the flow of gas between the two hubs or the other way around. The analysis is carried out for the three time periods (earliest data from 2015) and four hypotheses are tested for each period:

Granger causality H0: Gas import to the UK do not Granger-cause price deviation

Granger causality H0: Price deviation do not Granger-cause gas import to UK

Granger causality H0: Gas export from the UK do not Granger-cause price deviation

Granger causality H0: Price deviation do not Granger-cause gas export from UK

6.2.1 ***Analysis result of BBL gas flow compared to price deviation between NBP and TTF period 2015 – 2023***

2015-2023	
Null hypothesis	P-value
UK import do not Granger-cause price deviation	0.9933
Price deviation do not Granger-cause UK import	0.7683
UK export do not Granger-cause price deviation	0.06898
Price deviation do not Granger-cause UK export	1.071e-12

Figure 33. P-values and null hypothesis for BBL pipeline flow (2015-2023).

Between 2015 and 2023 the Granger causality analysis infer that the divergence in price between NBP and TTF is useful in predicting export of natural gas from the UK to the Netherlands. This result is bi-directional as the analysis result suggests that the UK export can be used to predict price deviation. It did on the other hand not detect strong Granger causality between the import of gas in the UK and the differences in price, nor that the UK export could be useful in predicting price divergence.

6.2.2 *Analysis result of BBL gas flow compared to price deviation between NBP and TTF period 2015 – 2020*

2015-2020	
Null hypothesis	P-value
UK import do not Granger-cause price deviation	0.04817
Price deviation do not Granger-cause UK import	4.467e-06
UK export do not Granger-cause price deviation	0.125
Price deviation do not Granger-cause UK export	1.443e-14

Figure 34. P-values and null hypothesis for BBL pipeline flow (2015-2020).

The analysis conducted between the years 2015 and 2020 reveals the presence of bidirectional Granger causality between UK natural gas imports and the price divergence observed between the NBP and TTF hubs. This indicates that information pertaining to imports into the UK via the BBL pipeline holds predictive value in understanding price deviations between these hubs. Furthermore, it signifies that the price deviation can be useful in predicting the volume of natural gas imports into the UK through the BBL pipeline. Additionally, the findings suggest that price divergence serves as a valuable predictor of natural gas exports from the UK to the Netherlands.

6.2.3 *Analysis result of BBL gas flow compared in price deviation between NBP and TTF period 2021 – 2023*

2021-2023	
Null hypothesis	P-value
UK import do not Granger-cause price deviation	0.9995
Price deviation do not Granger-cause UK import	0.9956
UK export do not Granger-cause price deviation	0.02662
Price deviation do not Granger-cause UK export	7.482e-05

Figure 35. P-values and null hypothesis for BBL pipeline flow (2021-2023).

Between 2021 and 2023 the analysis suggests a shift in the Granger causality, from the previous period, where the flow of natural gas to UK no longer predict price difference nor is predicted by the price difference. The results now suggest a bidirectional Granger causality between the UK gas export and the price difference between NBP and TTF, which means export from the UK to the Netherlands is useful in predicting the price difference and vice versa. This result is similar to the results from the full sample (2008-2023), but there is a stronger bidirectional causal relationship, when only looking at the last period.

7

Discussion

The following chapter provides a discussion of the results discovered in both the quantitative and qualitative research which have been conducted. The discussion will highlight possible reasons for the gas price deviations between the UK and continental Europe in 2022 and examine potential implications. Natural gas as a commodity should in theory be bound to the LOP and there should normally be minor differences in gas price between the trading hubs. This was not the case in 2022, which raises the question of which factors have contributed to the significant deviation.

7.1 Gas Price Decoupling

As aforementioned, the general shortage of natural gas in Europe resulted in a price increase in both the UK and continental Europe, observed by the rise in prices for the NBP and TTF markets in 2021. In 2022, a significant price deviation occurred between the hubs, with TTF prices being much higher than NBP prices.

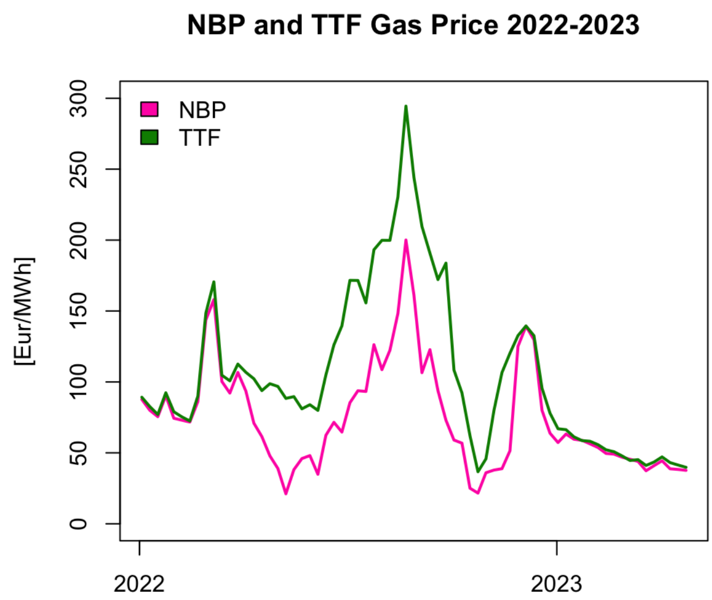

Figure 36. NBP and TTF prices from 2022-2023.

As detailed in the analytical section, the outcome of the Granger causality examination indicates low degree of Granger causality between the two gas prices in period 2008-2021. Thus, the respective prices are not useful in predicting the other. Nevertheless, the assessment indicates that the prices have a stronger causal relationship and are more useful in predicting the other during the period 2021 to 2023. The noticeable disconnect between prices during this period, signifies that there is lesser correlation, and the deviation should be attributable to external factors.

As stated in the theory chapter, if markets are efficient, it becomes impossible to "beat" the market by identifying undervalued or overvalued securities, but limitations and constraints may drive the market to be inefficient. If there is a strong correlation between gas prices in different trading hubs, this would according to EMH be an efficient market. Consequently, a weak correlation would indicate an inefficient market. In addition, if there is any Granger causality between the trading hubs it would indicate an inefficient market. From 2008 to 2021 the prices have closely followed each other indicating an efficient market. Conversely, the bidirectional Granger causality from 2021-2023 indicate that the EMH is no longer fulfilled. The result appears reasonable given the fact that the two markets have traditionally been considerably correlated, and now experience significant price disparities.

The decoupling of prices is also observed in the cointegration analysis. The findings of the cointegration test suggest the presence of at least one cointegrated relationship in the natural gas prices from 2008-2021. The existence of a long-term relationship between the variables indicates efficient incorporation of available information in the market, thus supporting the EMH.

However, the study also reveals a weakening of the relationship between NBP and TTF gas prices in the period of 2021-2023. Specifically, the cointegration test indicates no cointegrated relations, and the correlation test results show that a lower correlation coefficient is observed, suggesting a weaker relationship between the two variables. These findings indicate a less efficient natural gas market during this period, and further support the theory that external factors may have affected the relationship between the two prices.

7.2 BBL Flow

The BBL analysis findings seemingly have important implications for the European gas market, as the BBL pipeline plays a critical role in balancing gas supply and demand between the UK and the Netherlands as well as sustaining the market integration.

The Granger causality analysis reveals that during the initial period from 2015 to 2020, price deviation exhibited predictive power for both import to the UK and export from the UK to the Netherlands. However, in the subsequent period from 2021 to 2023, a notable shift occurred, as the causal relationship between price deviation and import to the UK ceased to exist. Simultaneously, a new relationship emerged, indicating that import to the Netherlands now holds predictive value for price deviation, and vice versa. This observation is of particular interest, as it implies that the fluctuations in pipeline export from the UK to the Netherlands may constitute a crucial determinant of the substantial price deviation.

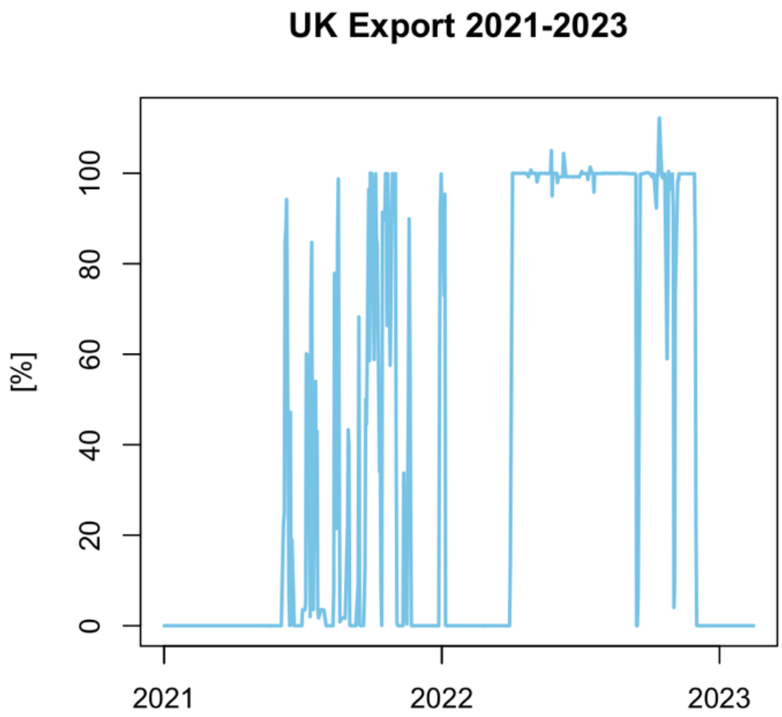

Figure 37. UK natural gas export (2021-2023).

As shown in figure 37 of the UK's natural gas exports to the Netherlands in 2022, it is evident that for a significant portion of the year, the export flow was consistently operating at maximum capacity. This shows how the Netherlands was struggling to meet the demands of natural gas in the country, while the UK had an excess in supply, compared to their storage capacity. The BBL pipeline is meant to stabilize gas prices in the region by ensuring a reliable supply of natural gas for both countries, but was not able to function this way due to running on maximum capacity. According to the theory of supply and demand, an increase in demand leads to a rise in price, while a surplus of supply leads to a drop in price. Hence, the NBP price is expected to be lower than the TTF price, which is consistent with the data.

Additionally, pipeline maintenance, specifically on the pipeline from Norway to Germany, contributed to the supply shortage in Europe, forcing natural gas to go through the UK. If the gas from Norway did come to Germany, as usual, the gas could be transferred further to the Netherlands from the pipeline connection between Germany and the Netherlands. Since a major portion of the Norwegian gas ended up in the UK, and the BBL pipeline could only transfer at a certain maximum flow rate, the Netherlands ended up not getting the supply needed, resulting in a further rise in gas price on the TTF compared to the surrounding European countries.

7.3 UK Storage

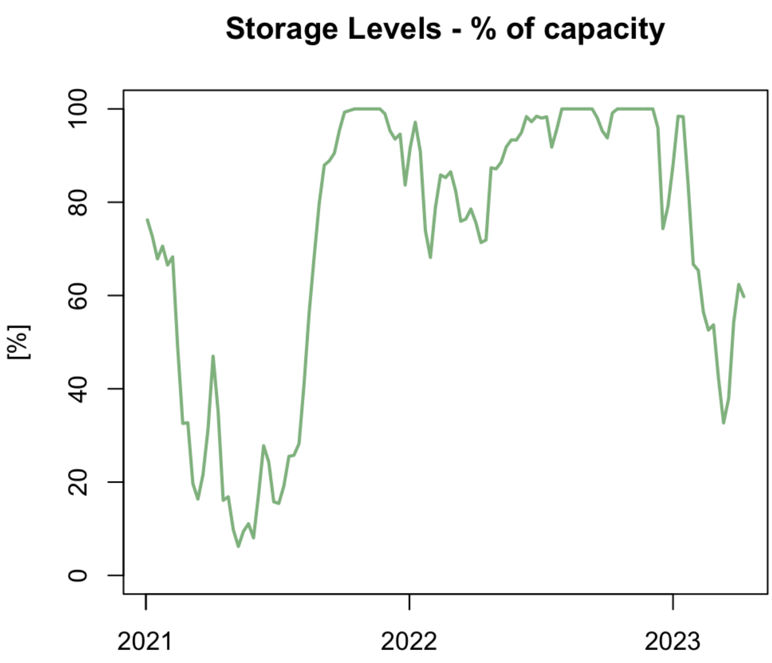

Figure 38. The Uk storage levels % of max capacity (2021-2023).

Despite the high demand for natural gas in the UK, the country's storage capacity quickly reached its maximum limit due to relatively low storage capacity. Storage theory suggests that the storage of natural gas can influence the market price of the commodity. In situations where the storage capacity is full, the producers may have to sell their excess supplies to avoid any further storage costs.

The theory of storage assumes that traders will buy commodities when prices are low and store them for future sale when prices are high. However, when UK storage capacity is full, additional supplies cannot be stored and UK was forced to sell excess inventory at lower prices, leading to a decrease in market prices. This may have led to a situation where the traditional relationship between NBP and TTF no longer held, and market dynamics became more complex. This may be a contributing factor to the discount in NBP price compared to the TTF price.

7.4 LNG Demand

As aforementioned, LNG became key for European countries to be able to get enough gas supply following the removal of supply of Russian gas. Due to limited regasification capacity, the Netherlands was not as prepared as the UK for the extreme surge in LNG to the European market. This meant that the UK had a superior capability to take advantage of LNG trading, compared to the Netherlands. The UK's increased supply of LNG was seemingly led by a discounted NBP price relative to TTF, which aligns with economic theory indicating that a rise in supply results in a drop in price. The study has also revealed that countries like France and Spain have a great advantage in access to regasification capacity, compared to the Netherlands, and that the price of the large trading hubs in these countries also had a discount to the TTF in 2022. This supports the theory that an advantage regarding regasification capacity could be a contributor to driving price deviations.

7.5 Combining Factors

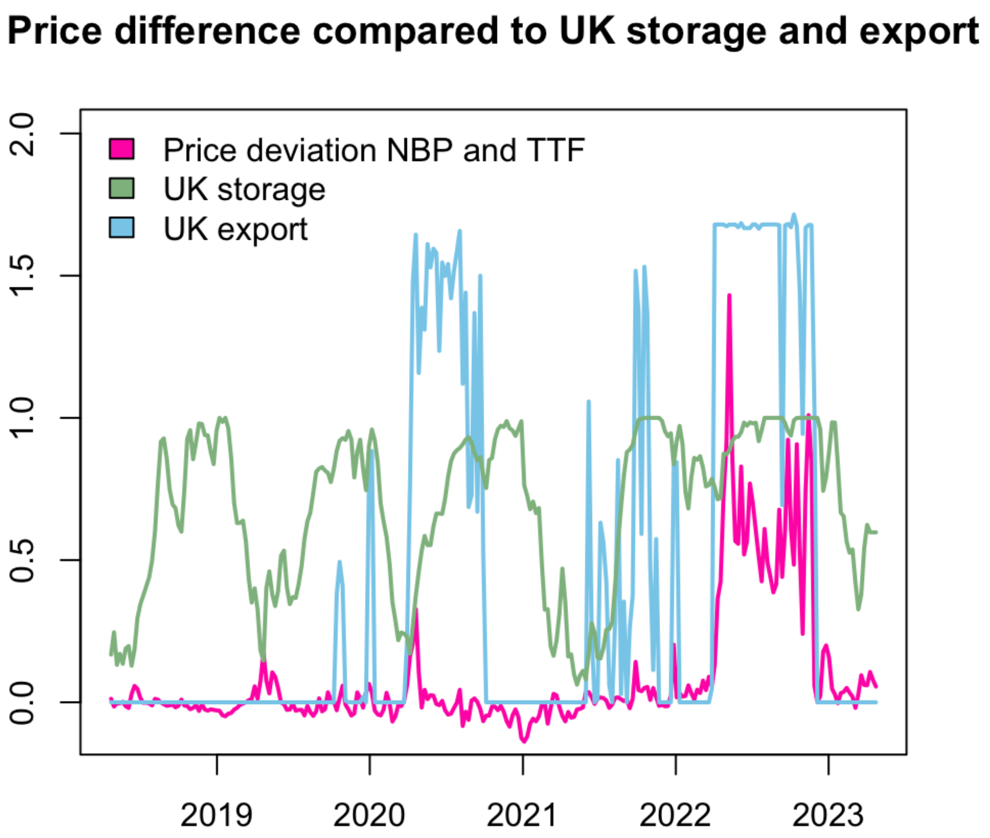

Figure 39. Price deviation, UK storage and UK export through BBL pipeline.

The plot in figure 39 showcases the logarithmic values of price deviation, the storage of natural gas in the UK, and exports to the Netherlands through the BBL pipeline. Observing the plot depicts that the storage of natural gas in the UK reached its maximum capacity in 2022 and for the first time, since the UK started export through the BBL pipeline, the storage and export capacity were maxed out simultaneously.

While the UK exported natural gas to the Netherlands at maximum capacity, the limits to arbitrage may have been inhibiting traders' ability to take advantage of the price discrepancy by buying natural gas at the lower NBP price and selling it at the higher TTF price. This may be a contributing factor to what is preventing arbitrage from taking place, leading to price differentials. This is supported by storage theory, which states that the intertemporal pricing condition does not hold when storage is at maximum levels. Storage theory also suggests that the price will spike downwards when the storage is at full capacity, which could explain the reason for the NBP price being at a discount to the TTF price.

As aforementioned, the research found evidence of a causal relationship between NBP and TTF prices after 2021. The relationship is not unforeseen, given that supply and storage constraints are drivers that may cause inefficiency in the natural gas market. This implies that natural gas trading may not be fully efficient, and there may be opportunities for traders to generate excess returns by exploiting market inefficiencies during the geopolitical or abnormal events in 2022.

7.6 Future Markets

The UK is developing larger natural gas storage facilities to ensure the country's energy security in the future. Meanwhile, the Netherlands is investing in higher LNG import capacity and Europe is expanding their use of other energy sources like wind and solar power. The shift towards greater domestic energy self-sufficiency has potential to bring more balance to the natural gas market. It may result in a reduced need to export natural gas through the BBL pipeline, as well as prevent the UK's natural gas storage facilities from reaching maximum capacity. As the world moves towards a more sustainable and diversified energy mix, it will be interesting to see how the gas market continues to evolve in these areas and around the globe.

8

Conclusion and Further Work

This final concluding section brings together all the key findings and arguments presented throughout the study. By combining quantitative and qualitative research methods, the study aimed to provide a comprehensive understanding of the differences in gas prices, offering insights into what might cause price deviation in the future. The conclusion tie together all the pieces of the thesis, providing a clear and concise summary of the research that was conducted and the results that were achieved. The conclusion of the rapport aims to answer the aforementioned research problem: *Analyse the European gas market to find possible drivers of the gas price deviation between NBP and TTF in 2022.*

The findings of the study highlight the interconnectedness of natural gas supply and demand dynamics in Europe. The cut in Russian natural gas supply created a shortage of natural gas in both continental Europe and the UK. The reliance on LNG suddenly became much greater and the European countries had to adapt to the change in gas supply. The Netherlands, which inhabits the largest gas trading hub in Europe (TTF), was not prepared for the drastic change in 2022. The LNG regasification capacity was now extremely important for getting the amount of gas supply needed. The Netherlands only had a regasification capacity of 12 bcm per year, while the UK boasted a much more impressive capacity of 49.2 bcm per year. The UK's large supply of natural gas through pipelines and LNG led to storages quickly filling up to maximum levels. This set up the situation where the Netherlands had a supply shortage, and the UK had a supply excess of natural gas. Conversely, the oversupply of natural gas, compared to storage capacity, seemingly led to lower NBP prices compared to TTF prices.

By the analysis conducted on day-ahead prices from NBP and TTF, it was discovered that the European gas market was historically a fluid and well-integrated market due to the direct pipeline connection between the Netherlands and the UK. However, the analysis from the period 2021-2023 showed that there had been a decoupling between the markets and that TTF held a stronger predictive power over NBP in this period. These results show analytical evidence suggesting that outside factors were driving the price disparities.

To understand how the decoupling between the two markets appeared, the BBL pipeline was studied. Findings from the Granger causality analysis, on the BBL pipeline gas flow and the price difference, suggested that there was a bi-directional causality between the supply to the Netherlands and the price difference in the period 2021-2023. These results infer that the export of gas from the UK to the Netherlands could be useful in predicting the price deviation. The export data showed that the UK had been exporting at maximum or close to maximum levels during the period when the price deviation occurred. According to the analysis, these large export levels from the UK could be a key factor to the price deviation. Also, because of the UK's maxed-out storage capacity and maximum export to the Netherlands, the price deviation can be partly attributed to the concept of limits to arbitrage and the intertemporal pricing condition not holding.

From the result from analysis and research, the deviation in gas price between the NBP and the TTF would appear to have emerged as a consequence of different factors working simultaneously. The following key factors are highlighted:

- Supply shortage in the Netherlands
- Low regasification capacity in the Netherlands
- Excess supply in the UK, compared to storage capacity
- Export levels at maximum from the UK to the Netherlands trough the BBL pipeline

The study implies that the analysis results highlight the importance of the BBL pipeline in the European gas market and underline the need for continued investment in gas infrastructure to ensure a stable and competitive market for consumers and businesses alike. Infrastructure and capacity building enhance natural gas supply diversification, which can help to mitigate supply disruptions and manage price volatility.

The UK's focus on expanding their natural gas storage capacity, combined with the Netherlands' investments in higher LNG import capacity and Europe's move towards renewable energy sources, signals a shift towards greater domestic energy self-sufficiency. This shift could lead to a more balanced gas market, potentially reducing the need for exporting natural gas through the BBL pipeline and preventing the UK's natural gas storage facilities from reaching maximum capacity. Ultimately, this could provide greater stability and security in the European energy market and mitigate price deviations in the future.

Further exploration of the present thesis would be of great interest, as the results have high practical value for traders in the natural gas market. By providing information on the connections between gas prices in Europe, the UK, and the Netherlands, the findings can help market participants better understand and predict price movements. It would also be valuable to assess the generalizability of the results by comparing them with those from other gas trading hubs worldwide. Additionally, it would be worthwhile to investigate potential constraints that may arise in the future that could lead to price deviations in gas markets globally. Such research would help to identify factors that could affect the stability and predictability of gas prices in the long run, which could aid in the development of effective risk management strategies for market participants.

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