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**102**

# Master thesis

# Analysis of the Russo-Ukrainian war and the 2022 Energy Crisis in the Context of Hybrid Threats

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Samtykker til tilgjengeliggjøring i digitalt arkiv Brage JA ☒ NEI ☐

# PREFACE

This thesis marks the end of my master of science in business administration. I am glad I chose to major in Digital Management and Business Analytics as this degree has offered loads of frustration and a lot of new insight into areas that I had little previous knowledge of. It has given me the oppoortunity to master new skills and learn about new fields of study and their exiting developments. If I could I would have written a whole lot more about hybrid warfare, in particular disinformation, and its role in a increasingly digitalized society.

I would like to thank my supervisor Muhammad Yahya who first presented me with the idea of using natural gas price data, for always being willing to assist with invaluable guidance.

I would also like to thank ithe Norwegian Institute for Defence Studies that granted me a master's scholarship as a part of the project "Information warfare and data-driven operations".

I started working on this thesis in a time that was wery difficult to my family and I, and I wish to thank them for their resolute support. The thesis is dedicated to Daniel, whose absence is just darkness.

Victoria Ellingsund,

Oslo, 26.04.2023

## ABSTRACT

By analyzing TTF natural gas prices together with the geopolitical risk (GPR) index, this thesis claims that the prices of natural gas were influenced by the geopolitical risk in Europe in 2021 and 2022. By showing how movements of natural gas prices were affected by the GPR - essentially the war and hybrid threats posed by Russia, the thesis seeks to investigate whether the Russian manipulation of its natural gas exports to Europe ultimately caused the 2022 European energy crisis.

The starting point for this thesis was an observation that as hybrid threats are becoming increasingly common, energy is the perfect tool to exert pressure on state actors as many states are in a relationship with energy suppliers that make them vulnerable to manipulation and extortion. The occurrence of the Russian invasion of Ukraine and the following energy crisis in Europe posed an opportunity to study the events in the context of hybrid warfare.

Time series of natural gas prices and GPR are statistically analyzed through volatility analysis and wavelet transform analysis. Gas prices are checked for volatility and volatility clustering using the GARCH model framework. GPR and gas prices are checked for cross-correlation and co-movement through wavelet transform analysis.

A key finding is that gas prices and GPR move together at the same frequencies indicating that there is covariance, coherence, and that the two time-series move in phase from the beginning of 2021 to the end of 2022. High gas prices and high volatility in the prices are linked to the war in Ukraine and tensions in Europe related to the war, through the GPR index. These findings are discussed together with the pretext of the war in Ukraine and the workings of hybrid warfare.

The study finds that as Russia has incorporated a number of hybrid tactics and strategies in earlier disputes and conflicts, it is more than likely to apply such techniques again and it is reasonable to assume that the energy crisis was result of attempts of hybrid warfare.

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## SAMMENDRAG

Etter å ha sammenlignet priser på TTF naturgass og den geopolitiske risikoindeksen (GPR) hevder denne oppgaven at prisene på naturgass var påvirket av den geopolitiske situasjonen i Europa i 2021 og 2022. Ved å vise hvordan bevegelsene til gassprisene ble påvirket av GPR – av krigen og hybride trusler fra Russland, undersøker denne oppgaven om manipulasjon av eksport av naturgass fra Russland sin side forårsaket energikrisen i Europa i 2022.

Utgangspunktet for denne oppgaven var observasjonen av at hybride trusler blir mer vanlig og at ettersom mange stater befinner seg i avhengighetsforhold med sine energileverandører så er de i en utsatt posisjon der energi kan brukes som pressmiddel for å oppnå sikkerhetspolitiske mål. Den Russiske invasjonen av Ukraina og den påfølgende energikrisen i Europa bød på en mulighet til å studere slike hendelser i lys av hybrid krigføring.

Tidsserier av priser på naturgass og GPR analyseres ved hjelp av volatilitetsanalyse og wavelet analyse. Gassprisene undersøkes for volatilitet og klynger av volatilitet ved hjelp av GARCH modeller. GPR og gasspriser sjekkes for korrelasjon og sambevegelse ved hjelp av wavelet analyser.

Et viktig funn i denne studien er at gasspriser og GPR beveger seg sammen på de samme frekvensene, noe som indikerer kovarians og korrelasjon, og at de to tidsseriene beveger seg i samme fase fra begynnelsen av 2021 til slutten 2022. Høye gasspriser og høy volatilitet knyttes til krigen i Ukraina og spenninger i Europa som er relatert til krigen, gjennom GPR indeksen. Disse funnene diskuteres i lys av omstendighetene som førte til krigen i Ukraina og i lys av hybrid krigføring.

Denne studien finner at ettersom Russland tidligere har benyttet seg av hybride virkemidler i andre konflikter, og mest sannsynlig vil gjøre det igjen, så er det rimelig å anta at de Russiske handlingene som førte til energikrisen var et resultat av forsøk på hybrid krigføring.

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# 1. INTRODUCTION

## 1.1 Introduction to the thesis

On the 5th of September European Commission president Ursula von der Leyen tweeted "*Putin is using energy as a weapon by cutting supply and manipulating our energy markets*" (Karaian & Russel, 2022). Public figures, thinktanks, and media have since the breakout of the war in Ukraine accused Russia of weaponizing energy. The economic interpretation of energy security has changed over time. It was initially equated with dependence on oil imports, but as regional markets have been shaped by history and geography, other energy resources and commodities have become dominant. For a long time, many European countries have been reluctant to dive deep into the geopolitics of energy, with little unity in EU member states' policies. Russia has been the EU's primary supplier of oil and gas for more than twenty years and has taken advantage of the lack of coherence within the EU. McGowan (2011) finds that the invasion, and Russia's cutting of gas exports has led to uncertainty about the future reliability of energy supplies, about the future cost of energy and about the ways which energy suppliers might translate market power into political influence. Nick and Thoenes (2014) state that the Russian-Ukrainian gas disputes of 2006 and 2009 were examples of supply risk related to natural gas imports from Russia. According to Lochner (2011) both incidents were made possible by high dependence on one import route and limited infrastructure flexibility in the affected countries. Stern (2006) notes that European countries' efforts to reduce their dependency on Russian gas was expected to intensify after both disputes, and the incidents should have prompted the EU to take the Russian potential for disrupting energy supply to its member states more seriously. The 2022 Russian invasion of Ukraine came as a shock to European countries and their leaders, shaking the EU's collective sense of ontological security. It has substantially damaged Russia's relations with Western countries and accelerated the transition towards a fragmented world order (EIU, 2023). According to Baran (2007) Russian power and influence is no longer measured in ballistic missile accuracy or bomber production but in miles of pipeline constructed and barrels of oil per day exported. At the time around the invasion, indications of geopolitical risk was higher than they had been in many years. The prices of natural gas on the European market reached an all-time high as Russian gas supplies were unpredictable and limited, causing an energy crisis. Basdekis et. al (2022) state that the impact of the energy crisis in Europe seems to be much more pronounced than in other developed economies, due to the greater dependence of European countries on Russian energy sources. During the Euromaidan in 2014 the Russian-friendly Ukrainian president was forced to resign. As a response, Russia annexed the Ukrainian Peninsula Crimea and staged a separatist rebellion in the Donbas region of Southeastern Ukraine. In the time since 2014, Russia has engaged in hybrid warfare in Ukraine. In the aftermath of the Russian Crimea annexation, the idea of hybrid warfare has quickly gained prominence as a concept to help explain the success of Russian military operations in Eastern Ukraine. Weissmann et.al (2021) describes hybrid warfare as a military strategy that blends conventional warfare, irregular warfare, and cyber-attacks with other influencing methods, such as disinformation, diplomacy, and foreign political intervention. As the Russian invasion of Ukraine in February 2022 demonstrated, conventional warfare is not dead. Danyk and Briggs (2023) find that since the Cold War, the scope of the security field has broadened, mainly due to the development of cyberspace. Disrupting the cognitive sphere and shifting the nature of available information has the potential to cause harm to democracies, because well-functioning democracies depend on trust between public and political institutions and the population. The actions of the Russian government and the following energy crisis has been an eye opener in the sense that energy as a security policy tool and as a tool in hybrid warfare has been demonstrated, and that hybrid threats are more likely today than in past wars. This thesis investigates how an energy commodity essential to the functioning of our modern societies can be manipulated and used as a tool to exercise power. Li et.al (2020) has found a strong correlation between geopolitical factors and crude oil prices during periods of political tensions. The geopolitical risk (GPR) index mirrors outcomes obtained from automated text searches of electronic archives, which capture eleven national and international newspapers selected by Caldara and Iacoviello (2020). GPR is a news-based measure of adverse geopolitical events such as terrorist acts and wars, and associated risks (Caldara & Iacoviello, 2020). It is applied in order to quantify and measure the security situation in Europe in 2021 and 2022. The time period selected in this analysis starts on the 1st of January 2019 - a period of normality before the Covid-19 pandemic and escalations in Russo-Ukrainian tensions. The analysis ends on the 2nd of December 2022, almost a year into the war, and after the initial gas price highs.

## 1.2 Research problem

The goal of this thesis is to shed light on the causes of the energy crisis, the war and how they are interlinked through hybrid warfare that incorporates unexpected and untraditional methods. In this thesis, I aim to discuss whether the high gas prices could be a result of an attempt at hybrid warfare.

The research problem of the thesis is as follows:

**Did Russia cause the European energy crisis through acts of hybrid warfare?**

This problem will be addressed by examining the relationship between natural gas prices and the GPR index, using the following research questions:

Research question 1: did the outbreak of the war have a negative impact on natural gas prices?

Research question 2: is there a significant relationship between prices of natural gas and GPR?

## 1.3 Limitations

Before conducting the analysis, based on the overview of the selected literature for this assignment, I will assume that the different markets have a short-term effect on each other. This study will not incorporate an analysis of the long-term relationship between TTF natural gas and the geopolitical risk (GPR) index. Even though that might have given an overview of the historic correlations between the two in relations to other events associated with high geopolitical risk, it is beyond the scope of this study. GPR is assumed to incorporates the severity of the situation in Europe, both the war and the escalated risks associated with it. The energy crisis in Europe did not arise solely as a result of natural gas disruptions, and other commodities could have been analyzed. This would however have required a broader and less of an in-depth study.

## 1.4 Structure of the thesis

This thesis is structured as follows: The literature review of this thesis starts with an introduction to energy and the environmental considerations of energy consumption. The natural gas market in Europe and its 2022 energy crisis is discussed along with the energy dependencies that evolved to become one of the primary security issues in the build-up to the Russo – Ukrainian war, and the primary cause of the energy crisis. The review then takes on the background for the turbulent relationship between Ukraine and Russia, the Russian invasion, and the following war. The literature review ends with an account of hybrid warfare and how disinformation and manipulation of energy is a tool in this.

In the data and research methodology chapter, the research design of this thesis is presented, along with the data and the choices of analysis. The main survey and the statistical analysis is presented here.

The results chapter presents the main empirical findings derived from the statistical analyses, including descriptive statistics for the relevant data, results of the correlation analysis, and the regression analysis.

For the final analysis of the research problem and research questions of the thesis, a discussion based on the results of the statistical analysis arising from the survey along with the main conclusions will be presented.

The thesis is completed with a conclusion. Implications and suggestions for further research that have been discovered through the research process are presented.

# 2. LITERATURE REVIEW AND THEORETICAL GROUNDING

This literature review is structured as follows: the first part is about energy, the natural gas market and prices and the workings of the energy crisis in Europe in 2022. The second part focuses on the war in Ukraine and the most important events that preceded it. The third part scrutinizes how energy is a tool in hybrid warfare. The geopolitical risk (GPR) index is accounted for, and lastly the research problems and their hypotheses are presented.

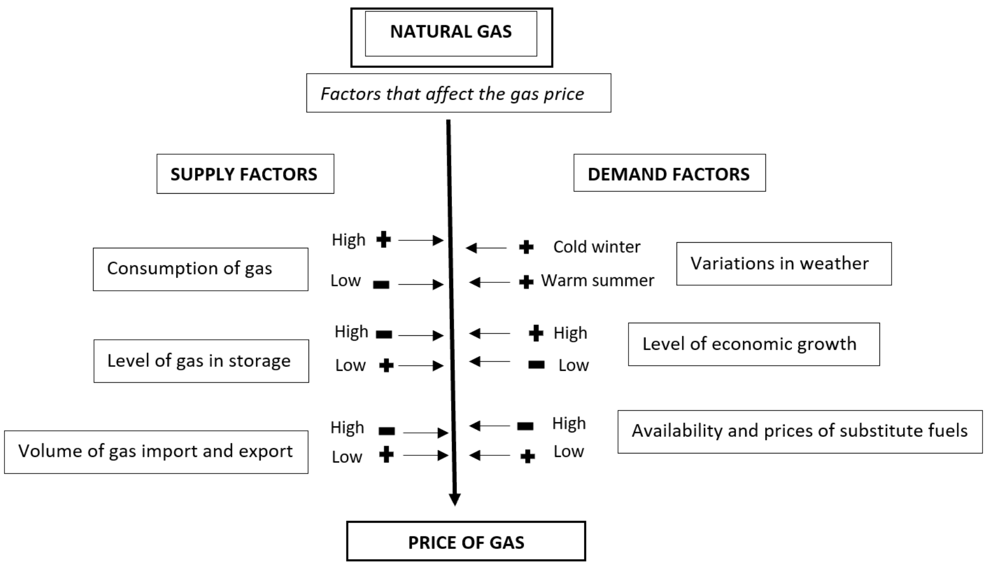
## 2.1 Energy lessons

This part of the review focuses on natural gas, the natural gas market, and disruptions in the European natural gas market. That focus reflects technical constraints on energy infrastructure in Europe that could prevent a full replacement of supply. According to Di Bella et. al (2022) coal and oil markets are likely better able to adjust to disruptions through trade diversion. As Kuzemko et.al (2022) note the energy crisis has the potential to escalate other to crises in the future, as reframing energy as a geopolitical security concern in acute crises has, tended to obfuscate and downplay other energy policy goals, such as phasing out fossil fuels.

### 2.1.1 About the energy market and pricing of natural gas

In economic terminology, “energy” includes energy commodities and resources that embody large amounts of physical energy and has the capacity to perform work (Sweeney, 2004). Sweeney (2004) states that energy commodities such as gasoline, diesel fuel, natural gas, propane, coal, or electricity, can be used to provide energy services for activities such as lightning and heating. Energy resources can be extracted or harvested to produce energy commodities (Sweeney, 2004). Energy demand depends on demand for desired services, not the energy commodity itself. The global energy market is a commodity market for the trade and supply of energy commodities and resources, and the biggest commodities are oil, natural gas and coal (World Bank Group, 2022). The US Energy Information Administration states (2022) that natural gas is found in two basic forms, associated gas and non-associated gas, on land and offshore. Associated natural gas is natural gas that occurs with deposits of crude oil either as free gas (associated) or as gas in solution with crude oil (dissolved gas). Non-associated gas is natural gas that is not in contact with significant quantities of crude oil in the reservoir where it can be found. It stands to reason that extraction and production of natural gas is closely entwined with the extraction and production of crude oil. Nick and Thoenes (2014) find in their study that natural gas price fluctuations follows the fundamental signals both from supply, such as interruption of imports, and demand, such as low temperatures. The most important price factors are visualized in figure 1. The prices decreases when the supply of gas increases and vice versa. An increase in demand leads to high prices, and high prices tend to moderate demand which in turn lowers the price. There are some major supply-side factors that affect prices; amount of natural gas consumption, the level of natural gas in storage, the volumes of gas imports and exports. The major demand-side factors are variations in winter and summer weather, the level of economic growth – a strong economy will increase the consumption of gas, and the availability and prices of other fuels (EIA, 2021). The latter factor will again be influenced by to what degree infrastructure is adapted to substitute energy sources. The gas prices have a seasonal component, which is primarily caused by how weather disrupts gas production and affects demand for gas. Severe weather phenomena such as hurricanes and very low temperatures can have a negative impact on production, thereby reducing supply of gas and increasing the prices (EIA, 2021). Very cold winters and hot summers will lead to an increase in demand for gas for heating and cooling purposes, thus driving prices upwards.

*Figure 1: Self-composed model of factors that affect the gas prices*




In the long-term, gas prices are closely tied to coal prices, crude oil prices, the economic climate and the substitution relationship between different energy commodities (Nick &

Thoenes, 2014) (Villar & Joutz, 2006). In their work on the relationship between crude oil prices and natural gas prices, Villar and Joutz (2006) however, argue that the prices of crude oil and natural gas have moved independently from one another on an increasingly frequent basis for the past years. The crude oil price is determined on the world market, and the market for natural gas is more regionally segmented. The oil price affects the natural gas price and not vice versa. Despite this there are a number of economic factors linking oil and natural gas prices through both supply and demand (Villar & Joutz, 2006). An increase in the oil price motivates consumers to substitute oil products with natural gas, thereby increasing the demand and the price of natural gas (Villar & Joutz, 2006). The increases in crude oil prices resulting from an increase in crude oil demand may increase the amount of natural gas produced as a co-product of oil, which would tend to decrease natural gas prices (Villar & Joutz, 2006). The connections between geopolitical tensions and supply/demand is analyzed by Zakeri et.al (2022) whom have found in their analysis of the Ukraine war, the Covid-19 pandemic and energy transitions that the war impacts energy production, energy supply and trade. They also find that demand is affected by actions and decisions by nations and individuals, as well as anticipations of supply disruptions.

### 2.1.2 The European market

During the 1990s, at a time when most national electricity and natural gas markets were still monopolies, the European Union and the Member States decided to open these markets gradually to competition (Ciucci, 2022). Through the implementation of a number of directives and Energy Packages from 1996 and until 2021, the energy market was increasingly liberalized. According to Pirani et. al (2009), despite this, Russia has overall been the largest supplier of natural gas to the European Union since the fall of the Soviet Union in 1991. The debate on the EU’s fifth energy package changed radically after the Russian invasion of Ukraine and the ensuing energy crisis, which resulted in Russia unilaterally turning off the gas supply (Ciucci, 2022). According to Zakeri et.al (2022) the physical blockade of gas and sanctions imposed on Russia significantly increased gas prices and disrupted the energy trade, sparking an energy crisis in Europe. The European energy market experienced high electricity prices that year as a consequence of these events. Electricity prices also reflected high prices of oil, insufficient production of substitutes, such as nuclear energy, and an unexpectedly fast economic rebound after the Covid-19 pandemic which led to a high demand for electricity (IEA, 2023). Zettelmeyer et al. (2022) state that the result was that the market had become so tight that even small changes in natural gas supply had a large effect on electricity prices. According to Nick and Thoenes (2014) Germany was particularly vulnerable because it has been one of the largest European gas markets for many years and has been heavily dependent on natural gas imports via pipelines. They state that German industry is the motor in the economy of the EU. This is part of the reason why the fact that Germany had made itself dependent on Russian gas, and therefore the supply shortage of natural gas hit German economy hard, has had grave consequences for the rest of the EU. On the 1st of March 2022 the European Parliament condemned Russia's military aggression against Ukraine, called for the scope of sanctions to be broadened and for them to be aimed at strategically weakening the Russian economy and industrial base. In April the EU Parliament adopted a resolution calling for an immediate full embargo on Russian imports of oil, coal, nuclear fuel, and gas, for Nord Stream 1 (NS1) and Nord Stream 2 (NS2) to be completely abandoned, and for a plan to be presented to continue ensuring the EU's security of energy supply in the short-term (Ciucci, 2022). To mitigate the problem, Norway increased its imports of natural gas to Europe, and liquified natural gas (LNG)  from the U.S.A became the second largest source of gas imports to Europe (Palti-Guzman et al., 2023) as LNG is the main substitute energy resource for natural gas (Zettelmeyer et al., 2022). The impact of the crisis on macroeconomic and financial stability could be devastating because of accelerated inflation (Zettelmeyer et al., 2022). Many European countries have faced higher interest rates in 2022 and 2023 as a consequence of the war and the energy crisis.

## 2.2 The security and dependency

If the producer can go longer without revenue than the consumer can go without gas, their relationship will not encourage stability (Rühle & Grubliauskas, 2015). For the past 20 years or so, what European countries have called security of gas supply has essentially been a growing dependence on imported energy. According to the European Commission (2014) in 2014, the EU was the world's largest energy importer, and the majority of its member states were highly dependent on imports of oil and gas. The gross inland consumption of natural gas of all the EU member states was 23, 4% (The European Commission, 2014). Natural gas was the second highest energy resource consumed in the union, and its main suppliers were Russia and Norway. Schmidt-Felzmann (2020) find that Germany has been the primary driver for the Russian transboundary submarine gas infrastructure projects NS1 and NS2, owned and managed by a whole-owned subsidiary of Gazprom. NS1 (2005-2011) and NS2 (2015-2019)

(Schmidt-Felzmann, 2020) each consist of two parallel pipelines running from Russia across the Baltic Sea to Germany (McGowan, 2011). According to Schmidt-Felzmann’s (2020) analysis of the challenges surrounding NS2 and the import of Russian gas to the EU, NS1 which had been in the workings since the Soviet period and was taken into use in 2012, was for a long time a source of conflict both with Russia and within the EU. The launch of NS2 was contested because of Russia’s illegal actions in Ukraine. After the 2014 annexation of Crimea and start of hybrid war Donbas and Luhansk, Russia reduced gas flows to European countries that marked their stand against Russia’s actions in an attempt to deter them from supporting Ukraine (Krajewski & Lopatka, 2014). Since 2014 and the loss of Ukrainian territorial control in parts of Eastern Ukraine, Gazprom has billed Ukrainian oil and gas company Naftogaz for the Russian gas that Gazprom supplies to the Donbas region – stating that as long as Kyiv consider Donbas Ukrainian it has to pay for its gas. Russia applies a similar tactic in Transnistria, where it charges The Republic of Moldova for the gas supplied to Transnistria. In 2015 Moldova had accumulated a gas debt of around half of the country’s GDP (Rühle & Grubliauskas, 2015).

### 2.2.1 Russo-Ukrainian gas relations

In 2004, Gazprom exported gas to 22 European countries. All gas, except for gas to Finland and the portion of Turkish export transited through the Blue Stream[1] pipeline (Stern, 2006) transited through Ukraine, Belarus and Moldova. These are former Soviet countries and have historically paid a lower price for oil and gas originating in Russia than other countries. According to Stern’s (2006) analysis of the Russian–Ukrainian crisis of 2006, Ukraine held the pivotal geographical position in the transit of Russian natural gas, and was incremental to exports, transiting 80 percent of all gas, with Belarus and Moldova transiting the remainder of it. In the 1960’s this gas came mainly from Ukraine’s own onshore fields, but these went into decline in the 1970’s. Pirani et al. (2009) find in their assessment of the Russo-Ukrainian gas dispute of 2009 that by 1991, Ukraine was heavily dependent on gas from the western Siberian gas fields in Russia. Furthermore, disagreements concerning the pricing of the gas between Naftogaz and Gazprom, Ukraine’s inability to pay and its high debts caused Russia to cut off gas supplies to Ukraine on several occasions during the 1990’s (Pirani et al., 2009). They were

[1] Blue Stream is an underwater pipeline that carries natural gas from Russia to Turkey across the Black Sea. The pipeline was officially commissioned in 2005, and is operated by Gazprom and Turkish BOTAŞ (Bilgin, 2007).

also the primary causes of the gas disputes of 2006 and 2009. Russia has also had disputes with Belarus concerning the price of oil imports in 2004, 2007, 2010 and 2019 (Zhdannikov, 2019) (BBC, 2007). The Russian government has a controlling interest in Gazprom, and some believe that Gazprom operates as an economic and political arm of the government. Countries that have agreed to share ownership of their pipeline systems with Russia - Belarus and Armenia, have been able to negotiate longer timetables for price increases on imported gas. Gazprom has raised prices more rapidly in countries like Georgia and Ukraine, whose governments have sought to distance themselves from Russia politically (Pirani et al., 2009).

### *The 2006 gas dispute*

The gas dispute of 2006 was the first incident where gas supplies to a large number of European countries were significantly disrupted (Pirani et al., 2009). Russian gas through Ukrainian gas pipes was drastically reduced for three days. According to Stern (2006), the dispute was politically motivated efforts to constrain gas from Ukraine. Russia insisted that it was delivering contracted supplies to Europe to the Ukrainian border and Ukraine insisted that it was not diverting gas from the transit pipelines, but EU countries were experiencing reduced gas flows (Stern, 2006), and countries such as Hungary, Austria and Romania lost about one third of its gas supply. After the 2006 dispute, questions were raised as to whether Russian gas could be considered a secure source of gas supply, and if fundamental changes should be made to European energy policies in the direction of reducing Europe’s dependence on Russian gas (Stern, 2006).

### *The 2009 gas dispute*

According to Lochner (2011) Ukraine transited 65 percent of all Russian gas to the EU in 2009 - more than 100 billion cubic meters of natural gas per year. In January the same year, Russia completely cut off the export of gas to Ukraine for two weeks in what became known as the Russo - Ukrainian gas dispute of 2009. Pirani et.al (2009) find that the cause of the dispute was that the two sides failed to agree on a price for Russian gas exports to Ukraine and a tariff for the transit of the gas to Europe through Ukraine before the previous agreements expired. They argue that Putin prioritized punishing the Ukrainian government for wooing the EU and NATO, above ensuing a steady supply of gas to European consumers (Pirani et al., 2009). The cutoff hit countries in south-eastern Europe which were fully dependent on Russian imports, and partially other countries for 13 days. The consequences involved humanitarian emergencies with parts of the populations in the Balkans unable to heat their homes and severe economic consequences for other countries such as Hungary and Slovakia (Pirani et al., 2009). In order to maintain the gas supply, suppliers had to resort to the stored natural gas and divert gas flows within the natural gas transmission system in Europe (Lochner, 2011).

## 2.3 The War

This part of the literature review focuses on the Russo-Ukrainian war and the events that led to it. Scazzieri (2017) argues that Russia's actions in 2014 and 2022 were aimed at preventing Ukraine's integration with the West, and eventually drawing it back into its own orbit. Helseth (2023) argues that without a credible navy, a country can only aspire to be a regional superpower and not a global one. Hellestveit (2022) points out that The Crimean Peninsula is strategically placed between the Sea of Azov and the Black Sea. Access to the Sea of Azov, the Kerch Strait and the Black Sea with the Crimean Peninsula is important to Russia because it ensures the Russian Black Sea Fleet entry to The Mediterranean Sea and the Red Sea, as well as consolidating Russia's exclusive rights to fisheries in the Sea of Azov. During the early 2000's, Russia tried to define the Sea of Azov as an internal Russian water - as it was in the times of the former USSR (Kormych & Malyarenko, 2022). Without the Black Sea, The Russian Navy is limited to the Baltic Sea and the Arctic Sea in the north, and the Pacific Ocean in the east, where many of its ports are covered in ice during the winter. The deputy general secretary of NATO, Mircea Geoană, claims that the war in Ukraine is essentially about the Black Sea (euronews, 2022), and Hellestveit (2022) argues that in a geopolitical frame, Russia wants to consolidate the Black Sea Fleet in Crimea, ascertain Russian interests in the Sea of Azov and Russian dominance in the Black Sea. Kormych and Malyarenko (2022,1) support this view and find in their study of Russian hybrid warfare in Ukraine that the conflict that emerged after the annexation of Crimea was an element of the Russian strategy of establishing and consolidating a new and more favorable internationally recognized maritime order in the Black Sea, Kerch Strait, and the Sea of Azov. The annexation extended the Russian geographical dominance over the resource-rich Black Sea area and its former Ukrainian offshore gas fields that Russia "nationalized" in 2014. The Russian government have outwardly pointed to other reasons for the invasion of Ukraine, but the geostrategic value of the peninsula for Russia in competition with NATO in the Black Sea ranks first among all arguments (Kormych & Malyarenko, 2022, 7). Nations (2015) and Kilcullen (2016) supports Hellestveit in her analysis of Russian interests in the Caucasus. Nations (2015) emphasizes that Russia attempts to assert its influence in the Caucasus region because it is critical as a land bridge linking the Black Sea, Sea of Azov, and Caspian Sea – areas that have strategic importance in terms of both geopolitics and energy resources.

### 2.3.1 Russian sphere of influence

Russia has since the dissolution of the Soviet Union considered the post-Soviet nations to be a part of the Russian sphere of influence and has had a firm hold on Russian republics that have had a desire to become independent, most notably Chechnya. In his analysis of Russian sentiments towards Chechens Russel (2005) state that the Russo-Chechen wars (1994 to 1996 and 1999 to 2009) have cost perhaps as many as 200 000 lives. According to Nation (2015) Russia pursues an assertive regional policy, particularly in the Caucasus. During the invasion of Georgia in 2008, and still-ongoing occupation of Abkhazia and South Ossetia, Russia has demonstrated the will and capacity to use military force against a neighboring country. Energy security is an important driver of Russia's attempt to ascertain authority in the region as the Caucasus-Caspian region's role as an energy producer and a corridor for shipments of oil and gas to Western markets give it geostrategic importance (Nation, 2015). After 1991 NATO has pushed eastward as more and more countries in Eastern Europe have decided to join. In 2004, Estonia, Latvia, and Lithuania joined NATO and the European Union. Kormych and Malyarenko (2022, 5) claim that Russian strategies are derived from the Russian governments general trend to challenge the US-led system both regionally and globally. President Vladimir Putin – inspired by the ideas of Ivan Iljin and Alexander Dugin, stated in his state of the nation address in April 2005 that "*... the collapse of the Soviet Union was the greatest geopolitical catastrophe of the century…Tens of millions of our countrymen ended up outside our country's borders*" (BBC, 2005).

### 2.3.2 Russia and Ukraine: how it all started

***The Soviet Union***

Ukraine was one of 15 national republics in the Soviet Union and gained its independence in December 1991. In *The gates of Europe* Plokhy (2015) writes that former Communist Party officials led the new Ukrainian state, and for years to come, Russia consolidated its influence on Ukrainian national affairs by backing 'Moscow-friendly' presidential candidates. This has coincided with what was to become one of the primary sources of friction between the Russian government led by President Vladimir Putin and Ukraine: a steady evolving aspiration among Ukrainians to join the European community: the EU and NATO.

### *The Orange Menace*

Gessen (2017) writes in her book *The Future is History* on totalitarianism in Russia that in 2004 Russia firmly took hold of the Ukrainian presidential election. She states that the Russian government opposed the election of the pro-western challenger to the current regime. Moscow-backed candidate Victor Yanukovych lost at the polls, but still claimed victory. This led Ukrainians to take to the streets (Horvath, 2015). An estimated 200,000 people came to the Maidan, Kyiv's Independence Square, to protest the election fraud. This marked the start of the Orange Revolution which received its name after the colors of candidate Yushchenko's presidential campaign (Plokhy, 2015). The protesters set up camp in Kiev's central square and refused to disperse until The Ukrainian Supreme court ordered a revote. Viktor Yushchenko, who positioned himself as independent from Moscow was elected president (Gessen, 2017). To explain their failure in Kiev, the Russian government blamed USA for financing and organizing Eastern European revolutions beginning with the overthrow of Slobodan Milošević in Yugoslavia in 2000, followed by The Rose Revolution in Georgia[2] in 2003 in an attempt to expand American influence east (Gessen, 2017).

### *Maskirovka and the Maidan*

From the time the Russian Empire annexed Crimea in 1783, it was a part of Russia for nearly two centuries. In 1954, Nikita Khrushchev[3] redrew the borders of the constituent republics of the Soviet Union and assigned Crimea to Ukraine. As a consequence of Stalin's purge of the Tatars in 1944, Ukraine gained nearly a million ethnic Russian residents (Gessen, 2017). According to Pomerantsev (2019) Eastern Ukraine have traditionally had a majority of Russian speakers, where Russian state TV and media have been common. Shulman (2004) states in his analysis of Ukrainian national identity that in the early 2000's people from the

[2] The Rose Revolution in Georgia was a nonviolent revolution where crowds of Georgians demanded the resignation of President Eduard Shevardnadze and his party Citizens' Union of Georgia. Mikhail Saakashvili of the New National Movement party became president when Shevardnadze resigned and implemented democratic reforms. The revolution marked the end of post-Soviet influence in Georgian politics (Øverland, 2004).

[3] Nikita Khrushchev was the First Secretary of the Communist Party of the Soviet Union from 1953 to 1964 (Smith & Melanie, 2011).

Donetsk region felt much better about Russians in Russia than about Ukrainians in western Ukraine. The linguistic divide and the opposing historical memories have contributed to the wedge between Ukraine's east and west (Plokhy, 2015). In late November 2013, hundreds of thousands of people poured into the streets of downtown Kyiv demanding reforms, closer ties to the EU and the end of government corruption. In February 2014 the uprising culminated after violent and fatal clashes between demonstrators and police forces the Russian-backed president fled to Russia (Bilefsky et al., 2022). This became known as the Maidan Uprising or the Euromaidan[4]. Russia took advantage of this Ukrainian crisis and on February the 26th, armed men in unmarked uniforms took control of the Crimean parliament. Under their protection, Russian intelligence services engineered the installment of the leader of a pro-Russian party, as the new prime minister of Crimea (Plokhy, 2015). On March the 16th, a referendum was held, and the new Crimean authorities claimed that 97 percent of the voters had supported the reunification of Crimea with Russia. The UN general assembly concluded that the referendum had no legal effects (Holtsmark & Ulfstein, 2022). On the 18th of March president Putin called on Russian legislators to formally annex the Crimea (Plokhy, 2015). Putin claimed neo-Nazi forces had taken power in Kyiv and it was necessary to respond to defend the Russian-speaking majority in eastern Ukraine (Marples, 2020) In early April, paramilitary units showed up in Donbas, the main regional center in the industrial Donetsk region of southern Ukraine, seizing public buildings and set up the Donetsk People's Republic (DPR), and the Luhansk People's Republic (LPR) (Scazzieri, 2017) (Gessen, 2017). The Donetsk region is not only rich in Russian-speaking Ukrainians, but also in energy resources and infrastructure – producing 90 percent of Ukraine's coal (Rühle & Grubliauskas, 2015), and housing large gas fields.

### 2.3.3 Russia and Ukraine: how it is going

On the 24th of February 2022, a Russian force of about 200,000 troops (Hellestveit, 2022, 21) invaded Ukraine from Russia, Belarus, and Crimea. The largest mobilization of military personnel that we have seen in Europe since The Second World War followed. Ukrainian president Volodymyr Zelensky declared martial law on the 23rd of February. NATO and the

[4] The word Euromaidan comes from the words 'Euro' which refers to 'Europe' and the word 'maidan' which means 'square' and refers to the Maidan Nezalezhnosti (Independence square) in Kyiv where most of the protests took place (Pomerantsev, 2019).

EU, along with other western nations such as the USA condemned the invasion. President Putin stated in the beginning of the war that his ultimate goal was to capture Kyiv and remove the Ukrainian government (Troianovski, 2023). Russia is a military power superior to Ukraine, but the majority of Russian forces are poorly trained and equipped, and the equipment that they have is old (Holder et al., 2022). The Ukrainian military forces have showed an enormous will to fight and have been joined by foreign fighters and civilian Ukrainians that have displayed determined resistance. The Russian forces were headed for Kyiv but were forced to retreat and have later focused their effort on Eastern Ukraine. The Russian armed forces have through the winter of 2022-2023 been redirecting their focus towards taking the Donbas region where it has the advantage of already fortified positions and established supply lines (Santora et al., 2023). The shift from a low intensity hybrid conflict to a full-fledged war is consistent with Kormych and Malyarenko's (2022) view that Russia's policy towards Ukraine is driven by a form of competitive influence-seeking where hard power is used when soft power falls short in achieving Russia's goals. They also argue that the war might over time turn into a low-intensity conflict again (Kormych & Malyarenko, 2022). Western countries, spearheaded by USA, have donated vast amounts of money, humanitarian equipment, military equipment and military assistance to Ukraine since the beginning of the war. USA has increased its number of troops in Europe, and NATO has enlarged and strengthened its presence in NATO countries bordering Russia (Bilefsky et al., 2022). According to the UN Refugee Agency (UNHCR), on the 7th of February 2023 more than 8 million refugees from Ukraine were recorded across Europe (UNCHR, 2023). EU sanctions have been implemented limiting the Russian government's ability to use its foreign currency reserves. Russia has also been denied access to the international SWIFT banking system. Millions of Russians are unable to use their credit cards, access their bank deposits or travel abroad (Bilefsky et al., 2022).

## 2.4 Hybrid Warfare

Russian military deception, sometimes referred to as "*Maskirovka*" meaning 'disguise', and active use of hybrid threats has since the annexation of Crimea and Russian interference in the 2016 American presidential election appeared more frequently in the media and scientific literature. According to Diesen (2018) hybrid warfare aims to take advantage of modern information – and communications technology in a struggle for the narrative of reality and political legitimacy in a modern conflict. The term hybrid warfare was coined by Hoffman (2007) in his "*Conflict in the 21st Century: The Rise of Hybrid Wars*", where he states that hybrid warfare can be conducted by both state and non-state actors, and it incorporates a wide range of different kinds of warfare, including terrorist acts, indiscriminate violence and criminal disorder, as well as conventional military tactics. Weissman et.al (2021) write that multiple instruments of power can be taken into use in hybrid warfare, with an emphasis on threats, non-military as well as military, operating below the threshold of open war. It does present a challenge to conventional military thinking, as it essentially seeks to disrupt and undermine the trust between a state and its population. Diesen (2018) states that hybrid warfare is population-centric, and by that he means that the perception of reality and sentiment that the population hold, is strategically important. Liberal democracies are more vulnerable because they depend on the trust of the population, whereas autocracies don't. He refers to Mark Galeotti's statement that conventional warfare is war on governments and hybrid warfare is war on governance (Galeotti, 2016). Hybrid warfare is contextual, and it take advantage of social, political, and religious opposites in a society that can be used to fit a purpose (Diesen, 2018). Barques et al (2022), and Kormych and Malyarenko (2022) refer to hybrid warfare as 'the grey zone', as it renders the distinction between war and peace blurry. Hybrid attacks are often vague and ambiguous (Bilal, 2021), which makes it demanding to attribute blame and to implement a fitting response. Although it has been a contested term, NATO has increasingly addressed hybrid warfare since the annexation of Crimea. According to Bilal (2021) the Russian strategy in Eastern Ukraine involved the use of special forces, local armed actors, disinformation and using the conventional media as well as social media as a tool to take advantage of socio-political polarization. Disinformation is an undercommunicated hybrid threat, and Grendahl Sivertsen et.al (2021) describe disinformation as the development and distribution of wrong or misleading information intended to influence people's perception of reality, as well as their attitudes and actions. Put in the context of hybrid warfare, disinformation is a low-cost, high-impact weapon  that seeks to undermine the credibility of public institutions, opening channels to alternative sources of information. OECD (2022, 2) find that platform and algorithm designs can amplify the spread of disinformation by facilitating the creation of echo chambers and confirmation bias mechanisms that segregate the news and information people see and interact with online. As bad is stronger than good (Baumeister et al., 2001), people tend to spread falsehoods "farther, faster, deeper, and more broadly than the truth, in particular false political news (Vosoughi et al., 2018). An example of hybrid warfare is how China's overtly civilian distant-water fishing (DWF) fleets engage in a wide variety of operations outside of the Chinese exclusive economic zone and play a vital role in aggressively asserting Chinese maritime claims in the South China Sea (Luo &

Panter, 2021). They work as maritime militia units, constantly stretching the limit of what can be considered acceptable behavior. The DWF's have a degree of deniability, and the sheer scale of them demonstrate how China is honing the art of grey zone operations.

### 2.4.1 The weaponization of energy

Rühle and Grubliauskas (2015) write in their paper on energy as a tool of hybrid warfare that NATO has to incorporate energy into its doctrines if it wants to be serious about countering hybrid threats.

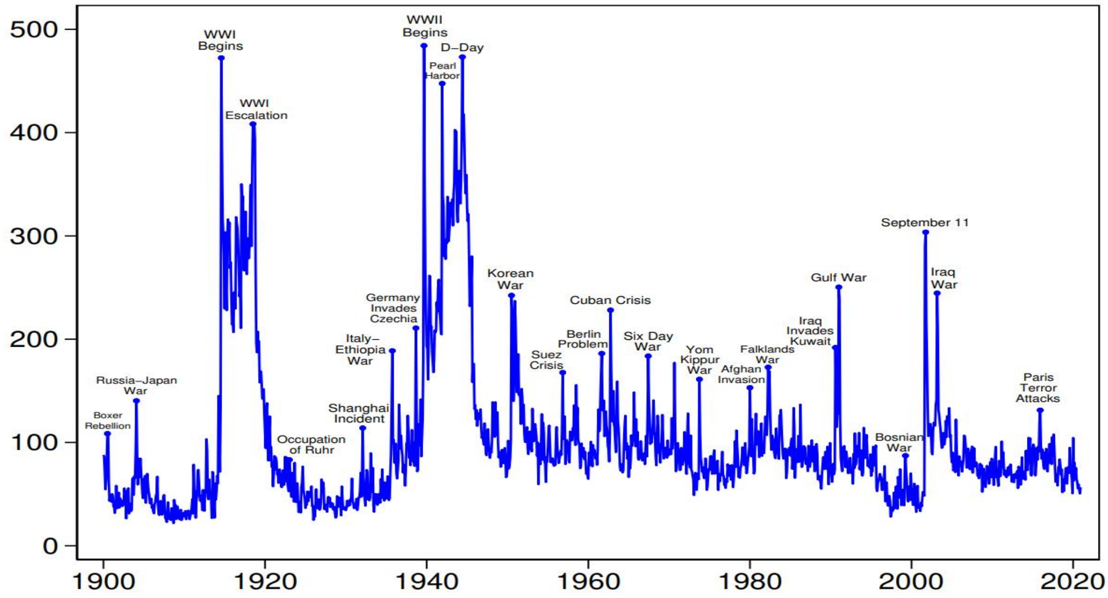
When it comes to energy, geography is still destiny (Rühle & Grubliauskas, 2015). In 2014, Russia applied a combination of military, semi-military, and strategic communication tools to destabilize Ukraine. It also incorporated energy into its strategy by putting pressure on gas prices and expropriating Ukrainian energy assets (Rühle & Grubliauskas, 2015). Before its annexation, Crimea received almost all of its energy from mainland Ukraine. As a part of the attempt to gain control, Russia "nationalized" Chornomornaftogaz – the Ukrainian gas company operating in Crimea (Rühle & Grubliauskas, 2015, 2). It would have been difficult for Russia to take over Crimea without it becoming independent on gas supplies from mainland Ukraine.

On the 26th of September 2022 the Nord Stream pipelines suffered major underwater gas leaks as a result of explosions. Work that was done on the site of the gas leaks by Swedish government representatives revealed traces of explosives, and the explosives are thought to have been placed on the pipes as acts of sabotage (Åklagarmyndigheten, 2022). The sabotage is also an example of what some refer to as *Cable Warfare* (Helseth, 2023). In the world of hybrid warfare, the worlds' network of underwater internet cables is are valuable targets (Scott, 2022). The notion that withholding and disrupting the supply of energy as a tool for achieving political and security means had not been very high up on anyone's agenda before the sabotage of the NS pipelines, although the likes of it was demonstrated in the Russo-Ukrainian and Russo-Belarusian oil and gas disputes. In hybrid warfare, the manipulation of energy supply, financial markets, national institutions, and political relations can have a just as big impact on a society's sense of safety as guns and rockets. According to Kilcullen (2016), weaponizing oil and gas supplies are examples of ways Russia has attempted to put economic pressure on other nations. Palti-Guzman et.al (2023) write that the Russian government was cutting gas shipments "*hoping economic pain would break European and transatlantic resolve to support Ukraine*".

## 2.5 Geopolitical Risk

Caldara and Iacoviello (2020) define geopolitical risk as the threat, realization, and escalation of adverse events associated with wars, terrorism, and any tensions among states and political actors that affect the peaceful course of international relations. The recent GPR index starts in 1985 and is based on automated text-searches on the electronic archives of 10 newspapers: six newspapers from the US, three from the United Kingdom, and one from Canada, which reflects Caldara and Iacoviello's intention to capture events that have global dimension and repercussions (Caldara & Iacoviello, 2020). The index counts, each month, the number of articles discussing rising geopolitical risks, divided by the total number of published articles. Systemic risk is an event that affects a number of systemically important intermediaries or markets, of which a trigger could be an exogenous shock (European Central Bank, 2009). Geopolitical risk comprise domestic and global socio-economic shocks, it is therefore regarded as a systemic risk (Salisu et al., 2022). Caldara and Iacoviello (2020) point out that high GPR leads to a decline in real activity and lower stock returns. They also state that when GPR is high, capital flows away from emerging economies and towards advanced economies, making emerging economies particularly vulnerable to geopolitical tensions (Caldara & Iacoviello, 2020). Salisu et.al (2022) and Zhang et.al (2023) both find that GPR can affect stock market volatility positively, increasing volatility. Zhang et.al (2023) find in their study that GPR has a greater impact on stock market volatility for emerging economies, crude oil exporting countries, and countries at peace. GPR affects volatility in the following ways: a rise in GPR can reduce global trade and investment, GPR can delay the decision-making process of market participants (Salisu et al., 2022), and higher GPR increases the risk associated with investing in financial markets (Zhang et al., 2023). Monge et.al (2023) find that the crude oil price (WTI) and the Baltic Dry Index (BDI) is affected by geopolitical destabilization, on a short-term basis, and on a long-term basis, respectively. Li et.al (2020) has investigated the relationship between crude oil prices and geopolitical risks based on wavelet analysis over the period of 1985–2016 and found a high degree of co-movement in the short-run for the sample period.

*Figure 2: GPR index from 1900 to 2020 (Caldara & Iacoviello, 2020)*




The evolution of the GPR index since 1900 shows that it rose dramatically during World War I and World War II. It has drifted upward since the beginning of the 21st century and has remained at a higher level after 9/11 than before 9/11.

## 2.6 Research questions and hypotheses

Based on the research problem og literature review of this thesis, two research questions with adjourning hypotheses are formulated.

**Research question 1: did the outbreak of the war have a negative impact on natural gas prices?**

**$H_1$:** ***The outbreak of the war led to an increase in prices and volatility in the European gas market.***

Vasileiou (2022) has found that the Russia-Ukraine war has led to increases in natural gas prices and volatility. Fang and Shao (2022) have also found that the war significantly increases the volatility risk in commodity markets. An increase in volatility is generally considered negative because it increases uncertainty which again discourages investments. The severity of the war should have negative effects on natural gas prices through an increase in prices and in volatility.

**H2: *The geopolitical risk (GPR) index reflect the geopolitical situation in Europe in the sample period*.**

According to Sharif et.al (2020) the geopolitical risk (GPR) index is more relevant than other uncertainty indexes when analyzing geopolitical risk since it includes words related to geopolitical tensions and other adverse geopolitical extreme events such as wars. GPR is considered to be a reliable metric for the tensions in Europe leading up to and after the outbreak of the war.

**Research question 2: is there a significant relationship between prices of natural gas and GPR?**

**H3: *There is a positive cross-correlation between the gas price returns and GPR.***

Uddin et.al (2018) has detected a strong relationship between the price of crude oil and GPR. Villar and Joutz have found that there are a number of economic factors linking oil and natural gas prices through both supply and demand (Villar & Joutz, 2006). It is therefore possible to assume a positive relationship between GPR and natural gas.

**H4: *Gas price returns are influenced by GPR.***

GPR and natural gas prices were both high at the time surrounding the outbreak of the war, and analyzing the nature of the relationship between the two is crucial to determine if and how they might have impacted each other.

## 2.7 Summary

This literature review has looked at the mechanisms that drive natural gas prices such as supply and demand factors – and the relationship between gas and oil. It has then focused on the security and dependency aspect of energy. It drew on examples of dependency in the Russo-European energy relationship and the workings of the European gas market in order to get a clear view of the state of European energy affairs before the Energy crisis of 2022. The third part of the review has focused on the war in Ukraine, and the events that led to it. The fourth part described hybrid warfare and the geopolitical risk index was presented. The chapter is finalized with the hypotheses that aim to help answer the research questions.

# 3. RESEARCH METHODOLOGY

Methodology comes from the Greek word “methodos” and it means a prescribed process for completing a task or reaching a goal (Johannessen et al., 2021). In this part of the thesis, firstly research design, acquirement of data, selection and variables will be accounted for, then the analysis of the data will be described before reliability, validity and ethics are assessed. The research methodology is summarized in the end.

## 3.1 Research design

Research design refers to the overall plan of how to conduct research or a survey (Johannessen et al., 2021). The analysis of the time-series is conducted in R, and the script is in appendix A. The statistical properties of the time-series are analyzed and are presented in 3.4 Descriptive statistics (1), 3.5 Analysis of gas volatility (2) and 3.6 correlation analysis (3).

(1) Descriptive statistics cover the basic statistical qualities of daily closing prices, log returns and GPR along with normality, autocorrelation, and stationarity tests.
(2) The volatility data analysis consists of two methodologies; (1) an estimation of a regression model (2) a volatility analysis using the GARCH (1,1) method.
(3) The gas price return and GPR are analyzed by measuring cross-correlation and performing wavelet transform analysis in order to provide an overview of the relationship between the two timeseries.

## 3.2 Describing the data

### 3.2.1 About time series

Time-series is a continuous sequence of observations on a population, taken repeatedly - normally at equal intervals, over time (Bernal et al., 2017). The purpose of using time series data is either to try to understand the past, or to try to predict the future by employing predictive analysis. This study analyses past time series data for a period of four years and describes the movement of natural gas prices under the assumption of geopolitical risk for that period. Most time series models are based on that a time series O, is comprised of the components *trend* (T), *seasonality* (S) and *residual* (I). A time series will contain random variations that cannot be modelled by time or other variables – errors such as white noise. This effect on the series is described as the residual (I), denoted as $\varepsilon_t$. The random element in most data analysis is assumed to be white noise —normal errors independent of each other. In a time-series, the errors are often linked so that independence cannot be assumed. By differencing the time series, the trend and seasonality components are often removed. An additive time series model is written in the following form:

(1) $O = T_t + S_t + I_t, \; t = 1,2,3, \dots,T.$

### 3.2.2 Natural Gas

This study utilizes natural gas prices from Dutch Title Transfer Facility (TTF) gas futures, a benchmark hub for gas prices in Europe. The price quotation is (in euros per megawatt hour). The selected data spans from the 1st of January 2019 to the 2nd of December 2022, with a total of $n$ = 1221 observations in the time-series. The price data are obtained from FirstRateData[5] that specializes in providing high-resolution stock market, crypto and futures data. There are no Saturdays in the data as there is no trade on that day of the week. The gas price data was obtained with the variables listed in table 1.

*Table 1: Variables in the Natural Gas Prices data*

| VARIABLE | DESCRIPTION |
|---|---|
| Date | The date of the observation |
| Open | The price at the time the market opens |
| High | The price at its highest point of the day |
| Low | The price at its lowest point of the day |
| Close | The last transacted price before the market officially closes for normal trading |
| Volume | The volume of gas sold, in euros per megawatt hour |

### 3.2.3 Geopolitical Risk Index

GPR mirrors outcomes taken from automated text-search of the electronic archives which captures eleven national and international newspapers selected by Caldara and Iacoviello. The number of words related to geopolitical risk are counted each day in each newspaper to calculate daily GPR index (Caldara & Iacoviello, 2020). Afterward, the entire index is

[5] https://www.firstratedata.com

normalized by equating the average value corresponding to the 2000–2009 decade to 100 (Sharif et al., 2020). The GPR index dataset was obtained from Iacoviello's website[6]. The data was obtained with a frequency of 1 index measurement/observation per day, spanning from 01.01.1985 to 20.02.2023. The number of observations are $n = 1432$.

*Table 2: : Variables in the Geopolitical Risk (GPR) Index data*

| VARIABLE NAME | DESCRIPTION |
|---|---|
| Day | Day |
| N10D | Number of articles (10 recent newspapers, 1985-) |
| GPRD | Daily GPR (Index: 1985:2019=100) |
| GPRD ACT | Daily GPR Acts (Index: 1985:2019=100) |
| GPRD THREAT | Daily GPR Threats (Index: 1985:2019=100) |
| Date | Date |
| GPRD MA30 | 30 day moving average of Daily GPR |
| GPRD MA7 | 7 day moving average of Daily GPR |
| Event | Major event label |

## 3.3 Preparation of the data

### 3.3.1 Natural Gas

The data was obtained with a frequency of 1 observation per minute. It was converted to daily observations in Excel by adding the minute-observations together and finding the mean for the day, separately for all the price variables. The data was imported into R Studios for further statistical analysis. The daily closing prices were extracted from the other data, made into a time series object, and transformed into logarithmic returns through differencing.

Logarithmic returns measure the rate of exponential growth, the percentage change in observations from day to day. Logarithmic returns are better than linear price scales to illustrate development in prices as they show less severe increases and decreases in price, but linear prices scales will in some cases be better suited at illustrating the magnitude of changes. Logarithmic price scales will be applied in this analysis, but graphs with linear price scales will be used in order to illustrate the development in prices. The closing price is applied here

[6] https://www.matteoiacoviello.com/gpr.htm

because it is the standard benchmark used by investors to track performance over time. $P_t$ and $P_{t-1}$ are the closing prices of the current and previous day respectively.

$$R_{t,i} = \ln(P_t - P_{t-1}/ P_{t-1}) = \ln(P_t) - \ln(P_{t-1})$$

### 3.3.2 Geopolitical Risk Index

The GPR data was pre-processed in Excel, where the time-period was limited to a period of observation from 01.01.2019 to 02.12.2022. The data was imported into R Studios for further statistical analysis. The daily GPR (GPRD) index is used in this analysis, and simply referred to as GPR. The GPRD was extracted from the original data and made into a time series object. The GPRD was transformed into logarithmic returns when conducting the correlation analysis, where Pearson's r requires two variables in a multivariate time series to be of the same form. For all other analysis, the GPRD was analysed with its original linear scale values.

## 3.4 Descriptive statistics

The assumptions of a linear regression model are often not met in the case of time-series. The most common problems are firstly that the residual errors are correlated instead of uncorrelated – the data is autocorrelated, and secondly that the mean and the variance of the time series changes over time instead of being constant –non-stationary data instead of the preferred stationary data. Uncorrelated errors and constant mean and variance are necessary for the calculation of reliable test statistics. In statistics, common parametric tests assume normality - that data is normally distributed.

### 3.4.1 Normality

The natural gas and GPR data are tested for normality by applying four statistical tests; the Jarque-Bera normality test, the Shapiro-Wilk test, the Kolmogorov-Smirnov test, and the D'Agostino normality test. The hypothesis for these four tests are that the null hypothesis ($H_0$:) states that data follows a normal distribution. The alternate hypothesis ($H_1$): states that the data does not follow a normal distribution. Skewness and kurtosis measure the shape of the distribution. Skewness measures the asymmetry of a distribution and kurtosis measures the tailedness of a distribution (Cowpertwait & Metcalfe, 2009). For normally distributed data the expected value of kurtosis is 3 and the expected value of skewness is 0.

## 3.4.2 Unit Roots and stationarity

The estimation of an ARMA model and a GARCH model requires a time-series to be stationary. Three stationarity tests are applied in this analysis. The Augmented Dickey-Fuller (ADF) test, the Phillip-Perron (PP) and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test. These tests analyze the statistical properties of the data and detect stationarity (KPSS) or the presence or absence of a unit root (ADF and PP). The presence of a unit root is the manifestation of 'integratedness' (I(0/1)) of a time series (Mills, 2015). If there is a unit root the series is integrated of order one - I(1), if it is stationary without a trend it is integrated of order 0 – I(0). An I(1) series is differenced once to be I(0). The order of integration helps us decide which ARMA and GARCH models to apply in the analysis. The ADF test tests $H_0$: the data has a unit root and is non-stationary. It can be used by assuming p is large enough to capture the essential correlation structure, which in this case we do.

The Augmented Dickey-Fuller test can be applied by estimating the model:

$$\Delta y_t = \theta_0 + \theta_1 t + (\delta - 1)y_{t-1} + \sum_{j=1}^{k} k\Delta y_{t-j} + \epsilon t$$

Where lagged values of $y_t, \sum_{j=1}^{k} k_j \ \Delta y_{t-j}$ , captures the autocorrelation in the process.

The Phillip-Perron test tests $H_0$: the data has a unit root and is non-stationary against a stationary alternative. It differs from the ADF tests mainly in how it deals with serial correlation and heteroskedasticity in the errors (Shumway & Stoffer, 2011), and ignore any serial correlation in the test regression. The test regression for the PP tests is:

$$\Delta y_t = \beta' \boldsymbol{D}_t + \pi y_{t-1} + u_t$$

where $u_t$ is *I(0)* and may be heteroskedastic.

The KPSS test is used for testing the null hypothesis that a time-series is stationary around a deterministic trend against the alternative of a unit root (Kwiatkowski et al., 1992). It is given by the regression equation:

$$x_t = \alpha + \beta t + \eta_t$$

Where $\{\eta_t\}$ is a stationary time-series.

### 3.4.3 Autocorrelation

The Ljung–Box test tests $H_0$: the residuals are independently distributed. $H_1$ is that the residuals are not independently distributed and exhibit a serial correlation. The Ljung-Box test statistic is:

$$Q = n(n+2)\sum_{k=1}^{h}\frac{\hat{\rho}_k^2}{n-k}$$

Where n is the sample size, $\hat{\rho}_k^2$ is the sample autocorrelation at lag k, and h is the number of tested lags (Ljung & Box, 1978).

The Durbin Watson test is used to detect autocorrelation in the residuals of a regression model. The null-hypothesis states that there is no correlation between the residuals. The test statistic, *d*, is calculated as

$$d = \sum_{t=2}^{T}(e_t - e_{t=1}).^2 \,/\, \sum_{t=1}^{T} e_t^2$$

Where T is the total number of observations, $e_t$ is the $t^{th}$ residual from the regression model.

Autocorrelation in the data will be illustrated by plotting the autocorrelation function (ACF) and the partial autocorrelation function (PACF) in correlograms - common for checking for randomness in data.

## 3.5 Analysis of gas volatility

A regression model is estimated for the log return of the gas price data so that volatility and volatility clustering can be analyzed by applying the GARCH model.

### 3.5.1 Measuring volatility using a GARCH model

Volatility, or variability of a time series is the degree of variation of a time-series over time, usually measured by the standard deviation of logarithmic returns. The data is also checked for volatility clustering, that volatility changes over time and that its degree shows a tendency to persist (Hanck et al., 2021). Models such as the autoregressive conditionally heteroscedastic or ARCH model, first introduced by Engle (1982), were developed to model changes in volatility. These models were later extended to generalized ARCH, or GARCH models by Bollerslev (1986) (Shumway & Stoffer, 2011, 291). The GARCH modelling technique is the standard approach for analyzing statistical models where the variance of the dependent variable depends on time and central explanatory variables. The benefits of applying a GARCH model is that it can produce volatility clusters, and the tails of the distribution are heavier than a normal distribution. The downside of the GARCH model is that it assumes positive and negative returns have the same effect because volatility depends on squared returns, the model has tight constraints on the model parameters and the model tends to overpredict volatility because it responds slowly to large isolated shocks (Shumway & Stoffer, 2011). The equation for the GARCH model is given by:

$$\sigma_t^2 = \omega + \alpha r_{t-1}^2 + \beta \sigma_{t-1}^2$$

Where the ARCH term is $r_{t-1}^2$ and the GARCH term is $\sigma_{t-1}^2$. In general, a GARCH(p,q) model includes p ARCH terms and q GARCH terms (Shumway & Stoffer, 2011).

To apply a GARCH model, three conditions must be met. The data must be checked for stationarity, volatility clustering and for the presence of ARCH effect. If there is no ARCH effect, then applying the GARCH model will not be appropriate for this data.

ARCH is an autoregressive model with conditional heteroskedasticity (Shumway & Stoffer, 2011). ARCH models identify volatility clustering through how large changes in $u_t$ are followed by more large changes. It assumes that a change in $u_t$ will give an increase in the variance, regardless of whether the change is negative or positive. Statistically, volatility clustering implies time-varying conditional error variance (Mills, 2015). The working null hypothesis states that there are no ARCH effects. The model assumes that the variance is a function of historical events or past news. The ARCH is developed by Engle (1982), and as the ARCH (p) follows an AR(p) process it can be written like this:

$$\sigma_t^2 = \omega + \sum_{i=1}^{p} \alpha_i r_{t-i}^2$$

In estimating the ARCH model, the stored residuals from the regression model are regressed on lagged values of themselves. The sample size (T) and the $R^2$ are stored. $TR^2$ are then calculated, and it has an $X^2$ (q) distribution where q is the number of lags.

In a GARCH model, the conditional variance is an ARMA process. The AR component of ARMA is an autoregressive component that checks how much inertia is there in the data. An AR(1) structure will have observations that are likely to be similar if they are close in time (Derryberry, 2014). The MA component is the moving average, and it checks how past random shocks affect the present value of the data. ARMA captures the changes of the mean return, while GARCH presents the variance change of the residuals issued from the mean equation. Plots displaying the ACF and PACF will be used to estimate the ARMA model parameters in this analysis.

Various extensions to the original GARCH model have been proposed to overcome some of the inadequacies mentioned above. The Threshold-GARCH (TGARCH) model allows analysis on the effects of negative and positive return shocks on the volatility. In the case of persistence in volatility, the integrated GARCH (IGARCH) model may be used (Shumway & Stoffer, 2011).

The best model for this data can be found by applying (1) Akaike's Information Criteria (AIC) and (2) Bayes' Information criteria (BIC).

$$(1)\, AIC = \log \hat{\sigma}_k^2 + \frac{n+2k}{n}$$

$$(2)\, BIC = \log \hat{\sigma}_k^2 + \frac{k \log n}{n}$$

Where *n* is the number of observations and *k* is the number of parameters in the model. For each of the models considered, the value of the information criterion is computed. All such values are ranked from low to high and the smaller the AIC or BIC, the better the model. AIC and BIC are penalized-likelihood information criteria that determine lag lengths (Hastie et al., 2017). AIC determines the information value of a model using the number of independent variables in the model, the number of parameters and the maximum likelihood function. BIC estimates if the posterior probability of a model is true under a certain Bayesian setup. They have a goodness-of-fit term and a penalty to control over-fitting. AIC often risk choosing a model that is too large and should be used for cases where *n* is small. BIC risk choosing a model that is too small and should be used when $n$ is large. The penalty for AIC is less than for BIC, and that causes AIC to pick a more complex model (Shumway & Stoffer, 2011).

## 3.6 Correlation analysis

### 3.6.1 Cross-correlation analysis

Cross-correlation analysis is applied to provide an overview of the movements of two or more time-series relative to one another in order to detect whether or not the series have a degree of correlation. Correlation is measured by the correlation coefficient which is a statistical measure for the strength of a linear relationship between two variables. The possible range of the correlation-coefficient is from -1.0 to + 1.0, where 0 indicate no correlation. -1.0 indicate perfect negative correlation, or inverse, and +1.0 indicate perfect positive correlation.

Pearsons's coefficient, or Pearson's *r* is the most common correlation coefficient. It is given by the equation:

$$\rho_{xy} = \frac{Cov\ (x, y)}{\sigma_x \sigma_y}$$

Where $\rho_{xy}$ is Pearson's coefficient, *Cov(x,y)* is the covariance of variables *x* and *y*, $\sigma_x$ is the standard deviation of *x* and $\sigma_y$ is the standard deviation of *y*. It tests a null hypothesis that there is no linear relationship between two variables, $H_0$: $\rho = 0$. Pearson's *r* is tested for statistical significance using a t-test. Normality is a prerequisite for the application of Pearson's *r*. The relationship between the variables analyzed must be linear and with no outliers. GPR and closing prices are made into return variables a multivariate time-series to calculate Pearson's r.

### 3.6.2 Wavelet transform analysis

Wavelet transform (WT) is a mathematical approach widely used for signal processing applications. A wavelet is a mathematical function that divides a continuous-time signal into different scale-components. By applying wavelet transform to analyse wavelet coherence, patterns that might not be obvious by time domain analyses can be found. It is applied here to identify how synchronized the GPR and gas return time-series are by looking at how they are represented in frequency and time.

The wavelets (daughter wavelets) are scaled copies of a finite length oscillating waveform (mother wavelet). Torrence & Compo (1998) state that by decomposing a time series into time–frequency space, one can determine both the dominant modes of variability and how those modes vary in time. The wavelet power spectrum, coherence and phase differences are computed by applying the Morlet wavelet. A Morlet wavelet transform of a time series ($x_t$) is defined as the convolution of a series with set of daughter wavelets generated by the mother wavelet by translation in time by $\tau$ and scaling by $s$:

$$Wave(\tau, s) = \sum_t x_t \frac{1}{\sqrt{s}} \psi * \left(\frac{t - \tau}{s}\right)$$

Where * denotes the complex conjugate (Schmidbauer & Rösch, 2018). A wavelet coherence plot will indicate whether two time-series are correlated or not. The square of the amplitude has an interpretation as time-frequency (or time-period) wavelet energy density, and is called the wavelet power spectrum (Schmidbauer & Rösch, 2018). Wavelet power describes the distribution of power into frequency components composing a signal. Wavelet power, wavelet coherence and phase differences will be analyzed and plotted. The advantage of wavelet coherence over wavelet power is that it shows statistical significance only in areas where the series involved actually share significant periods (Schmidbauer & Rösch, 2018). A phase measures the relative time difference between two sinusoidal functions. Phase differences will indicate if the time series are in phase, or which is leading or lagging.

## 3.7 Ethics

The collection of and analysis of data has to adhere to ethical standards. This study does not contain any information related to personal information of any kind. The data that are used are secondary, downloaded from the internet from credible sources and they are publicly available. The program used for conducting the statistical analysis is open-source, and the code from the analysis is in appendix A.

## 3.8 A summary of the research methodology

The intention of accounting for the details of the data and choices made in the research methodology of this thesis is to be open about the design of the study and to make the analysis verifiable and replicable. The data in this analysis was obtained from Iacoviello’s website and from First Rate Data, preprocessed to daily observations and the time period of 01.01.2019 to 02.12.2022 was selected. The time-series were checked for normality, the presence/absence of a unit root & stationarity, and autocorrelation. A regression model was estimated, and its residuals were checked for autocorrelation. The gas returns were checked for homoscedasticity with an ARCH model. It was then checked for volatility and volatility clustering using multiple GARCH models. To find the GARCH model with the best fit, AIC and BIC were applied. The correlation between GPR and gas returns was analyzed by calculating Pearson's *r*, and the power, phase, and coherence between the two time-series were analyzed by performing a wavelet transform analysis. In the end of the chapter the ethics of the research methodology was discussed.

# 4. RESULTS OF THE ANALYSIS

## 4.1 Descriptive statistics

To visualize the data, figures 3 and 4 show the daily closing prices together with the return of natural gas and daily closing prices together with geopolitical risk index between 01.01.2019 and 02.12.2022. In figure 3, large increases in gas prices beginning in the spring of 2021 are reflected in large spikes in return. The GPR increases in January 2022 and reaches sky high values at the time of the invasion in February 2022. To illustrate the discrepancy between gas prices and the volume sold on the European market, prices and volume is depicted in figure 5. The graph shows an increase in prices and a relatively unchanged demand reflected in the volume sold. Descriptive statistics of the data are presented in table 3.

*Figure 3: Daily closing prices together with log return of gas prices*

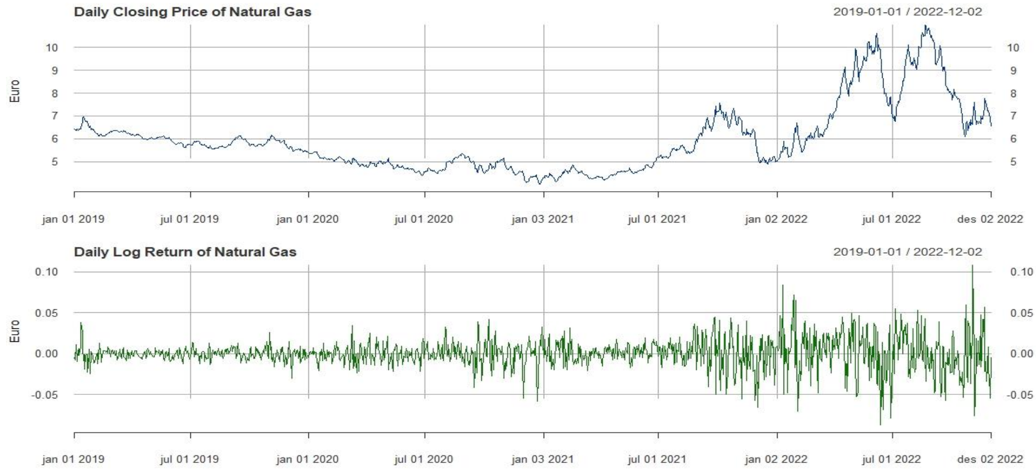



*Figure 4: Daily closing price and geopolitical risk index*

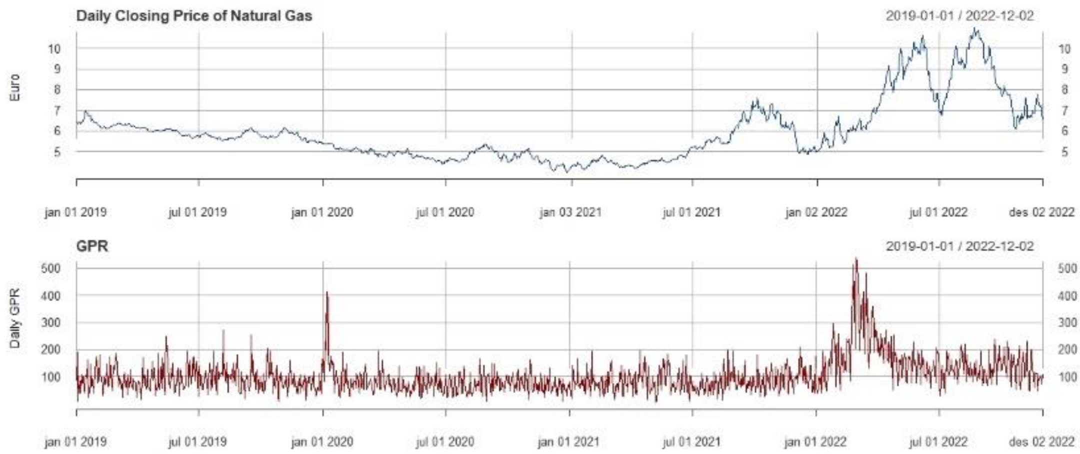


*Figure 5: Daily closing prices and daily volume sold.*

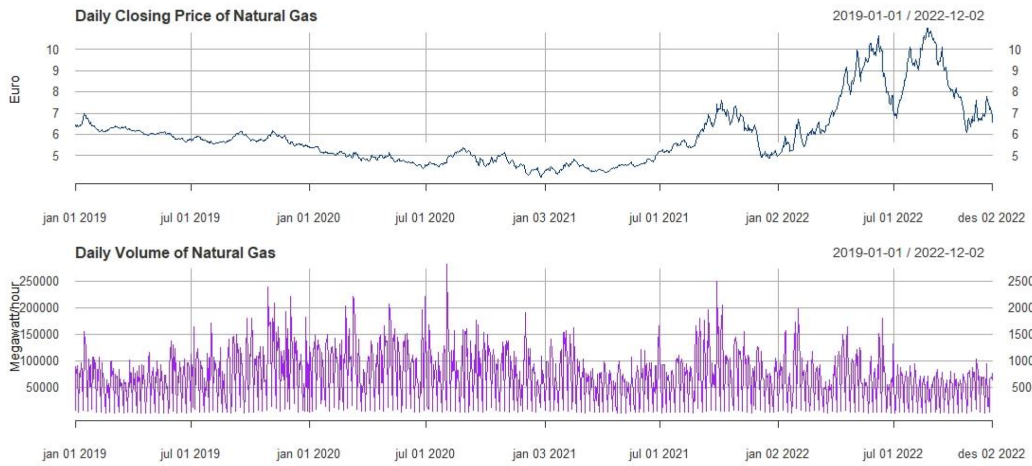



*Table 3: Descriptive statistics*

| | Natural Gas Return | Daily GPR Index (GPRD) | Daily Closing Prices of Natural Gas |
|---|---|---|---|
| Mean | 0.00001 | 101.5 | 5.94 |
| SD | 0.0179 | 63.65 | 1.465 |
| Var | 0.000321 | 4052 | 2.147 |
| Median | 0.0002 | 88.7 | 5.66 |
| Max | 0.1078 | 539.6 | 10.99 |
| Min | - 0.08702 | 3.6 | 4.0 |
| Skew | - 0.0968 | 2.27 | 1.398 |
| Kurt | 3.866 | 8.767 | 1.591 |
| JB stat | 726.2* | 5815.4* | 526.4* |
| Q (15) | 71.1*** | | |
| Q2 (15) | 249.7*** | | |
| KS stat | 0.0000* | 0.0000* | 0.0000* |
| SW stat | 0.0000* | 0.0000* | 0.0000* |
| D'agostino stat | 0.0000* | 0.0000* | 0.0000* |
| LB stat | 0.0000*** | 0.0000*** | 0.0000*** |
| ADF | 0.01** | 0.01** | 0.4 |
| PP | 0.01** | 0.01** | 0.5 |
| KPSS | 0.1 | 0.01** | 0.01** |

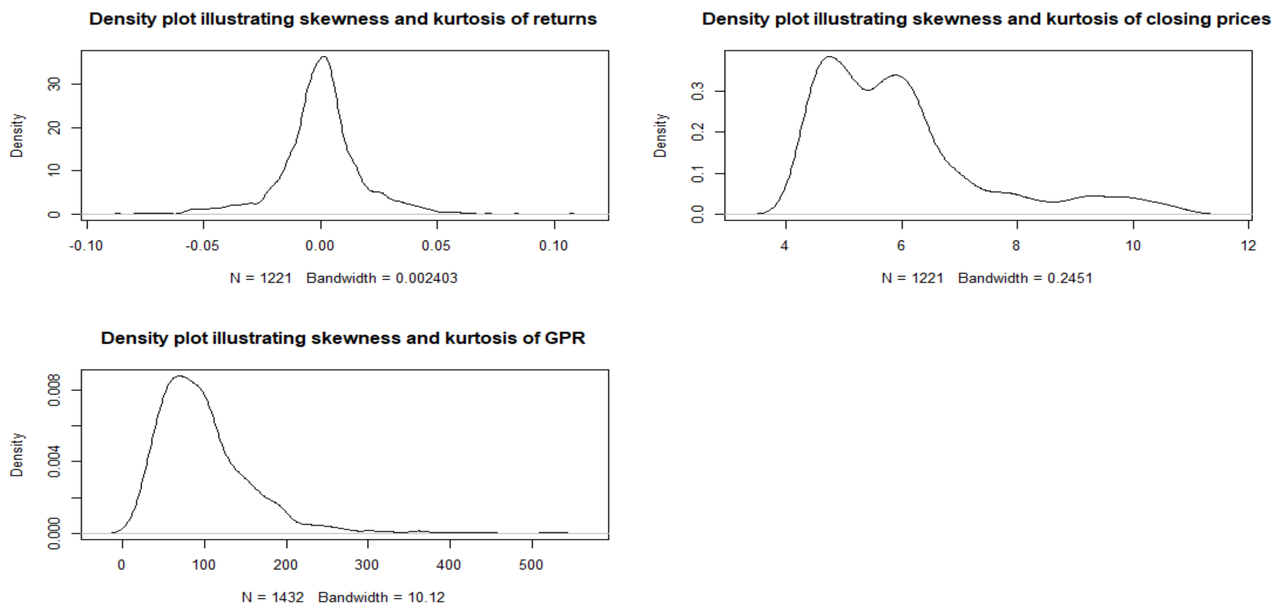
Note: The notations *,** and ***, indicate the rejection of the null hypothesis of normality at the 5% threshold level, stationarity at the 5% threshold level and no-autocorrelation at the 5% threshold level, respectively.

The mean of the closing price return is 0.00001, it is 101,5 for the GPR and 5.94 for the closing prices. The standard deviation is 0.0179, 63.65 and 1.465 for the returns, GPR and closing prices respectively. Strong seasonality or trend components are not detected in the return data.

### 4.1.1 Normality

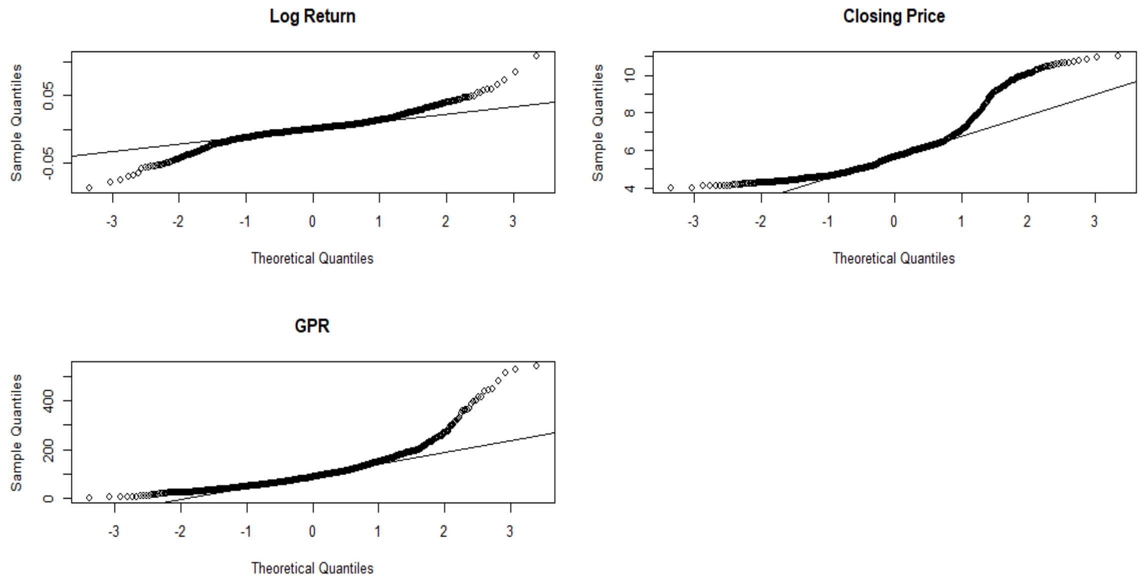
Table 4 illustrates the distribution of return which exhibit negative skewness, meaning it is skewed towards the left. The value of kurtosis for return indicate that its distribution is not far from normally distributed, but that it displays leptokurtic distributions. Closing price and GPR are positively skewed - towards the right. GPR display leptokurtic distributions and closing prices display platykurtic distributions. Skewed distributions is not normally a problem when the sample size is large (Derryberry, 2014), for the closing price and return data it is *n* = 1221, for the GPR it is *n* = 1432, which is sufficiently large.

*Figure 6: Density plots of the data*




The QQ-plots in Figure 4 illustrate that the data deviate from the diagonal line and are therefore not normally distributed. The t-statistics from the Jarque-Bera test reject the null hypothesis of normality for returns, closing prices and GPR. The null hypotheses of the Shapiro-Wilk test, the Kolmogorov-Smirnov test, and the D’Agostino normality test are rejected. There is sufficient evidence to say that the data for returns, closing prices and GPR index affirm the non-Gaussian distribution.

*Figure 7: QQ-plots of Log Returns, Closing Price and GPR.*




### 4.1.2 Unit Roots and stationarity

Price data can be expected to display a unit root, while returns are usually stationary (Shumway & Stoffer, 2011). The results of the KPSS test confirm this. The Augmented Dickey-Fuller test was significant at 5% level, which allowed us to reject the null hypothesis of the presence of a unit root for GPR and returns but not for closing prices, indicating that return and GPR are stationary. The Phillip-Perron test detected the presence of a unit root in the closing prices, but not in the return and GPR data, indicating that they display stationarity. ADF and PP does not detect a unit root in the GPR data, while KPSS does not detect stationarity. The reason for this could be that a unit root does not exist, and that the data is trend stationary.

### 4.1.3 Autocorrelation

The Ljung-Box test with 15 lags of returns and squared returns are significant, rejecting the null hypothesis of independence and no autocorrelation for the logarithmic returns. The Durbin-Watson test null-hypothesis of no correlation between the residuals is rejected, as the p-value is lower than 0.05, and the DW test statistic is 0.9999. The correlograms depicted below visualize the ACF for closing prices, GPR and return. The ACF for closing prices and GPR start out high and are exponentially reduced, they display geometric decay. As the closing prices are converted to returns, its ACF has correlations near zero, and display a significant lag at Lag 1. The PACF for closing prices and GPR show significant lags at Lag

1, and then displays significant but decaying lags towards lag 50. These qualities are typical of non-seasonal time series data. For the closing prices and for the logarithmic return of the closing prices both ACF and PACF display a gradual decrease, which indicates that the ARMA (1,0) model would be appropriate for the series.

*Figure 8: ACF for closing prices, returns and GPR*

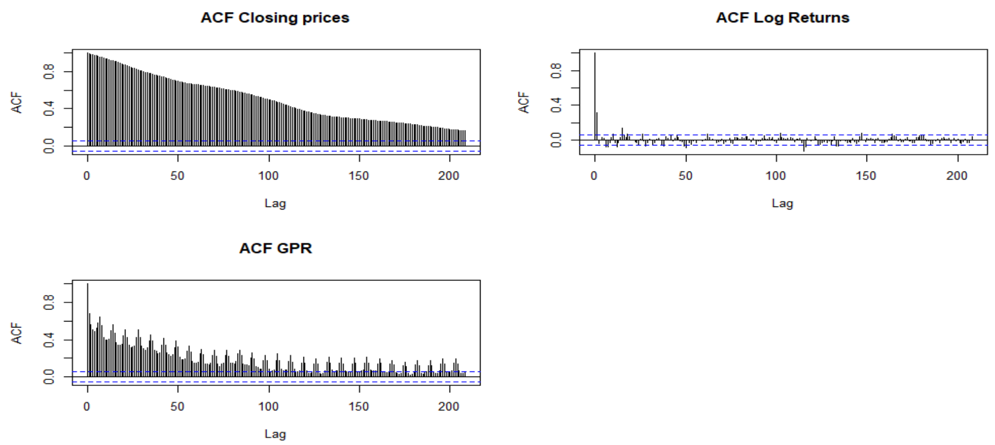
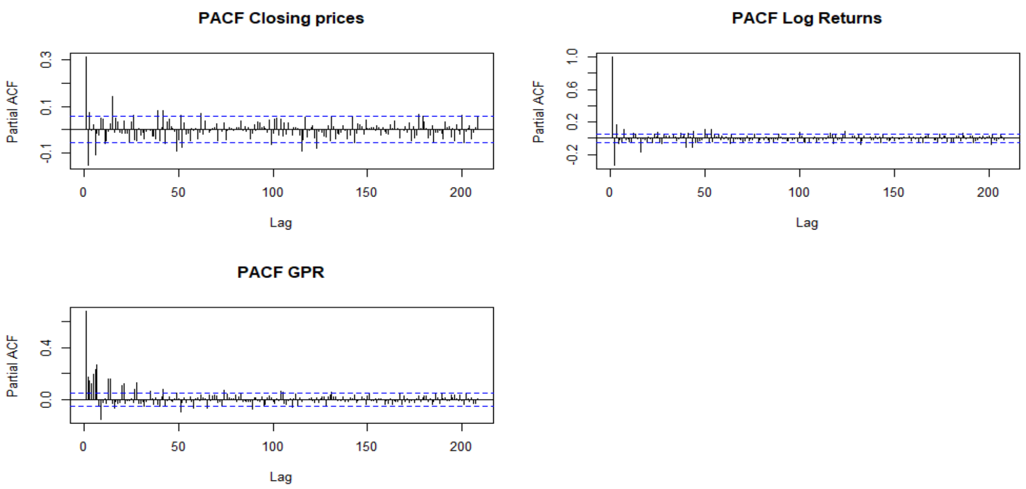



*Figure 9: PACF for closing prices, returns and GPR*

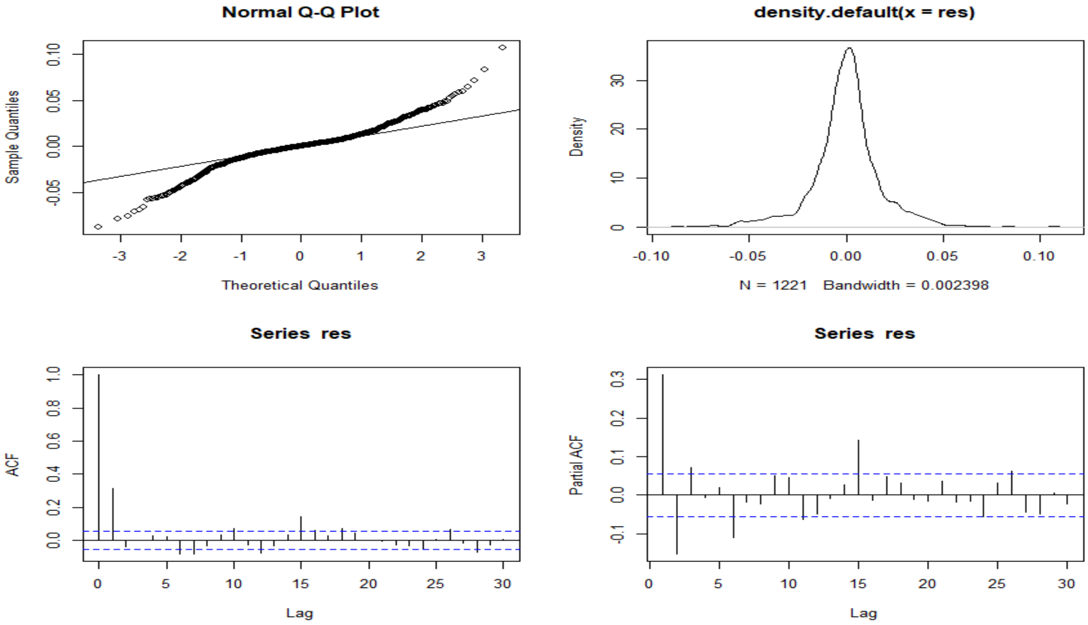



# 4.2 Analysis of gas volatility

## 4.2.1 Regression model

A Durbin-Watson test is conducted on the regression model for logarithmic return to detect residuals of the linear regression fit and detects autocorrelation greater than 0. The ACF and PACF plots in figure 8 show that the residuals exhibit a significant lag at Lag 1, 2 and 15. The QQ plot indicates that the residuals are not normally distributed, this is supported by the bell curve to the upper right which shows that the residuals do not display a normal distribution, albeit not far from it, and are slightly skewed to the left.

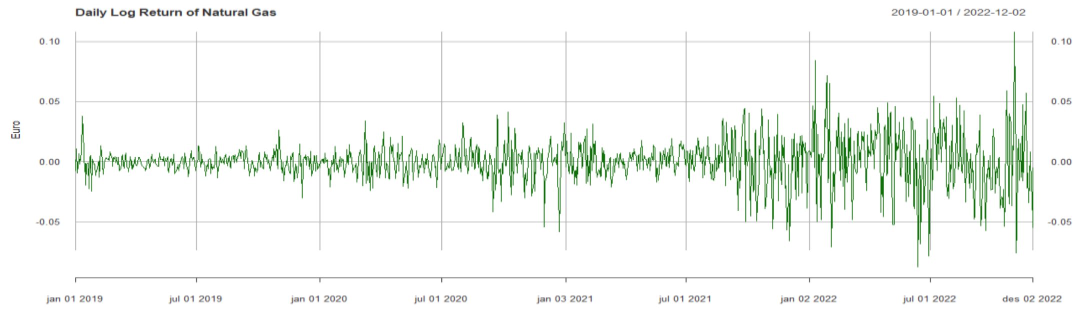
*Figure 10: Visualizations of residuals.*




### 4.2.2 Measuring volatility using a GARCH model

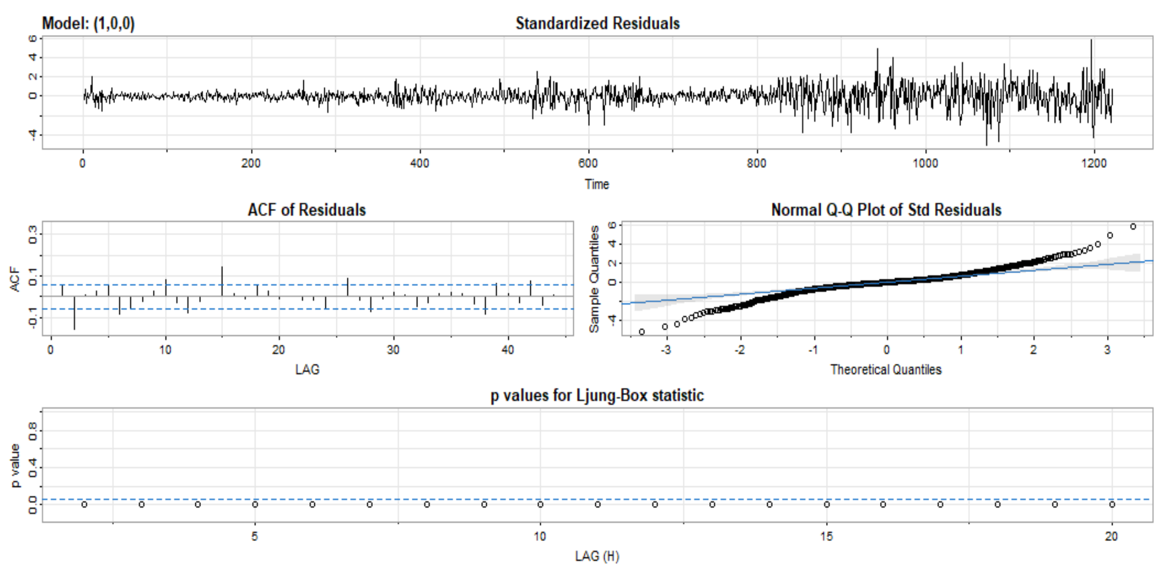
The data is checked for volatility clustering by inspecting a plot of the logarithmic returns for the time period. The graph clearly display volatile spikes in return in the end of 2020, in January and February 2022, July 2022 and then finally in the end of November and start of December 2022. The mean of the series appears to be stable with an average return of approximately zero, however, the volatility of data changes over time, and the data exhibit volatility clustering, most notably from the fall of 2021 and on towards the end of 2022. The leverage effect is illustrated in figure 1 and figure 9, where a large fall in prices occur in June 2022 followed by a spike in volatility at the same time, and a fall in prices in November 2022 is followed by another volatile spike.

*Figure 11: Daily logarithmic returns.*




The Lagrange Multiplier coefficient is calculated to affirm the homoskedasticity or heteroskedasticity of the variables. The ARCH test with 15 lags is significant at the 1% threshold level, thus rejecting the null hypothesis of homoscedasticity. The test revealed no ARCH effects in the data, and that the model has heteroskedastic residuals, which allows the use of the GARCH model. Before estimating the GARCH model, the AR and MA components were determined. By applying ARMA-fit tests in R, where AIC and BIC were both used as criteria and different ARMA parameters were compared, ARMA (1,0) appeared to be the best fit for the data. Figure 10 shows the residuals of the estimated AR model. The ACF of the squared residuals show that there may be some dependence, but that it's small. The strength of the band in Lags 2 and 15 indicate that there is correlation between nearby observations. The QQ plot shows that the residuals do not have a normal distribution.

*Figure 12: Visualizations of the AR model.*



Based on the results from the ARMA fit, a standardized GARCH (1,1) model is estimated. The estimated results from the model are listed in table 4.

*Table 4: Estimated results from GARCH(1,1) models*

| | TGARCH | sGARCH | iGARCH |
|---|---|---|---|
| mu | 0.00007793* | 0.000223* | |
| ar1 | | 0.298538 | |
| omega | 0.00018903*** | 0.000152 | 0.000000** |
| alpha1 | 0.49667770*** | 0.999000 | 0.077347** |
| AIC | -5.342 | -5.6607 | -5.8070 |
| BIC | -5.325 | -5.6398 | -5.8028 |
| gamma1 | 0.01295229 | | |
| beta1 | | | 0.922653 |

Note: The notations *,** and ***, indicate that the p-value is significant at the 5%, 10% and 1% threshold level, respectively.

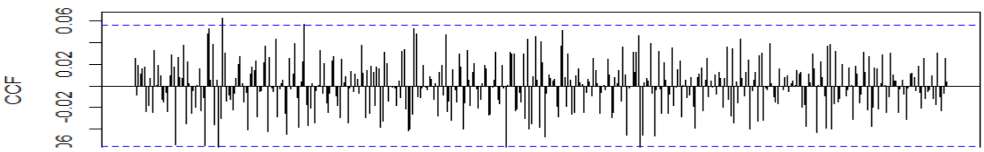
For the iGARCH model The ARCH coefficient (alpha1), the GARCH coefficient (beta), and the constant (omega), are positive justifying the positive value of the conditional variance and with p-values significant at the 1% level for omega and alpha. The total of alpha and beta is less than 1, and the model is considered robust. mu (mean) is significant in the standard GARCH model, all parameters are positive. The TGARCH model has the lowest AIC and BIC values, making it the GARCH model with the best fit for the data.

## 4.3 Correlation analysis

### 4.3.1 Cross-correlation analysis

The cross-correlation plot of the shows that the two series are not highly correlated. Pearson's r coefficient is 0.01001, which indicate that the cross correlation is very low. The cross-correlation plot in fig.13 shows no clear cross-correlation between the time-series.

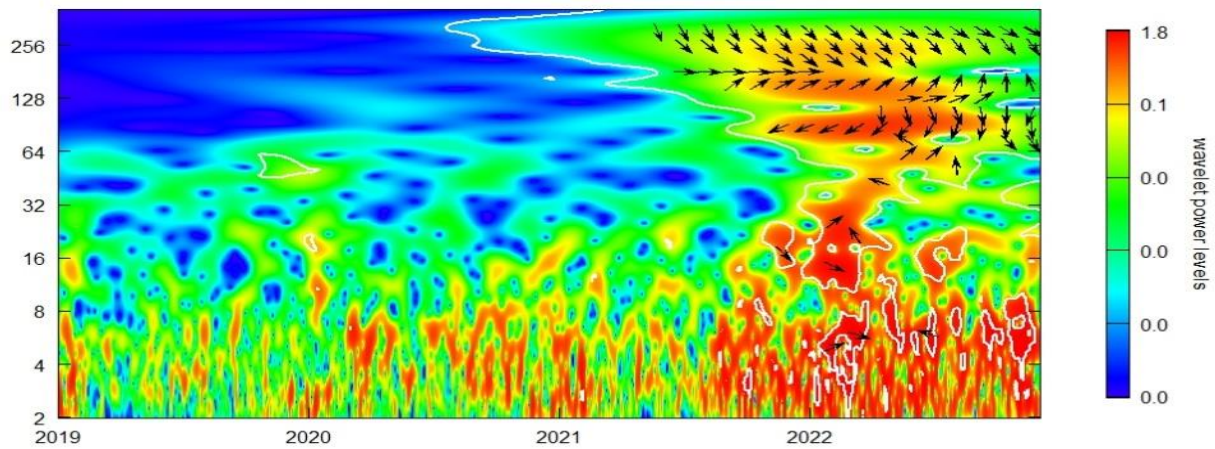
*Figure 13: Cross-correlation plot of GPR and closing price returns.*



### 4.3.2 Wavelet transform analysis

Figures 14, 15 and 16 depict the cross-wavelet power spectrum, the wavelet coherence analysis, and the phase differences where the correlation between log return of closing prices (*x)* and GPR (*y*) is analyzed.

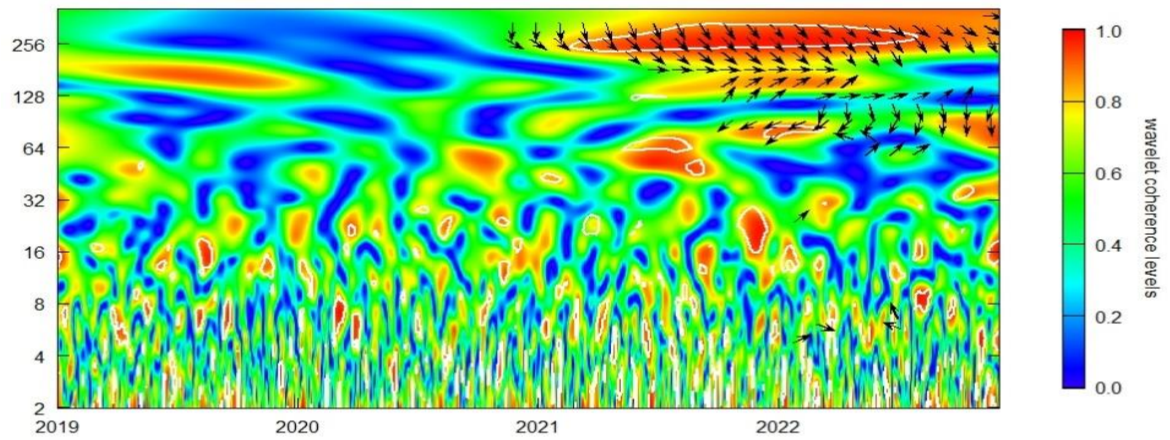
*Figure 14: Cross wavelet power spectrum.*




Note: The Y-axis measures frequency (scale) and X-axis represents the time period. The three-dimensional color presentation ranges from blue, which depicts low co-movement, to red, indicating high phase co-movement, or covariance. The white lines in the wavelet power spectrum delineate areas of high significance, the area within the whites have p-values below 0.1, rejecting the null-hypothesis. Increasing arrows (towards the right) indicate the series move in the same direction and are in phase. The opposite is true for decreasing arrows. Arrows, in phase (→) or anti-phase (←), determine the sign of correlation coefficient (Uddin & Yahya, 2020). Phase differences indicate varying degrees of dependence over time and across different frequencies. Arrows right up or left down indicate x leading y. Arrows pointing right down or left up indicate y leading x.

The significant area within the whites have p-values below 0.1, rejecting $H_0$: of no joint periodicity at the 10%-level. The power spectrum displays high covariance in lower periods in 2022. The significant periods have increasing arrows and the warmer levels have decreasing arrows indicating *x* leading *y*. To emphasize the joint periodic properties of *x* and *y*, a wavelet coherenc plot can give a better indication of the correlation between the series.

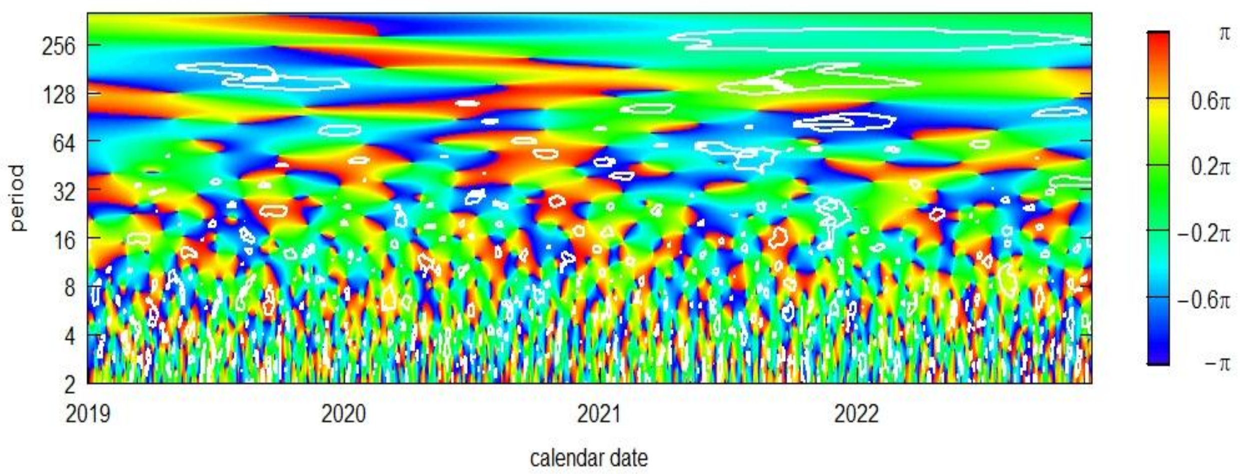
*Figure 15: Wavelet coherence analysis of GPR and log returns.*




Note: The Y-axis measures frequency (scale) and X-axis represents the time period. The color presentation ranges from blue, which depicts low coherency, to red, indicating high coherency (Uddin & Yahya, 2020). The white lines delineate areas of high significance, the area within the whites have p-values below 0.1, rejecting the null-hypothesis. Increasing arrows (right) indicate the series move in the same direction and are in phase. The opposite is true for decreasing arrows. Phase differences indicates varying degrees of dependence over time and across difference frequencies. Arrows right up or left down indicate x leading y. Arrown pointing right down or left up indicate y leading x.

The coherence analysis in figure 15 indicate that there is a strong periodic association between the two series in a time period starting in the beginning of 2021 and lasting until the end of 2022, most notably from the start of 2021 to mid-2022. The white lines in the plot delineate areas of high significance, where $H_0$: no joint periodicity is rejected at the 10%-level. In the significant area the arrows (right down) indicate that *y* is leading *x*, and that correlation between them is positive.

*Figure 16: Phase differences between GPR and gas returns.*



Note: The colors indicate the following; Green: phase differences close to zero, which means that the two time-series are in phase at the respective period. Yellowgreen: in phase, series 1 leading. Turquoise: in phase, series 2 leading. Red: phase differences are close to `+pi`, out of phase, series 2 leading. Blue: phase differences are close to `-pi`, out of phase, series 1 leading (Uddin & Yahya, 2020).

Figure 16 displays the phase differences between the time-series indicating that the time series are in phase in the same time period as in figures 14 and 15, and that there are several time-periods with significant areas where the time-series are both in phase and anti-phase.

## 4.4 A summary of the findings

The natural gas prices, the GPR and the return data are not normally distributed. Returns are negatively skewed and the other two are positively skewed. For kurtosis, GPR and return display leptokurtic distributions and closing prices display platykurtic distributions. Returns are stationary according to KPSS, GPR and closing prices are not. GPR and return are stationary according to ADF and PP tests, closing prices are not. The Ljung-Box test detect autocorrelation in the gas returns. ACFs and PACFs of the three time-series indicate no seasonality in the data. The Durbin Watson test detect autocorrelation, and QQ plots indicate that residuals are not normally distributed in the regression model estimated on the gas returns. The ARCH test reject the null hypothesis of homoscedasticity. Volatile spikes are observed at the end of 2020, in January and February 2022, July 2022 and in the end of November and start of December 2022. The data exhibit volatility clustering, most notably from the fall of 2021 and on towards the end of 2022. AIC and BIC indicate that ARMA (1,0) is the best fit for the data. sGARCH, iGARCH and TGARCH models are estimated on gas returns, AIC and BIC indicate that the TGARCH model is the best fit for the data. Pearson's r indicate that correlation between gas returns and GPR is low. A wavelet coherency analysis with power spectrum, coherence analysis and phase differences are visualized in three images, indicating that there is covariance, coherence, and the time-series move in phase from the beginning of 2021 to the end of 2022.

# 5. ANALYSIS AND DISCUSSION

## 5.1 Answering the problem

This thesis aims to investigate whether Russia caused the European energy crisis through acts of hybrid warfare through answering two research questions and their adjourning hypotheses. The process of answering the problem starts with the statistical analysis of the time-series of GPR and gas prices. Here, conclusions from the findings of the analysis are drawn, the hypotheses are discussed, and the research questions are answered with the theoretic foundation laid in the literature review.

## 5.2 Research question 1

Did the outbreak of the war have a negative impact on natural gas prices?

**$H_1$***: The outbreak of the war led to an increase in prices and volatility in the European gas market*.

Figure 3 show the gas prices together with the logarithmic returns of closing prices of gas. It displays an increase in gas prices and in volatility starting in the spring of 2021, decreasing in the end of 2021, increasing in the start of 2022, and staying at a high level until the end of 2022. This coincides with the geopolitical tensions in Europe caused by anticipations of a Russian invasion, and the following invasion. The gas prices reached a maximum value of 10.99 in August 2022, which until then was an all-time high for TTF natural gas. Table 4 shows the results from the estimated GARCH models on gas returns. A significant alpha1 of the TGARCH model confirm the presence of volatility clustering in the sample period, and volatility can be clearly observed in figure 3. This confirms hypothesis 1 that the outbreak of the war led to higher prices of natural gas and an increase in volatility in gas returns, supporting Vasileiou's (2022) findings, and Fang and Shao's (2022) findings.

**$H_2$: *The geopolitical risk (GPR) index reflect the geopolitical situation in Europe in the sample period*.**

Figure 4 depicts the development in the GPR along with the development in gas prices from January 2019 to December 2022. A short but high spike in January 2020 is attributed to tensions between China and USA (Caldara & Iacoviello, 2020) not related to this study. The

GPR has a clear and powerful spike in the end of February 2022 which can be attributed to the Russian invasion of Ukraine. After the notable spike in the winter and spring of 2022 the GPR has remained at a somewhat higher level than before the outbreak of the war. The mean of the GPR time-series is 101.5 and the maximum value is 539.6. In comparison, the beginning of The Second World War had an index value of 505,78 and when the U.S. declared war on Germany during The First World War the index value was at 552,6 (Caldara & Iacoviello, 2020). The GPR is based on automated text-searches and captures systemic risk caused by events such as wars, it is therefore reasonable to assume that the GPR reflects the situation in Europe from 2019 to 2022, confirming hypothesis 2.

### 5.2.1 Did the outbreak of the war have a negative impact on the European gas market?

High geopolitical risk is likely caused by tensions related to Russian aggression towards Ukraine and ultimately - the war. It reflects the geopolitical development in Europe in the sample period. High gas prices and increased volatility in gas returns are then caused by the same geopolitical circumstances. This is supported by wavelet analysis and scientific literature. The results of the analysis indicate that the outbreak of the war had a negative impact on the European gas market. Regarding the question as to why and how the war led to record high gas prices, Zhang et al. (2023) find that an increase in GPR increases the risk associated with investing in financial markets, which might have had a deterring effect on investors regarding the European gas markets in 2021 and 2022. This is supported by Salisu et al. (2022) who have found that a rise in GPR can reduce global trade and investment, and delay the decision-making process of market participants. This is also supported by Zakeri et.al (2022) who find that the Ukraine war has increased energy prices worldwide in the short term, a development anticipated by the breakout of the war and accelerated by the sanctions imposed on Russia. They also find that energy supply chains are vulnerable to trade shocks such as the ones caused by sanctions following the war. High gas prices and high volatility was also likely a consequence of supply uncertainty related to Russian gas exports following the invasion. Cutting of Russian gas as mentioned by Ciucci (2022) would have increased this uncertainty, both with consumers and policymakers. Sanctions imposed on Russia would also have had a negative effect on the market, further enforcing uncertainty related to supply and development in prices and volatility.

## 5.3 Research question 2

Is there a significant relationship between prices of natural gas and GPR?

**$H_3$: *There is a positive cross-correlation between the gas price returns and GPR.***

The gas prices increased substantially, and as figure 5 depicts, the volume sold is relatively unchanged where one would expect the volume to increase during the fall and winter months, which means that changes in price is not a result of changes in volume sold.
Pearson's *r* measures cross-correlation between GPR (returns) and gas returns to 0.01001. This indicates that cross-correlation is very low. As the relationship between GPR and gas returns is likely to change through the duration of the sample period, wavelet transform analysis captures the changes in correlation and phase differences in a more nuanced way. The power spectrum indicate a covariance between GPR and gas returns. Coherence analysis and phase difference plots both indicate that there is a positive cross-correlation between GPR, and gas returns at high frequencies, confirming hypothesis 3. The positive cross-correlation between gas returns and GPR is assumed to be short-lived as the significant area in the wavelet plot stops at the end of 2022. Findings by Monge et.al (2023) from their analysis of the relationship between GPR and WTI support this.

**$H_4$: *Gas price was influenced by GPR in the sample period.***

From the wavelet coherence analysis, we can identify an island of high dependence and high coherency between gas returns and GPR in figure 15, where GPR is leading gas returns and there is a positive correlation in the time period from the start of 2021 and until the end of 2022. The phase differences plot in figure 16 is dominated by green and turquoise colors which indicate that GPR and gas returns are either in phase or that GPR is leading gas returns at the same time-period as the coherency plot depict GPR leading gas returns. As Nick and Thoenes (2014) find that natural gas price fluctuations follows the fundamental signals both from supply and demand, we can also ascertain based on these results that under the extreme circumstances of 2021 and 2022 TTF gas prices were influenced by geopolitical risk, confirming hypothesis 4.

### 5.3.1 Is there a significant relationship between prices of natural gas and GPR?

As mentioned above, it is reasonable to assume that the unprecedented price and volatility of natural gas in 2021 and 2022 was a result of the geopolitical circumstances in Europe, and that GPR is a good representation of the geopolitical risk in situations such as those in Europe in 2021 and 2022. Figure 14, 15 and 16 display wavelet plots that show significant areas between January 2021 and December 2022, indicating that there is covariation, coherence, and positive cross-correlation between gas returns and GPR. We can therefore determine that there is a significant relationship between the two series. As increased volatility in gas returns have a negative impact and cause uncertainty in the market, this corresponds with Sharif et.al (2020) findings that high GPR has a negative impact on the economy, causing uncertainty in the US stock market, oil prices and the economic policy. How directly GPR influences gas returns is not possible to determine based on these findings. Geopolitical risk is likely to affect several markets as well as consumer behavior, and the increase in gas prices and volatility might be a result of something as random as extreme weather. The substantial changes in gas price is however unlikely to stem from such circumstances, as the prices are unprecedented, no extreme weather was reported, and demand was relatively unchanged in 2022 as mentioned above and as displayed by gas volumes sold in figure 5.

## 5.4 Did Russia cause the European energy crisis through acts of hybrid warfare?

The negative impact from the war onto the gas prices further increased prices and volatility leading the gas in a downward spiral leading to the price spikes observed in 2022. The high dependency on Russian natural gas led to a shortage of gas which again – in combination with other factors, led to high electricity prices. This all caused an energy crisis in Europe.

Although there has been a decline in trust in public institutions in recent decades (Perry, 2021), public trust is still high in most European countries. Trust between the population and political and public institutions is one of the most important factors to help a society resist the threat of hybrid warfare and make states resistant to hybrid threats. The energy crisis coincided with recession-like trends where interest rates have increased, and most Europeans experience substantially increased costs of living. In times of insecurity - in particular economic insecurity, conflicts between societal groups increase, and political parties play on people's fears in order to gain voters. Circumstances like these are ideal for actors such as Russia to take advantage of internal divides within countries by means of hybrid warfare.

The energy crisis with its high electricity bills caused disruptions and demonstrations in some European countries, making already fragile, but the EU countered with economic packages aimed at relieving the high costs of energy, marking itself as an efficient energy actor (Rühle & Grubliauskas, 2015).

As actors behind hybrid warfare seeks to take advantage of social, political, and religious opposites and considers them weaknesses, in most democracies they are considered strengths. Europe is quite robust in the sense that the privilege of societal freedoms is highly prized in many European countries. Using gas supply as a pressure point might have been more effective of more Europeans had shared Putin’s view of Ukraine as a part of the Russian sphere, but very few do.

Taking control of the narrative is a key strategy in hybrid warfare. During the 2014 crisis in Ukraine Russia focused on its important role as an energy supplier for Europe and underlined the notion that European countries had been pressured by the United States into backing Ukraine, something with according to Russia was not in their self-interest. Russia strengthened this narrative by reducing gas supplies to countries which marked their stand against the war in Eastern Ukraine (Krajewski & Lopatka, 2014). The same view was repeated after the full-scale invasion in 2022.

It would have been evident for anyone with experience in trading with gas that manipulating Russian gas exports in a time of high geopolitical uncertainty would lead the European energy market into a state of distress, given its dependency on Russian natural gas. The Russian government, as the primary decision makers behind trade and export of energy commodities from Russia would have been aware of this and it is unlikely that the acts of reducing and cutting gas supplies were not willed actions, possibly aimed at causing a crisis in Europe.

Whether the 2022 energy crisis could have been avoided is an interesting question. As pointed out in the literature review, manipulation in gas supply and uncertainty related to the war were not its sole causes. European energy infrastructure has been hardwired to natural gas as its main energy source. As noted by Stern (2006) one could argue that the European community should have been more cautious after witnessing the 2006 and 2009 gas disruptions. Russia’s ability and willingness to apply military force on other sovereign territories was demonstrated in the 2008 invasion of Georgia and again in Eastern Ukraine in 2014. The potential for disputes with Russia has been omnipresent for many of the former Soviet countries in Europe, and Russia's annexation of Crimea in 2014 should have been an eye opener for the rest of the European community. Instead, Europe has been sleepwalking into a confrontation with the Putin regime. Rühle and Grubliauskas (2015) wrote in 2015 that the Ukraine crisis is a reminder that energy security is a part of national security, and that to depend on Russia can be a strategic liability. Nations such as Germany have turned a blind eye, cooperating with Russia over NS1 and NS2, and have as Nick and Thoenes (2014) states instead made itself overly dependent on Russian gas supplies. As geography is destiny when it comes to energy, after cultivating a dependency on Russian gas since the fall of the Soviet Union, the crisis could hardly have been avoided. Thanks to the resolve of among others the EU, it was quickly mitigated and did not have as severe consequences as it possibly could have had.

It is difficult to isolate and measure hybrid threats, and one must assume that as GPR represents the geopolitical tensions in Europe, it can to some extent represent the risk of and severity of hybrid threats – in particular the ones that coincide with the keywords used to generate the GPR index. As Barques et.al notes (2022) it can be challenging to ascertain when a threshold is crossed as actions in themselves do not seem like much but the sum of them all can have a major impact. Actions of hybrid warfare are not necessarily easy to pinpoint in real time and can be easier to identify in retrospect. Examples of this are the 2006 and 2009 gas disputes and gas restrictions that Russia imposed on many European countries in and after 2014. The damages done to NS1 and NS2 were results of sabotage and given that it is reasonable to assume that such severe actions were related to the ongoing war in Ukraine, it was quickly identified as possible attempts at hybrid warfare. These actions have also served as a warning to other energy suppliers that energy infrastructure is a possible target. Attacks on critical civilian infrastructure is an attack on the enemy's will to fight – central to hybrid warfare. Hybrid warfare is primarily most successful when aimed at states that are fragile and internally divided, it can however sow discord and introduce sufficient ambiguity that decision making is made difficult for strong states and robust alliances such as NATO.

As a consequence of high gas prices and restrictions on supplied gas volume, ordinary people were made to suffer in a Russian attempt to blackmail European governments to refrain from supporting Ukraine. In the end, the use of gas supplies to pressure Europe did not work because the EU implemented measures which included reducing the use of energy, redirecting gas, using energy substitutes, and increasing the import of gas from Norway and LNG from the USA.

The energy crisis and the war in Ukraine in 2022 were both severe events that led to shifts in many countries' security and energy policies. It has become clear to both the EU and NATO that energy security and reliable energy supplies are essential to a stable and peaceful world order. As global warming is escalating, disputes over energy resources are likely to increase.

## 5.5 Toughts about the research methodology

Good concept validity means that there is a connection between the data collected and the phenomena one aims to measure (Johannessen et al., 2021). This analysis investigates the volatility of natural gas prices in Europe and its movements under the assumption of geopolitical risk. The gas prices data are of high quality, and the GPR index applied here is also applied in other scientific studies. The methods that are chosen are picked based on assumptions of what has been necessary to ascertain in order to investigate the research problem and answer the research questions. The study should therefore be suited to uncover new relationships within and between the time series. When applying models on our data, the models only shine a light on the aspects of the data that we have chosen to illuminate. This means that one has to be diligent in conducting background research on the methodologies available so that the analyses are up to the standards that are required of a scientific study. The research techniques that are used here are widely applied in other and similar studies, which help strengthen the validity of this study. Some of the methods, such as wavelet transform, are similar to those applied in other studies analyzing the movements of essential commodities under the assumption of geopolitical risk. The dependency on natural gas was one of the most important causes of the energy crisis. The movements of other energy commodities probably affected the situation as well, and a more extensive study could have analyzed other commodities at the same period. The use of several indicators will allow one to measure more aspects of a concept and reduce the risk of errors in an analysis (Johannessen et al., 2021). The fact that this study only covers natural gas reduces its validity. The GPR data is notable western-oriented, it represents the geopolitical situation in Europe and Northern America, as mentioned in the literature review. Despite this, it was deemed appropriate to use the index in this analysis because the objects of study – the energy crisis and the war, are primarily a concern for Europe and North America. The original data spans a long period of time.

Analyzing the long-term relationship of the two time-series would have given the analysis more validity, but it would not have been necessary for the statistical analysis, as the energy crisis and the war are the focal points of the study.

# 6. CONCLUSION AND FINAL REMARKS

## 6.1 Research model and conclusion

This thesis aims to investigate whether Russia caused the European energy crisis through acts of hybrid warfare. Detection of actions of hybrid warfare is challenging, as they often are easier to detect in retrospect than in real-time. They can also be small, easy to dismiss and refutable – which is why they are hard to prove, and one is merely left to speculate after the deed is done. The statistical analysis in this thesis does not accept or dismiss evidence of the use of hybrid threats or tools, but the discussion has aimed to shed a light on whether use of hybrid threats have been likely or not, given results from the analysis and the circumstances surrounding the build-up towards the invasion and the war.

To carry out this research, the following research questions have been asked: *did the outbreak of the war have a negative impact on the European gas market*? and *is there a significant relationship between prices of natural gas and GPR*? Four hypotheses have been formulated in order to answer the questions. The hypotheses were answered by applying statistical analysis on two time series.

Time-series of natural gas prices and the geopolitical (GPR) risk index have been analyzed. The methodology has consisted of descriptive statistics, a volatility analysis and a cross-correlation analysis. For the descriptive statistics normality tests, stationarity and unit root tests, and autocorrelation tests have been performed. For the volatility analysis, a linear regression model has been estimated. The logarithmic returns of gas has been tested for ARCH effects and volatility using the GARCH model framework. The TGARCH model indicated volatility and volatility clustering in the data. Wavelet transform with a wavelet coherency analysis was applied in the cross-correlation analysis, producing a plot of the power spectrum, coherency, and phase differences of the gas returns and GPR. The results showed that there was positive cross-correlation between the data and that gas prices data were affected by the geopolitical risk index from the start of 2021 and to the end of 2022.

The high gas prices were most likely a result of the geopolitical tensions following the war, as they were affected by the geopolitical risk together with cuts in gas supply from Russia and cannot be explained by demand and supply mechanisms alone. The motive for cutting gas supplies cannot be proved. There are no statistical tests that can indicate what the motivation for manipulating Russian gas exports were, and there is no methodological framework one can apply to detect and clearly identify hybrid threats. Despite this, one can assume that Gazprom and the Russian government were well aware of the potential for an energy crisis in European countries, as gas exports were reduced. As the European dependency on Russian gas was a fact and given Russia's history of manipulating energy supplies as means to achieve political goals, it is reasonable to assume that the reduction of supply was done with the intent of causing havoc in European countries and putting pressure on European governments. Whether this was an attempt at hybrid warfare is not possible to prove, but I believe so, as the manipulation of civilian infrastructure to achieve strategic, political, or military means is characteristic of this type of warfare.

The energy crisis and the war in Ukraine in 2022 were both severe events that led to shifts in many countries' security and energy policies. It has become clear to both the EU and NATO that energy security and reliable energy supplies are essential to a stable and peaceful world order. As global warming is escalating, disputes over energy resources are likely to increase. This study shows that the movements of natural gas prices were affected by geopolitical risk. As gas prices were a main driver of the European energy crisis, high geopolitical risk which can be attributed to the war in Ukraine led to high prices and high volatility. The high prices were also a result of reduced exports, possibly as an attempt to force European governments from supporting Ukraine in the war. This thesis does not present a clear answer to whether the energy crisis was a result of hybrid warfare but does hopefully discuss some key aspects of the crisis in Europe and how hybrid threats might have played a role. The thesis has to be considered a supplement to other studies studying energy security and the tackling of hybrid threats.

## 6.2 Suggestions for further research

The Northern Sea Route (NSR) connects the Pacific - and Atlantic oceans, and is considered a strategically important route for both Russia (Brigham, 2022) and China (Conley, 2018). One avenue for further research is to investigate how hybrid threats might be applied in contested areas such as in the Arctic. It would be in the interest of arctic nations to investigate how for instance underwater infrastructure can be protected from hybrid threats. As an extension of that, it would also be interesting to develop a framework for the prevention, identification and tackling of hybrid threats.

I also propose to further study how geopolitical risk can be applied in the prediction of movements of commodities such as oil, gas, or indexes such as the BTI.

## 6.3 Final remarks

This thesis analyses and discusses a research problem that has been challenging to answer. My hope is that this thesis will help shed light on future challenges concerning energy security and hybrid threats and acknowledge that as our climate changes and global temperatures are on the rise, conflicts over resources will increase and possibly escalate. In order to take in the importance of energy security, diplomats, military, and state leaders should be educated on energy and energy related issues, such as climate change and resource competition.

The energy crisis will force a major rethink of Europe’s gas security over the next decade. This will include diversifying outside sources of gas – starting with suppliers that are close by, such as Algeria and Libya, as well as looking further afield in Africa and the Americas; and increasing gas exchanges within Europe and ensuring gas stocks that are much higher than the historic lows they reached last autumn. The EU aims to become fully independent of Russian energy imports. Countries that depend on energy imports are more likely to look towards nations that are stable suppliers of energy in the future such as Norway. Russia is still attempting to put pressure on the European energy market, and as Russian gas exports to Europe have been efficiently cut, there might be an increase in the risk of Russian attempts to target other energy supplies to Europe from other countries, further escalating the energy crisis. Western sanctions towards the Russian gas and energy sector and the limited Russian infrastructure for gas deliveries to Asia (Etterretningstjenesten, 2023) make it challenging to redirect gas exports to Asian markets.

Hybrid threats and hybrid warfare is likely to become more common, not just from state actors but also from large corporations with the means and will to pursue their interests using new and radical tools. As societies are being increasingly digitalized, they are also more vulnerable to disinformation and other forms of operations affecting the cognitive sphere. I support Kormych and Malyarenko (2022) in their statement that any sign of grey zone conflict should be met with a strong reaction from the international community or the way is open to unlawful military conflict.

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# Appendix A

**Only the most important codes (cleaning data, tests, and models) are included in this appendix.**

**Parsing the data and creating time series for GPRD, NG closing prices, NG volume and NG return of closing prices:**

```
ng$OPEN <- parse_number(ng$OPEN, na = c(" ", "NA"), locale =locale(decimal_mark =
",", grouping_mark = " "), trim_ws = TRUE)
ng$HIGH <- parse_number(ng$HIGH, na = c(" ", "NA"), locale =locale(decimal_mark =
",", grouping_mark = " "), trim_ws = TRUE)
ng$LOW <- parse_number(ng$LOW, na = c(" ", "NA"), locale =locale(decimal_mark = "
,", grouping_mark = " "), trim_ws = TRUE)
ng$CLOSE <- parse_number(ng$CLOSE, na = c(" ", "NA"), locale =locale(decimal_mark
= ",", grouping_mark = " "), trim_ws = TRUE)
ng$AVG.DAY <- parse_number(ng$AVG.DAY, na = c(" ", "NA"), locale =locale(decimal_
mark = ",", grouping_mark = " "), trim_ws = TRUE)
ng$DATE <- as.Date(ng$DATE, format="%d.%m.%Y", optional = FALSE, tz="UTC")
gpr$GPRD <- parse_number(gpr$GPRD, na = c(" ", "NA"), locale =locale(decimal_mark
= ",", grouping_mark = " "), trim_ws = TRUE)
gpr$date <- as.Date(gpr$date, format="%d.%m.%Y", optional = FALSE, tz="UTC")

gpr1 <- gpr[,c(1,3)]
gpr11 <- na.omit(gpr1)
GPR_ts <- as.xts(zoo(gpr11$GPRD, gpr11$date))
is.xts(GPR_ts)

GPR_ts <- na.omit(GPR_ts)
colnames(GPR_ts) <- paste0("GPRD",1)

gprlog <- diff(log(GPR_ts$GPRD1))
gprlog1 <- na.omit(gprlog)

NG <- ng[,c(1,5)]
NGret <- diff(log(NG$CLOSE, base = exp(1)))
NG_ts <- as.xts(zoo(NGret, NG$DATE))
is.xts(NG_ts)

colnames(NG_ts) <- paste0("return",1)

NG_ts3 <- as.xts(zoo(ng$CLOSE, ng$DATE))
colnames(NG_ts3) <- paste0("Close",1)

NG_ts2 <- as.xts(zoo(ng$VOLUME, ng$DATE))
colnames(NG_ts2) <- paste0("Volume",1)
```

**Merging the log return of the two time-series and removing NA's to make it possible to use the ACF/ PACF**

```
matched <- merge.xts(gprlog$GPRD1, NG_ts$return1, join = "inner")
matched1 <- na.omit(matched)
```

**Merging returns and GPRD for use in the Wavelet Analysis**

```
TS1 <- merge.xts(GPR_ts$GPRD1, NG_ts$return1, join = "inner")
```

**Density plots**

```
par(mfrow=c(2,2))
plot(density(NG_ts), main = "Density plot illustrating skewness and kurtosis of r
eturns")
plot(density(NG_ts3), main = "Density plot illustrating skewness and kurtosis of
closing prices")
plot(density(GPR_ts), main = "Density plot illustrating skewness and kurtosis of
GPR")
```

**Descriptive statistics (only NG return TS shown in code): skewness, kurtosis, Jarque-Bera test, Kolmogorov-Smirnov test, Shapiro-Wilk's test, D'Agostino normality test, stationarity (ADF, PP & KPSS).**

```
skewness(NG_ts)

kurtosis(NG_ts)

jarque.bera.test(NG_ts)

ksnormNG1 <- ks.test(NG_ts, "pnorm")

shapiroTest(NG_ts)

unitrootNG1 <- adf.test(NG_ts[,1])

unitrootNG1

PP.test(NG_ts, lshort = TRUE)

kpss.test(NG_ts)
```

**Regression model for NG returns**

```
summary(fit <- lm(NG_ts$return1~time(NG_ts)))
```

**Durbin-Watson test for autocorrelation for regression model**

```
fitdw2 <- durbinWatsonTest(fit)
fitdw2
```

**GARCH models: I-GARCH, TGARCH & sGARCH**

```
#iGARCH
spec3 = ugarchspec(variance.model=list(model="iGARCH", garchOrder=c(1,1)),
                   mean.model=list(armaOrder=c(1,0), include.mean=FALSE),
                   distribution.model="norm", fixed.pars=list(omega=0))
fit1 = ugarchfit(spec3, data = NG_ts)
summary(fit1)

#TGARCH
m7 = garchFit(~aparch(1,0),data=NG_ts,trace=F,delta=2,include.delta=F)
summary(m7)

#sGARCH
garchFit(~arma(1,0)+garch(1,0), NG_ts)

fit.spec <- ugarchspec(variance.model = list(model = "sGARCH",
                                               garchOrder = c(1,1)),
                         mean.model = list(armaOrder = c(1, 0),
                                           include.mean = TRUE),
                         distribution.model = "std")
```

```
ugarchfit(data = NG_ts[,1], spec = fit.spec)
```

**Cross-Correlation Function**

```
ccf(diff(log(gpr$GPRD)),diff(log(ng$CLOSE)), 80, ylab="CCF", main = "Cross-correl
ation function of the transformed time series of closing prices and GPR")
```

**Pearson's r**

```
result = cor(matched1$return1, matched1$GPRD1, method = "pearson")
# Print the result
cat("Pearson correlation coefficient is:", result)
```

**Wavelet Transform Analysis: Power spectrum plot, coherence plot & phase difference plot.**

```
my.data <- data.frame(x = TS1$return1, y = TS1$GPRD1)
my.wc <- analyze.coherency(my.data, my.pair = c("return1","GPRD1"),
                           loess.span = 0,
                           dt = 1, dj = 1/100,
                           make.pval = TRUE, n.sim = 10)

#Power spectrum plot
wc.image(my.wc, n.levels = 250,
         legend.params = list(lab = "wavelet power levels"),
         periodlab = "periods (days)",
         show.date = TRUE, date.format = "%Y-%m-%d", timelab = "")

#Coherence plot
my.wc1 <- analyze.coherency(my.data, my.pair = c("return1","GPRD1"),
                            loess.span = 0,
                            dt = 1, dj = 1/100,
                            window.type.t = 1, window.type.s = 1, #Bartlett smoot
hing
                            window.size.t = 5, window.size.s = 1,
                            make.pval = TRUE, n.sim = 30)

wc.image(my.wc1, which.image = "wc", color.key = "interval", n.levels = 250,
         siglvl.contour = 0.1,
         siglvl.arrow = 0.05,
         which.arrow.sig = "wt",
         legend.params = list(lab = "wavelet coherence levels"),
         periodlab = "periods (days)",
         show.date = TRUE, date.format = "%Y-%m-%d", timelab = "")

#Phase difference plot
wc.phasediff.image(my.wc, use.sAngle = FALSE,
                   plot.coi = TRUE,
                   plot.contour = TRUE, which.contour = "wc",
                   siglvl = 0.1, col.contour = "white",
                   n.levels = 100,
                   color.palette = "rainbow(n.levels, start = 0, end = .7)",
                   useRaster = TRUE, max.contour.segments = 250000,
                   plot.legend = TRUE,
                   legend.params = list(width = 1.2, shrink = 0.9, mar = 5.1,
                                        n.ticks = 6,
                                        pi.style = TRUE,
                                        label.digits = 1, label.format = "f",
                                        lab = NULL, lab.line = 3),
                   label.time.axis = TRUE,
```

```
                  show.date = TRUE, date.format = "%Y-%m-%d", date.tz = NULL,
                  timelab = NULL, timetck = 0.02, timetcl = 0.5,
                  spec.time.axis = list(at = NULL, labels = TRUE,
                                        las = 1, hadj = NA, padj = NA),
                  label.period.axis = TRUE,
                  periodlab = NULL, periodtck = 0.02, periodtcl = 0.5,
                  spec.period.axis = list(at = NULL, labels = TRUE,
                                          las = 1, hadj = NA, padj = NA),
                  main = NULL,
                  lwd = 2, lwd.axis = 1,
                  graphics.reset = TRUE,
                  verbose = FALSE)
```