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The Future of Natural Gas as a Transition Fuel

Forecasting natural gas-generated power in Germany and the United Kingdom. What can we expect from Norwegian exports of natural gas in the years to come?

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Abstract

This thesis intends to answer the following research question:

What role will natural gas serve in the transition to renewable energy sources in the German and British power sectors, and what will be the implications for Norwegian natural gas exports?

To answer the research question, two dynamic regression models are built to forecast weekly natural-gas-generated power in Germany and the UK over the next two years. To create scenarios, the predictors of the models, which are other important power generation technologies, are given growth rates based on the German and British governments' climate action plans. Three scenarios are developed for both countries: (1) the Realistic scenario, (2) the Rapid I scenario and (3) the Rapid II scenario. The scenario forecasts are produced to provide insight into the future role of natural gas as a transition fuel and to observe how the use of natural gas will differ in the German and British power sectors. Furthermore, the point forecasts of the Realistic scenario for each country are monetized to quantify the impact on Norwegian exports of natural gas.

Natural gas can be a transition fuel in two main ways: (1) as a substitution fuel for heavier polluting energy sources and (2) as a stabilizing fuel for the intermittency of renewables. The predictions of the German model are conditional on the pace of the clean energy transition in Germany. For the Realistic scenario, the German model predicts a likely increase in natural gas in the German power sector, while the model predicts a decrease in the Rapid I and Rapid II scenario forecasts. Based on the Realistic scenario forecast and the German climate action plan, this thesis finds that natural gas will partially support renewables in replacing coal and that the use of natural gas in stabilizing intermittent renewables will increase. Thus, natural gas will be used both as a substitution fuel and as a stabilizing fuel in the German power sector in short term, which is expected to increase Norwegian natural gas exports to Germany. In contrast, the British model predicts a likely decrease in natural gas in the British power sector for all three scenarios. In the UK, natural gas has been used to substitute heavier polluting fuels and is the next fuel to be replaced in the power mix. Therefore, based on the Realistic scenario forecast and the British climate action plan, this thesis finds that natural gas's role as a substitution fuel has passed, while it will continue its role as a stabilizing fuel when renewable energy sources are intermittent. Thus, Norwegian natural gas exports to the UK are expected to decline in the short term. In the longer run, natural gas is expected to decrease in both the German and British power sectors and will eventually be phased out. Carbon capture and storage and blue hydrogen production can extend natural gas's relevance in Norwegian export markets.

Keywords – Forecasting, Dynamic regression model, Natural gas, Transition fuel

Contents

List of Abbreviations

Abbreviation	**Explanation**
ANN	Artificial Neural Network
ARIMA	AutoRegressive Integrated Moving Average
AR	AutoRegressive
BEIS	Department for Business, Energy and Industrial Strategy
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear
CCS	Carbon Capture and Storage
ENTSO-E	European Network of Transmission System Operators for electricity
EU ETS	EU Emission Trading System
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LNG	Liquefied Natural Gas
MA	Moving Average
UEPs	Updated Energy Projections

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1 Introduction

Norwegian exports have been heavily reliant on fossil fuels since the 1970s. Their impact on Norwegian welfare has been tremendous and enabled Norway to become one of the best countries to live in worldwide. However, following the Paris Agreement in 2015, most nations in the world are legally bound to drastically cut their emissions to reach the target of reducing global warming to 1.5 degrees. The report from the UN's Intergovernmental Panel on Climate Change (IPCC) states that if we do not immediately start rapid and powerful emissions reductions, a limit of 1.5 or even 2 degrees warming will be out of reach. As a result, Norwegian exports of fossil fuels will undoubtedly be impacted when countries transition to renewable energy sources in the future. However, the problem with most renewables is their fluctuating nature. The energy sources being harvested, wind and sun, is inherently difficult to store. As a result, renewables are still not the reliable and flexible energy sources needed to supply countries' power consumption by themselves. Until further investments and technological advancements in renewables occur, especially with respect to battery technology, demand for fossil fuels will most certainly have a future (IEA, 2020a).

The low CO_2 emissions from burning natural gas ("gas") compared to other fossil fuels combined with its reliable nature make gas a strong contender as a transition fuel to renewable energy sources. In 2019, the Executive Director of the International Energy Agency (IEA) Dr. Fatih Birol stated the following:

"Natural gas is one of the mainstays of global energy. Where it replaces more polluting fuels, it improves air quality and limits emissions of carbon dioxide" (IEA, 2019b).

On the contrary, many argue that gas is a fossil fuel and thus should be phased out in conjunction with other heavier polluting fuels (Gürsan & de Gooyert, 2021; United Nations, 2021). Furthermore, gas infrastructure is long-lived and expensive and can crowd out investments in renewable power generation technologies. Consequently, giving gas a vital role as a transition fuel toward clean energy sources is considered an unnecessary step that will delay the clean energy transition.

The role gas will serve as a transition fuel is controversial and will depend on each country's specific power mix and climate action plan. In countries where coal is the dominant source of energy, gas can replace heavier polluting fuels. Substituting coal for gas will have an important impact on reducing emissions from the power industry in the short to medium-term (Ember, 2021). In contrast, if a country has a great share of renewables in its power mix, gas could be used for balancing and providing energy security due to its reliability. Doing so implies ramping up gas-fired power in periods with no sun or wind and during cold winter days with spiking electricity demand. In this manner, gas can be used both as a transition fuel to (1) substitute coal and other heavier polluting fuels in the power sector and (2) stabilize the intermittency of renewables.

Germany and the UK are the two most important trading partners for Norwegian gas. Both countries are committed to ambitious CO_2 emissions reductions for 2030 and 2050. However, the two countries will have different paths to carbon-neutrality due to two different power mixes. Germany is heavily reliant on coal but has a phase-out plan in place for both coal- and nuclear-generated power. The capacity taken offline is to be replaced by an ambitious expansion in renewables and other low-emission sources. In contrast, the UK has managed to phase out coal almost completely, mainly replacing it with power generation by renewables and gas (Ember, 2021). Therefore, gas can be expected to serve different roles in reaching the targets of the German and British climate action plans.

These two countries importance as export destinations for Norwegian gas and the different compositions of their power mixes give reason to believe that gas will serve differently as a transition fuel. This has led to this thesis's research question:

What role will natural gas serve in the transition to renewable energy sources in the German and British power sectors, and what will be the implications for Norwegian natural gas exports?

To answer the research question, the thesis aims to forecast gas-generated power in the two countries based on other sources of energy. The method used is called a dynamic regression model, often referred to as a regression with AutoRegressive Intergrated Moving Average (ARIMA) errors. The dynamic regression model is considered an appropriate method because the model allows for both inclusion of relevant information from predictor variables and handling of the subtle time series dynamics of data. The models will be used to produce three different scenario forecasts for the next two years: (1) the "Realistic scenario", (2) the "Rapid I scenario", where the transition from fossil fuels to renewables progresses faster than expected, and (3) the "Rapid II scenario", where the transition accelerates even more. In the scenarios, the predictors are given constant growth rates based on power generation capacity targets retrieved from the German and British climate strategies. The predicted trajectories for gas-generated power will be discussed in relation to official climate action plans to better understand the role gas will play as a transition fuel in the future. As Germany and the UK are the largest importers of Norwegian gas, the predicted changes in gas used for electricity generation, will be quantified both in output (GWh) and monetary value (NOK) to assess the impact on Norwegian gas exports.

The German model produces opposing forecasts for the change in gas-generated electricity in the German power sector compared to the past two years. The Realistic scenario predicts a likely increase in gas in the German power sector, while the Rapid I and Rapid II scenarios predict a decrease. Based on a discussion of the Realistic scenario forecast and the German climate action plan, gas is expected to increase as it will to some extent support renewables in replacing retired coal and nuclear capacities. In addition, the use of gas as a stabilizing technology for the intermittency of renewables is expected to increase as coal, which is also used as a stabilizer, decreases. Therefore, gas will be used both as a substitution fuel and a stabilizing fuel in the short term. This thesis finds that the most likely increase in gas-generated power will lead to an increase in Norwegian exports of gas to Germany. For the UK, the model predicts a likely decrease in British power generation from gas in all three scenario forecasts. Gas has been used to substitute coal, making gas the next fuel to be phased out. Therefore, based on the prediction of the Realistic scenario forecast and the British climate action plan, it is found that gas will not play a role as a substitution fuel but is expected to continue its role as a stabilizing technology for the intermittency of renewables in the short term. These findings imply a decrease in the export of Norwegian gas to the UK. Furthermore, based on the climate policies, it is expected that gas will decrease in the long run in both the German and British power sectors and be fully retired in 2040 and 2035, respectively. Gas can prolong its role as a relevant fuel in European energy markets and power sectors through large-scale carbon capture and storage ("CCS") projects and through the production of hydrogen from gas using CCS ("blue hydrogen").

Chapter 2 of this thesis will provide relevant background information pertaining to the research question. The chapter includes a brief introduction of the dynamics of the gas market, the attributes of gas and a discussion of the arguments for and against gas as a transition fuel. Lastly, Chapter 2 will present Norwegian gas exports and the German and British power sectors. Chapter 3 will begin with a method review of previous authors forecasting gas demand in the power sector and gas consumption, followed by a brief elaboration on the ARIMA, seasonal ARIMA (SARIMA) and dynamic regression models. In addition, Chapter 3 will explain why the dynamic regression model was chosen. Chapter 4 presents how the time series data used in this thesis were retrieved in addition to the frequency and number of observations. Chapter 5 is the analysis chapter, and the structure of this chapter follows a tidy workflow process of producing forecasts for time series data. The stepwise procedure includes specifying the models, visualizing the data, checking stationarity, defining the structure of the models, checking residuals, and forecasting. After identifying appropriate models, Chapter 5 produces three different scenario forecasts for German and British power generation over a two-year period. The point forecasts are quantified to better understand the potential impacts on Norwegian gas exports. Chapter 6 discusses the predictions of gas-generated power in relation to official German and British capacity targets by technology and the expected developments in Norwegian gas exports for both the short and long term. A Critique is provided in Chapter 8 that discusses the models' limitations. Lastly, Chapter 9 concludes the thesis and is followed by a list of the cited literature.

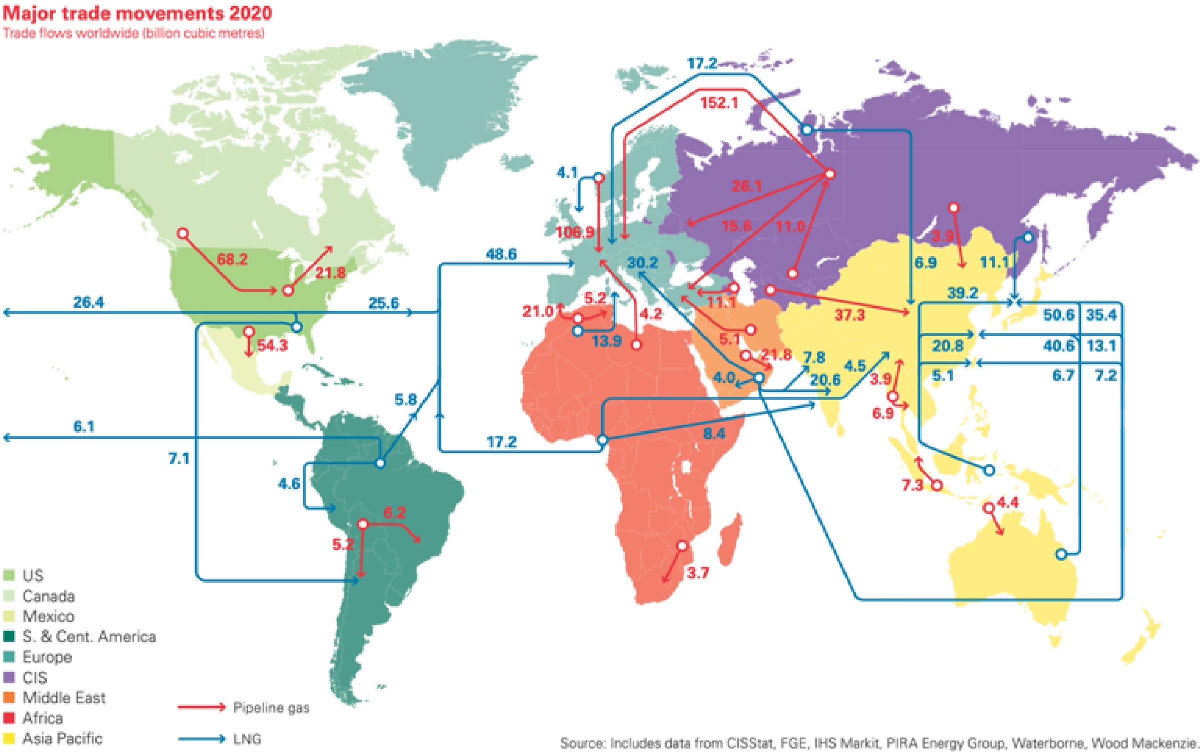
2 Background

The following chapter will provide relevant background information to understand the dynamics of gas markets, why gas is a potential transition fuel, and the importance of gas for Norwegian exports. In addition, Chapter 2 will explain the motivation for choosing

Germany and the UK and present both past and planned developments in the German and British power sectors while highlighting the role of gas as a transition fuel.

2.1 Natural Gas Markets

Gas is commonplace in cooking, residential and commercial heating, industrial process feed stocks, and electricity generation in most parts of the world (Norwegian Petroleum, 2021a). Pipelines are the most widespread method for transport of gas from the well-site to the consumers. Due to pipelines, gas markets have been regional rather than comprising one global market. Developments in transport of gas due to liquefied natural gas (LNG) are moving the regional markets closer to a global market (DNV, 2021). The reason for this is LNG being transported by specialised carriers, making it less vital to rely on expensive pipelines. As a result of the flexibility of LNG, gas no longer need to be sold on long-term contracts but can now be sold on spot (Nøstebakken, 2021).



Source: Includes data from CISStat, FGE, IHS Markit, PIRA Energy Group, Waterborne, Wood Mackenzie.

Figure 2.1: Global gas trade 2020

Figure 2.1 illustrates global gas trade movements in 2020. Compared to the same figure a decade earlier, there is a severe growth in LNG trade (see Figure A1.1). In 2020 gas constituted approx. 24% of total world energy demand, only surpassed by oil in meeting global energy needs (Ministry of Petroleum and Energy, 2021a). In the past decade gas has accounted for almost one third of the growth in global energy consumption. Gas demand is expected to continue to grow towards 2030 (IEA, 2021a).

Historically the gas price has varied greatly due to regional markets. Differences in prices have been a result of many factors, such as the distance the gas must travel, the availability and capacity of pipelines, volumes and characteristics of consumer demand, taxes and other charges, and the availability of competing fuels (EIA, 2021c). However, gas being a regional commodity traded by pipelines is changing. Substantial growth in both liquefaction and regasification terminals worldwide has significantly increased LNG trade, leading to global gas price convergence (see Appendix, Figure A2.1). This has mostly been caused by the US shale revolution, which made the US become an exporter rather than importer of gas (Lateni, 2021). The production, trade and consumption of LNG is disrupting the gas market (DNV, 2021).

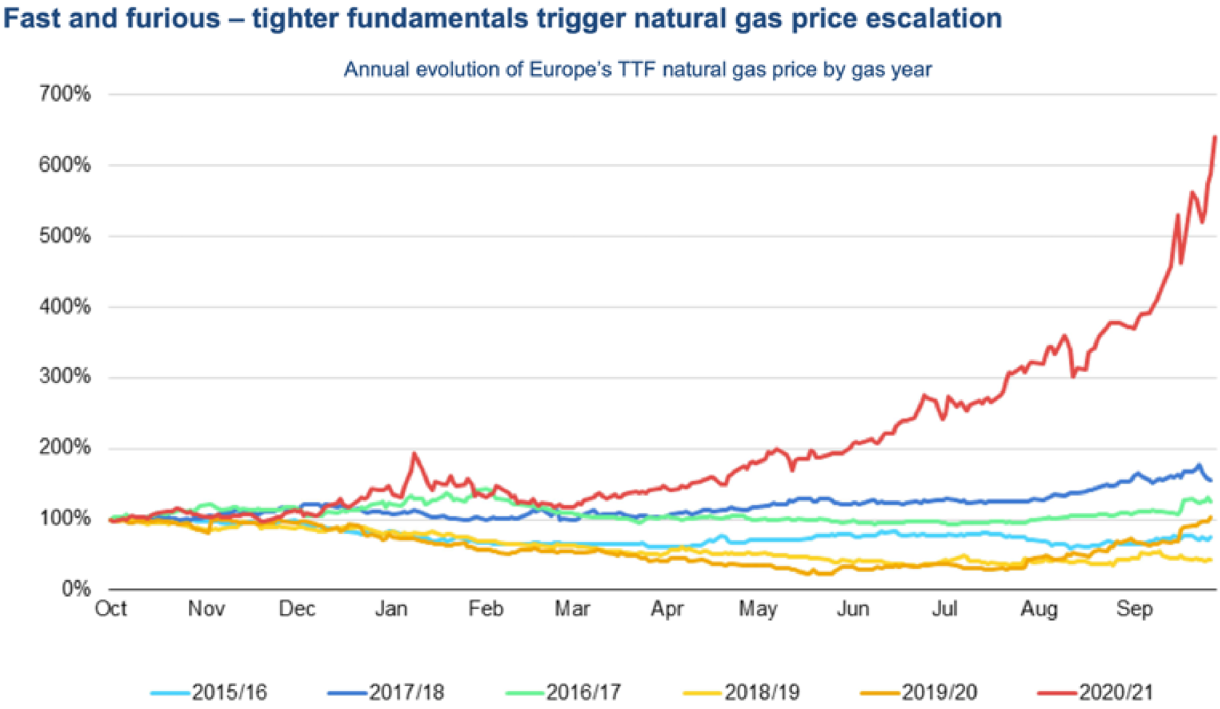


Figure 2.2: The surge in European gas prices in 2021

European gas prices soared in the period January to December 2021, climbing to a high of USD 13.88 per Metric Million British thermal unit (MMBtu) in the third quarter (Equinor, 2021b) (Figure 2.2). The tightening of gas markets has been caused by a combination of robust demand growth as economies recover from Covid-19, a prolonged northern-hemisphere winter that ran down the reserves of European countries and tighter-than-expected supply as a series of outages hampered gas production and export capacity from Russia and Norway (EIA, 2021b).

2.2 Advantages of Natural Gas

It is important to understand the attributes of gas to recognize its potential as a transition fuel. Thus, the following section will discuss the potential advantages of gas.

Several authors highlight gas as a reliable and secure energy source (Colombo, El Harrak, Sartori, et al., 2016; Gürsan & de Gooyert, 2021). Three categories are usually emphasized when discussing an energy source as a reliable resource: (1) intermittency, (2) flexibility, and (3) peak demand (Gürsan & de Gooyert, 2021). First, intermittency can be explained as the resource's variability in energy production. If a resource is intermittent, its energy generation will fluctuate and cannot deliver a stable source of energy. As gas can be easily stored, it is highly stable in its energy delivery. Second, flexibility refers to the resource's ability to shift energy production swiftly. Gas plants have a short on-and-off cycle and are thus considered a flexible resource. Compared to coal power plants, which may take many hours or even days to stop and restart, gas plants take between minutes and hours to start, depending on the specific technology (EIA, 2021a). Micro-management of energy production is a considerable advantage in dealing with short-term demand fluctuations. Lastly, peak demand implies the ability to provide the necessary energy on days with high demand fluctuations. This is typically on warm summer days or cold winter days. If the stored gas capacity is sufficient, it is relatively easy to meet high demand.

Furthermore, gas can be an attractive energy source from an environmental perspective. For the same amount of electricity output, gas-fired power plants emit between half and one-third of the CO_2 emissions from coal-fired power plants (Centre for Climate and Energy Solutions , 2021). Furthermore, the smog released in the mining and combustion of coal has negative health effects. Although extracting and burning gas have similar externalities, the emission levels are considerably lower than for other fossil fuels. It is the potential emissions reductions when substituting coal with gas that is highlighted as the environmental benefit provided by gas.

Gas is considered easy to transport and store (EIA, 2021c). The member states in the European Union (EU) have the capacity to store roughly one-fifth of the total gas consumption through a year (Chilar, Mavin, & Leun, 2021). The ability to store gas makes it a reliable resource. The reason being that gas storages increase energy security by easier balancing the intermittency of renewable energy sources and by improving the capability of meeting peak demand. Consequently, many countries use gas to serve both baseload, which is the minimum amount of power demand at any given time, and peakload.

Another advantage that is often highlighted is the abundance of gas. According to BP plc (2021), total proved gas reserves were at 190.3 trillion m^3 at the end of 2019. The abundance of gas creates an incentive to invest in new infrastructure and technology. Examples of such investments are CCS technologies and blue hydrogen production, which have the potential to secure a new spring for gas (Equinor, 2020).

2.3 A Transition Fuel?

Many consider gas an essential bridge to renewables when phasing out fossil fuels. Erik Wærness, Chief Economist at Equinor, said the following in 2018:

“Gas is the energy form that offers the quickest and easiest path to phasing out coal in the electricity sector, as it can act as a stable power source on the days when wind and solar power produce less power because the weather is calm or cloudy" (Equinor, 2018).

This argument has not just been emphasized by Wærness, but several other scholars and organizations give similar opinions (Ahmed & Cameron, 2014; Baron, 2013; Colombo et al., 2016; Van Foreest, 2010). Although it has been established that gas releases less CO_2 per KWh than coal and oil, the answer to whether gas is to be used as a transition fuel is more complex than comparing emissions levels of energy sources. The following section will discuss the most widely used arguments for and against the use of gas as a transition fuel to renewable energy sources.

The most important argument for gas being a transition fuel is that it is the cleanest burning fossil fuel (IEA, 2020a). The positive environmental impact of substituting heavier fossil fuels, like coal with gas, contributes to less greenhouse gas (GHG) emissions. According to IEA (IEA, 2019b), the EU reduced CO_2 emissions from electricity generation by 42 million tons in 2019 by replacing coal with gas. Such observations have led authors to expect similar emissions reductions in Asia if coal is replaced by gas, as the continent is heavily reliant on coal (Baron, 2013; Stephenson, Doukas, & Shaw, 2012). Furthermore, there are instances of gas-fired power generation being cheaper than coal-fired. The most cost-efficient gas plant has an investment cost of USD 1,100 per KW, while the most cost-efficient coal plant has an investment cost of USD 3,700 per KW (Shell, 2021). The EU Emission Trading System (EU ETS), which works as a carbon price, has severely weakened the investment case for coal and tipped the economics in favor of gas in the EU (Thomas, Hook, & Tighe, 2019). Gas becomes even more competitive with coal when taking the long-term environmental costs associated with climate change and air pollution, both for people and the environment.

While substituting coal with gas has proven to reduce GHG emissions locally, regional emissions reductions may have externalities affecting other markets. As a result, the substitution from coal to gas can affect other regions negatively and have a net negative global impact. Coal and gas can be seen as substitutes in power generation, and there have been observations of the price of both gas and coal falling in the US, thus leading to higher consumption of both fuels. When fracking was introduced in the US, the sudden abundance of gas caused local coal consumption to decline, while it caused the opposite in Europe (Ahmed & Cameron, 2014). In Europe, the price of coal dropped as they could import cheap coal from the US to run European coal power plants. This effect is called the carbon leakage effect, and it is a fossil spillover caused by reallocation in fossil industries (Gürsan & de Gooyert, 2021). The carbon leakage effect is recognized by the IPCC. The effect emphasizes that extracted coal spills over to other parts of the world when it cannot compete with affordable gas in the local market (Metz, Davidson, Swart, Pan, et al., 2001).

Another argument in favour of gas to be used as a transition fuel is gas's ability to be a reliable and secure energy source. The intermittency of wind and solar is the fundamental challenge of these technologies, and implies that the output and capacity factor depend on weather conditions and daily and seasonal variations. Economies are dependent on stable power delivery. Consequently, relying solely on renewables is difficult due to their intermittency. In addition, the adaptation of large scale energy storage systems is moving too slow (Brun, Allison, & Dennis, 2020). In contrast, gas is considerably easier to store. Various authors point out that gas is the most suitable energy source to balance renewables' intermittent energy generation (Baron, 2013; Stephenson et al., 2012; United Nations, 2021; Van Foreest, 2010). On the contrary, some other authors argue that utilities are wasting billions by investing in gas plants that will have to shut down before their useful lives end, in order to meet emissions reduction targets (Penn, 2020; Phadke, Wooley, Abhyankar, Paliwal, & Paulos, 2021). They further argue that the right actions to take are to expand renewables, energy storage systems and transmission lines while closing all coal plants and slashing gas use, thus a direct transition to renewables without going through gas.

The European energy crisis in 2021 has showcased the weak spot of renewables. A summer characterised by low wind has created a dangerously low supply of energy (Bernard, 2021; Mellor, 2021). Renewables' reliance on wind and sun to generate power weakens their flexibility. As gas is highly flexible, gas can complement renewables when energy demand surpasses the availability of wind and sun on a given day. In addition, the flexibility of gas works both ways. When renewables are sufficient to meet energy demand, gas plants can swiftly ramp down power production and minimise the carbon footprint from power generation (Arent et al., 2015). When the availability of renewable energy sources is uncertain (wind and sun) and peaks in demand occur, relying solely on renewables may be a challenge and less favourable due to the need for overbuilding capacity (Del Río & Janeiro, 2016). Gas may be used to avoid the need for overcapacity in the energy supply by introducing "peak" gas plants that compensate for unreliable renewable energy supply (Safari, Das, Langhelle, Roy, & Assadi, 2019; Van Foreest, 2011).

Natural gas being a polluting fossil fuel and the potential carbon leakage effect are not the only negative externalities of increased gas-generated power. In addition, increased gas-fired electricity can influence other generation technologies and investments. When two technologies compete for the same market, investments tend to flock to the most profitable technology. Therefore, investments may crowd out in the most desirable technology as it often is not the most attractive technology from an economic perspective (Gürsan & de Gooyert, 2021). Power generation by gas is widely considered a desirable technology until renewables become a viable option to provide stable power supply. However, if gas gains popularity as a substitute for coal, increased investments in exploration and production of new fields, new pipelines, and export and import terminals, can crowd out investments in renewables and have a negative impact on emissions in the long run (Baron, 2013; Dupont & Oberthür, 2012). In Europe, coal almost halved between 2015 and 2020. However, increased gas usage offset 43% of the potential emissions reductions Europe would have gained if renewables had replaced coal (Agora Energiewende & Ember, 2021). As a result of the crowd out effect, markets may experience what some authors call a carbon lock-in (Gürsan & de Gooyert, 2021). Every time gas is chosen at the expense of renewables, the relative position of renewables weakens. Consequently, it becomes tougher to develop the necessary network and infrastructure needed to make the energy transition. If markets allow gas to grow and technological advancements surpass those of renewable energy sources, gas can become financially superior regardless of negative externalities (Unruh, 2000). This is further underlined by the long-lived nature of gas infrastructure threatenening to lock in emissions levels above longer-term targets (Woollacott, 2020). kommet hit

2.4 Norwegian Exports of Natural Gas

As the research question seeks to answer what the future role of gas will be and the potential effect on Norwegian gas exports, this section will provide an overview of Norwegian gas exports. Norwegian gas exports is an important part of the Norwegian economy. In 2019, gas exports totalled to NOK 171 billion, equivalent to 19% of total Norwegian export earnings. Norway is the third largest gas exporter in the world and nearly all Norwegian gas is sold on the European market. In 2020, Norway exported about 112 billion m^3 gas to the EU or the equivalent of roughly 22% of the EU's gas consumption (Ministry of Petroleum and Energy, 2021a). Norway is only surpassed by Russia as the biggest gas supplier to the EU, with a market share of 34%. The main trading partners of Norway are Germany, the UK, France, and Belgium. Norwegian exports of gas has risen in previous years. However, estimates suggest that as little as one third of the gas reserves on the Norwegian continental shelf has been extracted (Ministry of Petroleum and Energy, 2021a).

Figure 2.3: Pipeline network exporting Norwegian gas

There is an extensive network of pipelines running gas from the Norwegian continental shelf (Figure 2.3). The Norwegian pipeline system is the largest in the world of its kind, accumulating over 8,000 kilometres of pipelines (Equinor, 2021c). The pipelines connect Norwegian offshore gas fields and onshore processing plants to landing points in Germany, Belgium, France, and the UK. Storage facilities are connected to the import terminals. For example, in Germany, Equinor has a gas storage facility capable of storing up to 1.2 billion m^3 of gas connected to the reception facilities in Dornum and Emden. As for Norwegian liquefaction of gas, the "Snøhvit" field is the only field converting gas to liquid state on a large scale. LNG shipped from the Snøhvit field makes up about 5% of Norwegian gas exports. Norway and Russia are the only countries in Europe that export LNG (Ministry of Petroleum and Energy, 2021a). However, the global growth in LNG is expected to increase the reach of Norwegian gas worldwide.

Traditionally, Norwegian gas exports has been sold on long-term contracts to large

European gas companies and suppliers. The operators and buyers entered take-or-pay contracts for the entirety of the field's lifespan. In the absence of a market price for gas, the sales price has been closely correlated with the oil price (Equinor, 2021b). However, the sales channels and market have evolved, and broken up the traditional gas value chain. In particular, the liberalization of transport networks has opened for equal terms for everyone. Norwegian gas is sold on long-term contracts, in the spot market and even directly to end-users, such as power plants or industry. As a result, the gas price is directly linked to the price in the marketplace (Equinor, 2021b).

The future of Norwegian gas export is to some extent uncertain. Although production is expected to rise until 2024, increased market competition may cause changes in Norwegian gas exports (Ministry of Petroleum and Energy, 2021b). Norway is to expect increased competition from Russia, due to the "Nordstream 2" pipeline which is designed to carry Russian gas directly to Germany. Furthermore, because of market liberalization and local markets becoming globalised, Norway should also expect more competition from LNG supplied by the US and the Middle East. In addition, the globalization of gas markets leads to changes in demand, where Europe and Asia are competing for the same gas supply (The Economist, 2021). CCS is expected to create greater space for continued use of gas (Solheim, 2021). The storage capacity within the geological layers on the Norwegian continental shelf gives Norway great opportunities to become a storage hub for ports of European countries (Figure 2.3). The IEA has found that to meet the Global Paris Agreement targets, 14% of the total emissions reductions by 2060 must come from CCS (SINTEF, 2021). In addition, production of blue hydrogen can be key to keep Norwegian gas valuable in a low-carbon future (Equinor, 2021a).

2.5 The German and British Power Sectors

As there will be built models to forecast gas-generated power in Germany and the UK, it is necessary to get an overview of the German and British power sectors and planned developments within them. This section will begin by explaining the motivation for picking Germany and the UK as the two research countries, followed by an introduction to the German and British power mixes and planned developments based on the German and British climate action plans for their power sectors.

2.5.1 Motivation for Germany and the UK

As presented in the previous section, Norway is an important supplier of European gas markets. Germany and the UK are undoubtedly the two most important markets for Norwegian gas. In 2019, Germany accounted for 37% of Norwegian gas exports, while the UK accounted for 23% (OECD, 2021). Furthermore, Germany and the UK have different power mixes, and gas is expected to play different roles in their clean energy transitions. The different compositions of their power mixes make it even more interesting to examine these two countries and the possible implications on gas-fired power under different scenarios. A third motivation for choosing the two countries, linked to the compositions of their power mixes, is the geographical locations of the two countries. The UK is Europe's largest island and placed in the outer of Europe, while Germany is Europe's largest economy placed right in the heart of Europe. This implies that the two countries have different prerequisites to reach carbon-neutrality, which will influence their pathways to renewable energy sources.

2.5.2 The German Power Sector

Power Mix

To better understand the German pathway to carbon neutrality, it is necessary to take a closer look at the German power mix. In late 2010, Germany initiated the "Energiewende", a major plan for making the German energy system more efficient and mainly reliant on renewable energy sources. The country has adopted a strategy for climate neutrality in 2050, which includes an accelerated phase-out of nuclear power by 2022 (Appunn, 2021). Germany has set clear goals to reach the ambitious Energiewende, for example that 65% of all electricity supply is to come from renewable energy sources by 2030 and an orderly long-term exit from hard coal by 2033 and lignite coal by 2038 (IEA, 2021b). Furthermore, Germany has proven to be an early leader in offshore wind and solar photovoltaic (solar PV), alongside investing large amounts in hydrogen capacity.

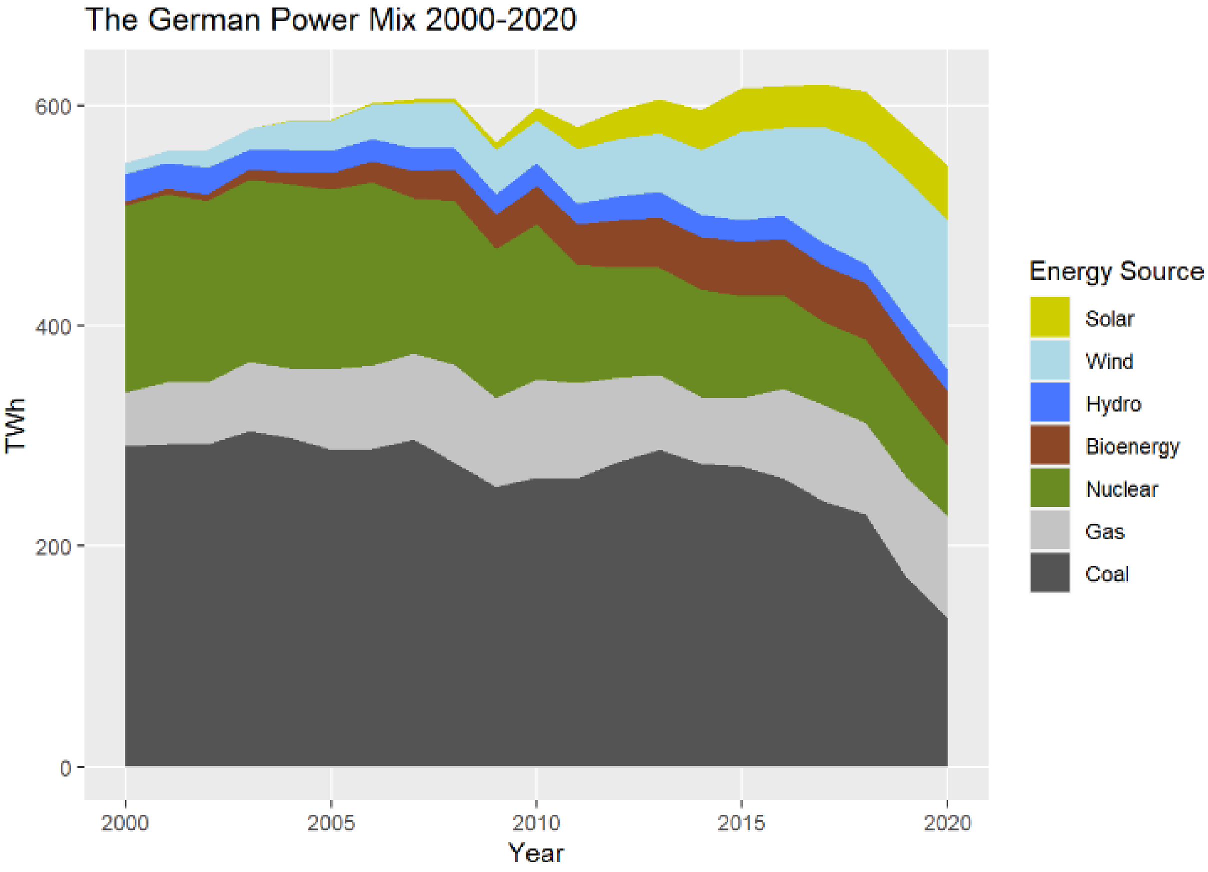


Figure 2.4: The German power mix 2000-2020

Figure 2.4 visualizes the annual power generation by the technologies in the German power sector from 2000 until 2020. One can observe that the composition of the power mix has changed considerably over the 20-year period. Renewables constitute an increasingly important share of total power generation. Furthermore, the energy efficiency of the power sector has only improved slightly over the past two decades. The German government adopted the Energy Efficiency Strategy 2050 at the end of 2019. This strategy sets out the first targets for reducing primary energy use in all sectors of the German economy by 2030 (Bundesregierung, 2020).

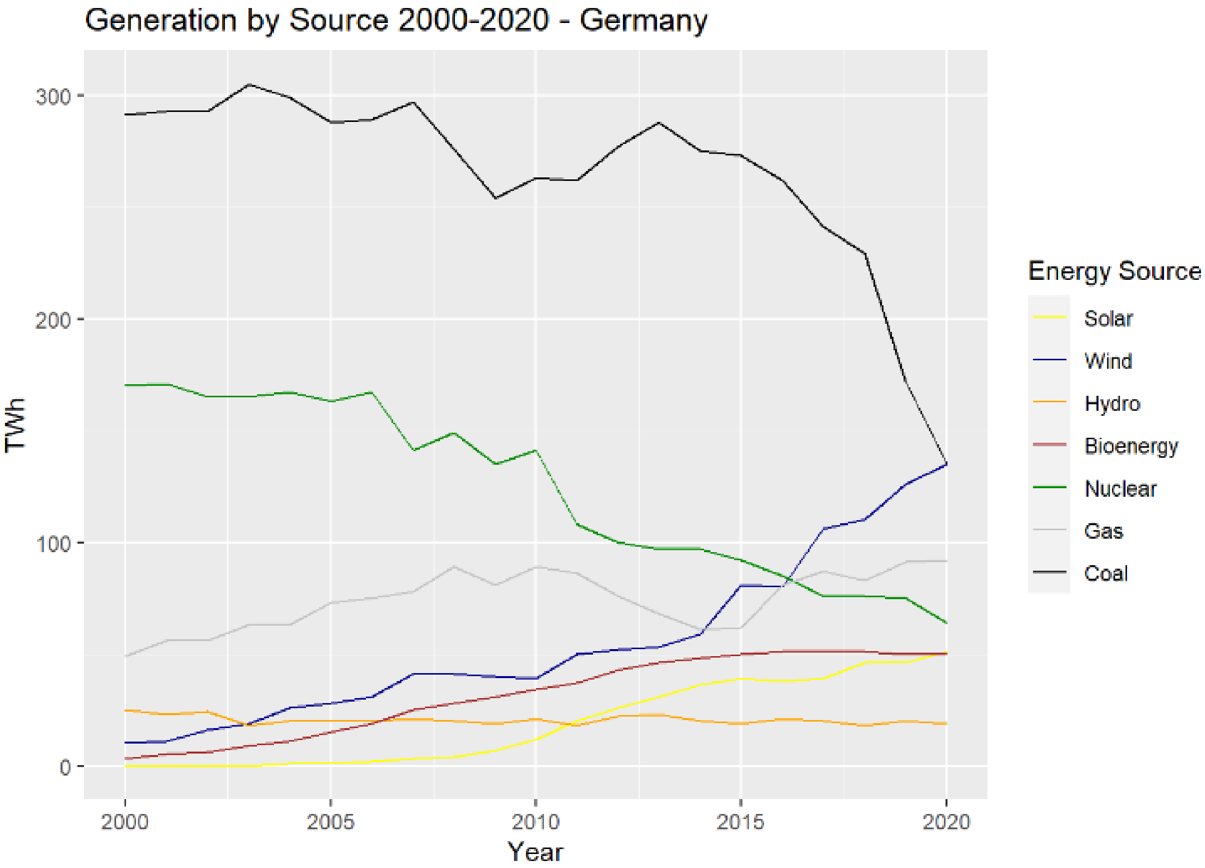


Figure 2.5: Power generation by energy source in Germany 2000-2020

Figure 2.5 provides a better overview of the development of each technology over the past 20 years. The figure illustrates that coal, wind, gas, and nuclear are the four most dominant energy sources in the German power mix. Renewables have experienced a rapid increase, especially in wind power. The increase in solar has been slower, not picking up its pace until about 2008, while bioenergy has had a steadier increase. Renewables rose to generate 46.3% of German electricity in 2020, up 3.8% from the previous year (Reuters, 2020). At the same time, fossil-fired power generation fell to about 40%. The milestone of renewables overtaking fossil fuels for the first time was achieved already in 2019 (Wehrman, 2019). Under the EU ETS scheme, the price of emission allowances has had increasing relevance in this transition, particularly since 2018 (IEA, 2021b). Furthermore, coal's decline continued in 2020, while power generation from gas increased both in 2019 and

2020 (Ember, 2021). Gas rose to about 13% of German power generation in 2020, despite the Covid-19 pandemic. Interestingly, the decrease in nuclear-generated power accelerated in about 2010, the same year the Energiewende was initiated. The phasing out of nuclear reactors within 2022 has been a controversial part of the Energiewende. This is because the phase-out of nuclear power is slowing down the transition from fossil fuels to renewables, as renewables have been unable to replace the full capacity gap from both nuclear and coal power plants that have shut down (Ember, 2021).

The Future of the German Power Mix

It is important to get a grasp of the planned future of the German power mix to be able to create realistic scenarios in the analysis chapter. In 2020, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) published the Climate Action Plan 2030, which includes measures for all sectors and cross-sector instruments in Germany. According to the Coal Phase-out Act of the Climate Action Plan 2030, coal is to be phased out by 2038 at the latest. Furthermore, the climate action plan focuses on a massive expansion of renewables with wind power at the centre of this clean energy transition. The nominal power generation capacity of onshore wind was 54.40 GW in 2020 and is targeted to increase to 71 GW by 2030. For the offshore wind power capacity, the Offshore Wind Energy Act stipulates an increase from 7.70 GW in 2020 to 20 GW by 2030. Alongside expanding wind turbines, the goal is to have an installed capacity of 100 GW of solar PV technology by 2030 compared to 53.80 GW in 2020 (Federal Ministry for the Environment, Nature Conservation, and Nuclear, 2020)

The post-Merkel coalition announced in November 2021 that they have agreed on a more progressive agenda for the energy transition. These climate measures include a phase-out of coal power by 2030 and an increase from 65% to 80% of electricity supply to come from renewables in 2030 (Braun, 2021). The deal also proposes phasing out gas for power generation by 2040 and setting a minimum carbon price of EUR 60 per ton of CO_2.

Having decided against the use of nuclear power and due to a lack of available hydro power, intermittent power generation from solar plants and wind turbines are key technologies of the Energiewende (Appunn, 2021). The Infrastructure Acceleration Act ensures the implementation of the first measures to simplify the planning and approval processes for wind power plants. In addition, the act gives German federal states the right to introduce their own distance regulations for wind turbines, which aims to boost the acceptance of onshore windmills (Bundesregierung, 2020). However, the continued expansion of renewable energy installations is at risk, primarily due to difficulties in licensing onshore wind power turbines. A planned minimum distance law from residential areas could shrink the available land area for new turbines. In this case, neither the goal of 65% or the enhanced goal of 80% renewables by 2030, will be feasible. If the minimum distance law passes legislation, gas is expected to prolong its lifespan in the German power sector (IEA, 2021b).

Gas as a Transition Fuel in Germany

In the previous sections, gas has been highlighted as a bridge fuel for its potential to substitute more polluting fossil fuels and to balance intermittent renewable energy sources. The BMU recognizes this potential and has stated that "Natural gas is being used as a bridge technology during the energy system's transition to renewable energy sources" (Federal Ministry for the Environment, Nature Conservation, and Nuclear, 2020). Especially the role as a stabilizing fuel until renewables provide enough and flexible electricity is highlighted.

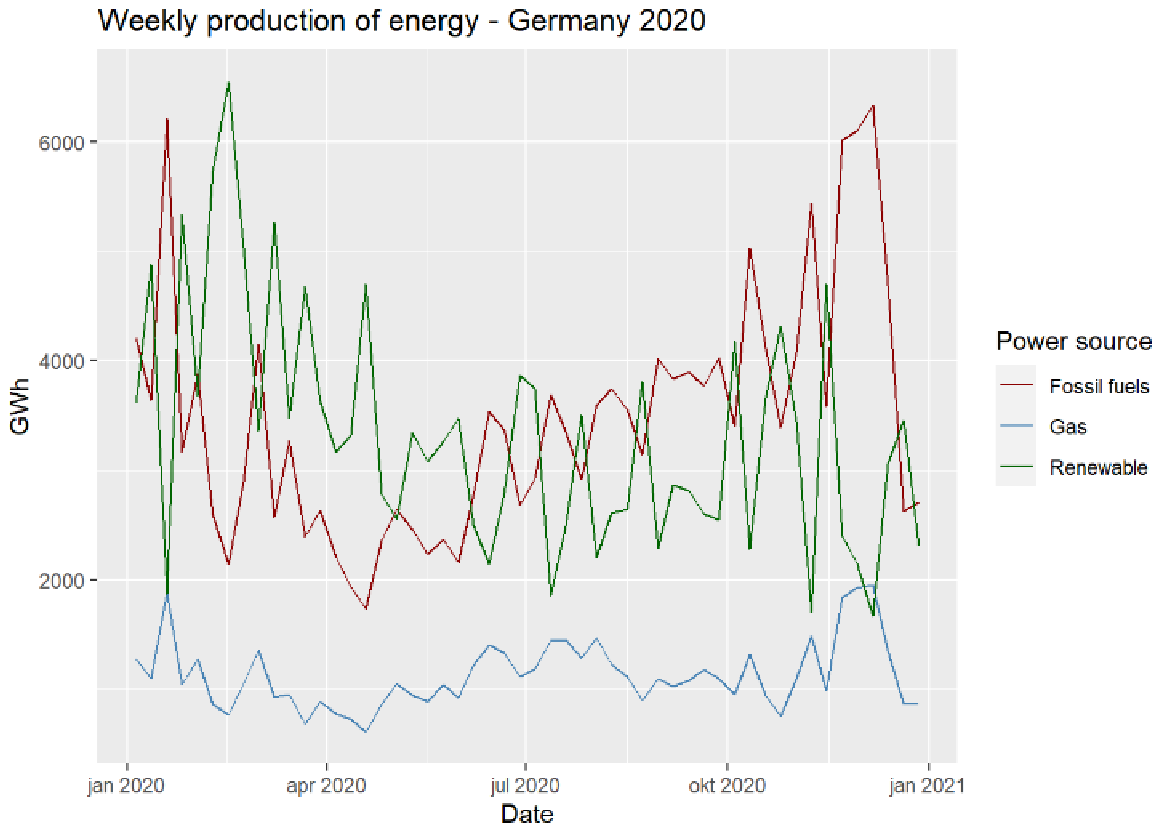


Figure 2.6: Weekly electricity production by fossil fuels and renewables in Germany

Figure 2.6 displays the weekly power generation by gas, renewables, and aggregated gas and coal (Fossil) in Germany for 2020. The figure illustrates the intermittency of renewables with output varying substantially from week to week. In Germany, the intermittency of renewable energy sources has risen sharply over the last few years (Amelang, Appunn, & Eriksen, 2021). The almost perfect negative correlation between renewables and fossil fuels reflects how coal and gas are used to stabilize the intermittency of renewables (Figure 2.6). In addition, gas has partially been used as a substitution fuel in the German power mix. However, the decline in coal-generated power since about 2013 has mainly been replaced by renewable energy sources (Ember, 2021).

Germany is aiming for renewables to replace fossil fuels. However, the simultaneous phase-outs of nuclear and coal power plants will increase demand for gas in the German power sector, especially as a stabilizing fuel for the intermittency of renewables. In the short to medium term, increased use of gas in electricity generation will tie electricity security to gas security (IEA, 2020b). Thus, making it increasingly important to continue efforts to diversify gas supply options for the time to come, including LNG reception terminals (IEA, 2020b). Even though the increased use of gas is seen as necessary by many, critiques warn that substituting gas for coal for short term CO_2 gains, will only prolong the energy transition to renewables and make it more expensive to reach carbon neutrality (Ahmed & Cameron, 2014; Safari et al., 2019).

2.5.3 The British Power Sector

Power Mix

This section will break down the British power mix between 2000 and 2020 to better understand the continued pathway to a net-zero society in 2050. The UK is a global leader in decarbonization, both in actual emissions reductions and ambitions. These ambitions are set out in five-year carbon budgets. The country has a plan to reduce economy wide GHG emissions by at least 68% by 2030 compared to 1990 levels (IEA, 2021c). According to the Department for Business, Energy and Industrial Strategy (BEIS), building on the countries strengths, improve energy efficiency and innovation are all at the centre of the British decarbonization policy. The innovative ambition of the UK is reflected in the "Prime Minister's Ten Point Plan for a Green Industrial Revolution" and the "Energy White Paper", both published in 2020. The green industrial revolution includes offshore wind, solar, hydrogen, nuclear power, carbon capture, alongside energy efficiency (Department for Business, Energy and Industrial Strategy, 2021b). The UK's coastal areas and excellent conditions for offshore wind are central in shifting to an energy system fit for the future. The UK has the largest installed offshore wind capacity worldwide (RenewableUK, 2021).

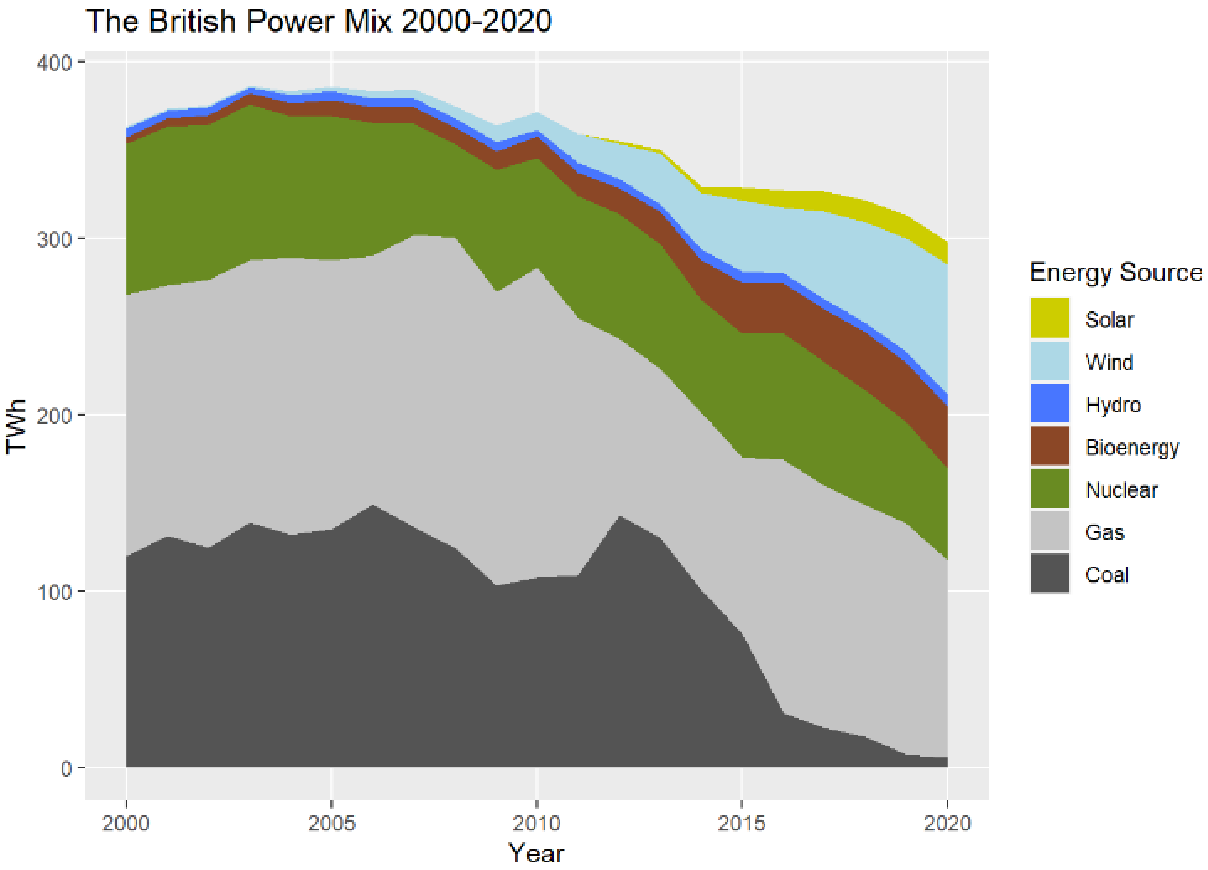


Figure 2.7: The British power mix 2000-2020

Figure 2.7 displays the British power mix over the past two decades. The figure reflects the ambitious climate targets, as renewables have grown and fossil fuels have declined. Coal is almost phased out, which stands in contrast to the German power mix (Figure 2.4). Furthermore, by the decrease in total power consumption, one can observe that the UK has had much success in implementing energy efficiency measures, which has been a top priority of the British decarbonization policy (Department for Business, Energy and Industrial Strategy, 2021b).

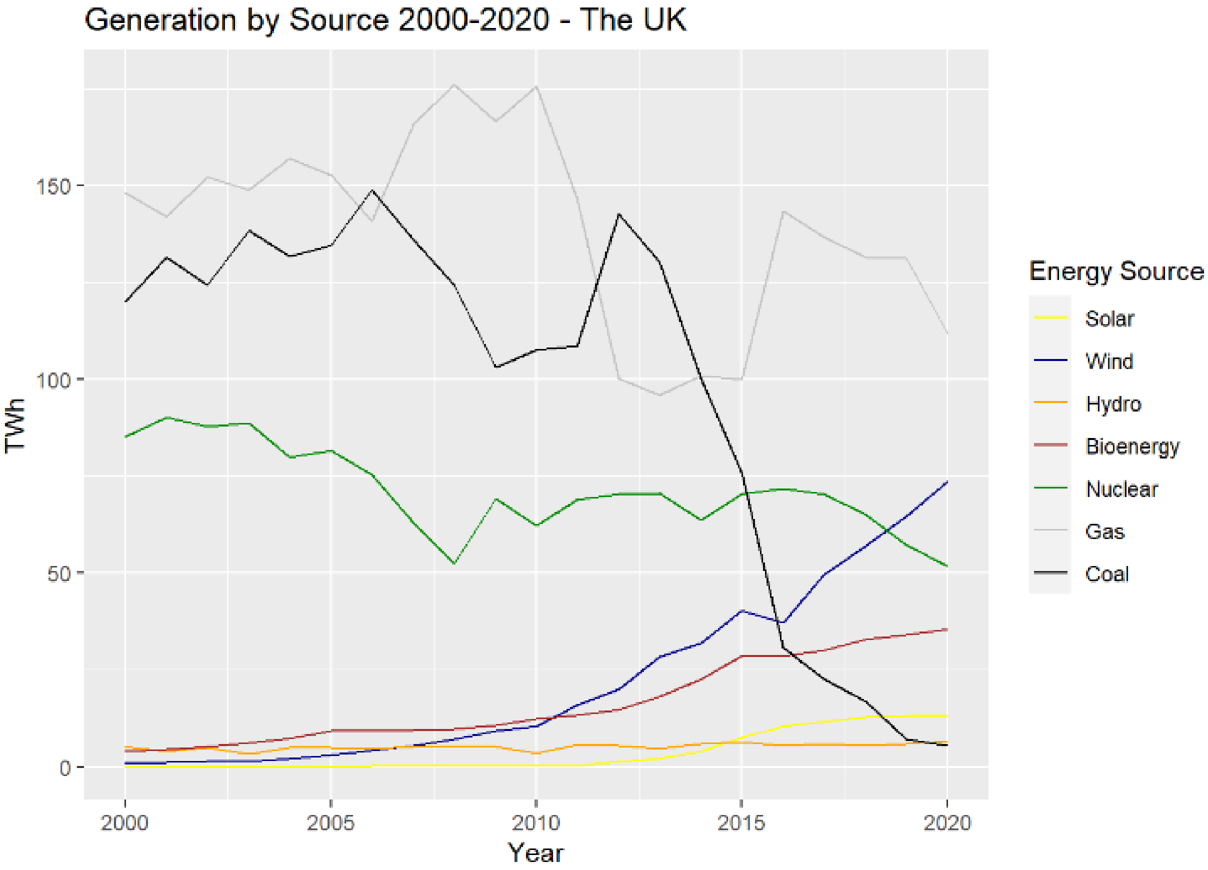


Figure 2.8: Power generation by energy source in the UK 2000-2020

Figure 2.8 displays the development of each of the power generation technologies part of the British power mix. Gas, wind, and nuclear are the three major energy sources in the British power sector. For renewables, the growth in wind power surged from approx. 2005, while the growth rate of solar accelerated from about 2012. Bioenergy has increased steadily over the past two decades. In 2020 renewables rose to generate 42% of British electricity, overtaking fossil fuels for the first time (Ember, 2021). Fossil-fired power generation fell to 41%. Gas was the largest energy source in the British power sector, accounting for almost 40% of power generation (Picard & Thomas, 2021). The UK has made tremendous progress in reducing the use of coal across the power sector, with coal accounting for only 1.8% of British power generation in 2020, compared to 40% almost a decade ago (Department for Business, Energy and Industrial Strategy, 2021c). The decrease in coal has been replaced by renewables and gas, and partially bioenergy. Since 2010, replacing coal with gas has contributed to a drop of 50% in the emissions intensity of British power generation. This change has been driven by the introduction of a carbon price floor in 2013, which imposed a minimum cost to generators of GBP 9 per ton of CO_2. This price was doubled in 2015 (IEA, 2019b).

The Future of the British Power Mix

The Ten Point Plan for a Green Industrial Revolution sets out the measures that will ensure that the UK is at the forefront of the global green industrial revolution. In addition, the British government has published The Energy White Paper that builds on the Ten Point Plan by specifying the steps the British government will take to cut emissions over the next decade. Continued deployment of renewables is at the core of the Energy White Paper strategy for the British power sector. The UK targets 40 GW offshore wind by 2030, a fourfold increase from the installed capacity in 2020. The Energy White Paper also stipulates a capacity target of 5 GW low-carbon hydrogen by 2030 (Department for Business, Energy and Industrial Strategy, 2020a). Furthermore, the third point of the Ten Point Plan is “Delivering New and Advanced Nuclear Power”. In contrast to Germany, the British government has decided to implement nuclear power as an important energy source in their clean energy transition, due to nuclear power being a reliable source of low-carbon electricity (Department for Business, Energy and Industrial Strategy, 2020b). For coal, the British government has chosen an aggressive approach to phase it out by October 2024, one year earlier than initially planned (Department for Business, Energy and Industrial Strategy, 2021a).

Until 2021, the BEIS published the Updated Energy Projections (UEPs) annually, which analysed and projected future energy use and greenhouse gas emissions in the UK. The UEPs 2019, published in December 2020, projects power generation from renewables to rise from 120 TWh in 2019 to about 185 TWh in 2030. Most of the increase in renewables will come from new offshore wind capacity. Furthermore, gas-generated power is projected to fall from 120 TWh to about 65 TWh. In the predicted trajectory, gas responds to increasing low-carbon power generation by falling rapidly until 2027. Gas-generated power then stabilizes as less new low-carbon generation capacity comes online, and by 2035 the capacity will be around 59 TWh (Department for Business, Energy and Industrial Strategy, 2020c). However, in October 2021, the British Prime Minister announced plans for a fossil fuel free UK power sector by 2035. This includes a plan to phase out gas (Shankleman & Morison, 2021). The proposed shift is motivated by further decarbonization and reducing the reliance on gas in the British power sector. In the third and fourth quarters of 2021, both electricity prices and gas prices soared due to a combination of extreme weather conditions and a shortage in the supply of gas (The Economist, 2021). The UK has been hard hit and the phase out of gas is a landmark move to end Britain’s dependency on volatile fossil fuels. The BEIS has stated that the volatile gas prices have demonstrated how the way to strengthen Britain’s energy security, ensure greater energy independence and protect household energy budgets in the long-term is through clean power that is generated in the UK (Department for Business, Energy and Industrial Strategy, 2021c).

Gas as a Transition Fuel in the UK

As a transition fuel, gas has had the role of substituting more polluting fossil fuels in the UK. The coal-to-gas switching combined with record investments in offshore wind and solar PV has transformed the British power sector (IEA, 2019a). Gas' role as a substitution fuel was over when the plans for a fossil fuel free British power sector by 2035 were announced. In contrast to Germany, the UK has no plans to shut down nuclear power and it will have a vital role in replacing gas in the power sector.

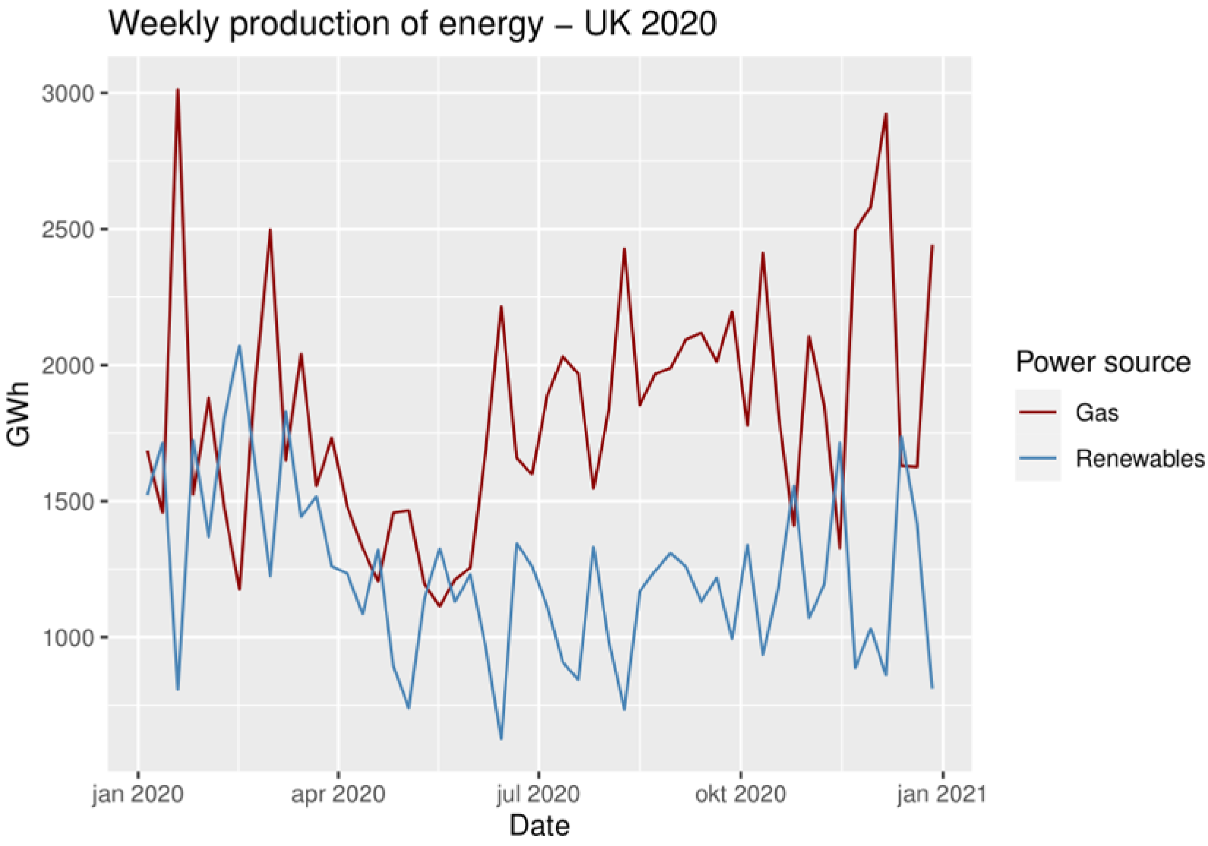


Figure 2.9: Weekly electricity production by gas and renewables the UK

Figure 2.9 visualizes the weekly power generation by gas and renewables from January 2020 until January 2021. The figure illustrates a close to perfect negative correlation between renewables and gas, showcasing the use of gas as a stabilizing energy source in the British power sector. Unlike Germany, which mainly uses coal to back up renewables, the UK relies almost exclusively on gas. Therefore, gas is expected to continue to be used for its reliable nature until better solutions to deal with the intermittency of renewables arrive (Shankleman & Morison, 2021).

The UK has begun its journey towards a gas power phase-out in 2035. However, flexible electricity markets and technologies are a priority for the UK to reduce emissions from power production. In the power sector, power generation from gas using CCS can provide flexible, low-carbon capacity to complement high levels of renewables. These characteristics mean that deployment of CCS projects in power generation will play a vital role in the clean transition of the British electricity system at low cost (Department for Business, Energy and Industrial Strategy, 2020b).

3 Methodology

The following chapter will begin by presenting methods used for similar forecasting purposes in previous literature to get an overview of possible methods to answer the research question. Then the chapter will provide an introduction to the ARIMA and the seasonal ARIMA (SARIMA) models, followed by an explanation of scenario-based forecasting. Lastly, this chapter will provide the motivation for the chosen method of this thesis.

3.1 Method Review

Predicting electricity consumption and demand is essential in managing the electrical grid and in governmental and private-sector decision-making (Arghira, Ploix, Făgărăşan, & Iliescu, 2013). Due to increased focus on power generation forecasts and the evolvement of machine learning, many different methods have been applied to this task. The purpose of this thesis is to forecast gas-generated power in Germany and the UK, while the studies in this section focus on the demand for gas and other energy sources in the power sector and gas consumption. Although the dependent variables are not the same, the similarities between them should give insight to suitable methods for forecasting gas-generated power.

Rehman, Cai, Fazal, Das Walasai and Mirjat (2017) forecast demand for different energy sources in Pakistan and compare the ARIMA, the Holt-Winter, and the Long-range Energy Alternative Planning (LEAP) model. The Holt-Winter method models three aspects of a time series: (1) a typical value (average), (2) a slope (the trend), and (3) repeating patterns (the seasons); while the LEAP model is a simulation software tool developed by the Stockholm Environment Institute for energy policy analysis. Rehman et al. (2017) forecast the demand for five energy sources in five different sectors. The energy sources are oil, gas, coal, wood, and LNG, and the Pakistani power sector is one of the sectors in the study. In the power sector, only the demand for gas, oil, and coal are forecasted, as these energy sources constituted the Pakistani power mix at the time. Rehman et al. (2017) use yearly consumption data from 1992 to 2014 to forecast the demand until 2035 without including exogenous variables in their models. Studying the demand forecasts of energy sources for the three methods, Rehman et al. (2017) find that the ARIMA model outperforms the two other models for two out of three energy sources in the Pakistani power sector. Furthermore, they find that the ARIMA model is also the best model when forecasting energy source demand in other sectors (Rehman et al., 2017).

Several studies use ARIMA models with higher frequency data. However, more frequent data implies more seasonality, and thus SARIMA models are commonly used. Yucesan, Pekel, Celik, Gul and Serin (2021) forecast daily gas consumption in Turkey by using both an ARIMA model and a SARIMA model, both with exogenous variables. Yucesan et al. (2021) use daily observations between 2017 and 2019 with exchange rates, month, day of the week, and holidays as exogenous variables ("predictors") in the models. The authors follow the procedure introduced by Hyndman and Athanasopoulos (2021) to select predictors and choose the appropriate number of AutoRegressive (AR) and Moving Average (MA)-terms. The study finds that, among the ARIMA models, an ARIMA (2,0,1) model and an ARIMA (4,0,3)(1,0,2) model are the best performing models and that the difference in performance between the two models is negligible (Yucesan et al., 2021).

Another study, by Šebalj, Mesarić and Dujak (2019) provides an overview of the most widely used methods for forecasting gas consumption. The researchers find that between 2002 and 2017, the most applied technique was the Artificial Neural Network (ANN) model, closely followed by the ARIMA model. In addition, the study finds that the most common data frequency is either yearly or daily observations and that most forecasts are for domestic gas consumption. Šebalj et al. (2019) conclude that the group of ANN models perform better in terms of average prediction error (average MAPE) compared to the group of ARIMA models in the study.

It is possible to combine the ANN and ARIMA models for forecasting purposes. Yucesan et al. (2021) explore this method in their previously mentioned study when forecasting daily gas consumption in Turkey. Daily gas consumption data often have linear and non-linear patterns. The ARIMA model only captures the linear patterns in the data but often performs well without capturing the non-linear patterns. In contrast, the ANN model is particularly good at capturing the non-linear patterns in the data. Combining the two models can thus lead to greater accuracy. The first step when modelling this hybrid model is to estimate the SARIMA model using the predictors of choice and then to use the same predictors and error terms as the input variables in the ANN model. The authors find that combining a SARIMA model with an ANN model outperforms the other models explored in the study. Furthermore, the authors suggest that including gas substitutes as predictors could potentially improve the hybrid model (Yucesan et al., 2021).

Obtaining a complete overview of the methods used to forecast the demand for gas in the power sector and gas consumption is challenging. Several articles have the sole purpose of finding the best performing model based on a specific criterion. Other articles are literature reviews exclusively dedicated to providing an overview of different forecasting techniques used to predict gas consumption. The methods vary with respect to the inclusion of predictors, the frequency of the data, the forecasting horizon, and the assessment criteria. Determining the most suitable forecasting method is often a time-consuming task and dependent on the available data and the purpose of building the model.

3.2 Dynamic Regression Model

ARIMA Model

The AutoRegressive Integrated Moving Average model seeks to explain the autocorrelation in the data and consists of three component functions. The first component function is an AR model, a specific type of regression that uses a linear combination of past values of the dependent variable to predict the dependent variable. The second component function of the ARIMA model is a MA model, which uses past forecast errors to predict the following observation (Hyndman & Athanasopoulos, 2021). Both AR and MA models, and thereby the ARIMA model, are restricted to stationary variables. If the data are non-stationary one can take the difference between consecutive observations to try to overcome this constraint. Taking the difference of the data is the final component of the ARIMA model, called the Integrated (I) part. When referring to a specific ARIMA model, one often sees the notation in the form of an ARIMA(p,d,q) model. For example, an ARIMA(2,1,3) is a model with two AR-terms, one degree of differencing and three MA-terms.

Seasonal ARIMA Model

A seasonal ARIMA model is often preferred when having data that display clear seasonality. A SARIMA model is formed by including additional seasonal terms in the ARIMA models. The seasonal terms are similar to the non-seasonal components of the model; however, they account for seasonality further back in the time series. The SARIMA model is written as follows, ARIMA(p,d,q)$(\mathrm{P,D,Q})_{\mathrm{m}}$. The $(\mathrm{P,D,Q})_{\mathrm{m}}$ is the added seasonal part of the model where the subscripted m refers to the backshifts of the seasonal period. For example, an m equal to 52 implies a seasonal period of one year for weekly data. As with the ARIMA model, it is possible to include exogenous variables to the SARIMA model.

Dynamic Regression Model

The dynamic regression model extends the ARIMA and the SARIMA models to allow information from independent variables to be included in the models (Hyndman & Athanasopoulos, 2021). When including exogenous variables, the ARIMA model becomes a dynamic regression model, often referred to as a regression with ARIMA errors. The dynamic regression model is similar to the linear regression model. However, instead of the error terms being uncorrelated, the error terms of a dynamic regression model are allowed autocorrelation which follows an ARIMA model. For more information and the notation for the ARIMA, SARIMA and dynamic regression model, see Chapter 9 and Chapter 10 in Forecasting: Principles and Practice (3rd edition) by authors Robert Hyndman and George Athanasopoulos (Hyndman & Athanasopoulos, 2021).

3.3 Scenario-based Forecasting with Dynamic Regression Models

When using a dynamic regression model for forecasting, it is necessary to forecast both the regression part of the model and the ARIMA part of the model, and combine the results (Hyndman & Athanasopoulos, 2021). The first step in obtaining the forecast is to forecast the predictors. If the values of the predictors are known for the forecast period, the forecast of the dependent variable is straightforward. However, if these values are unknown, they must either be modelled separately, or one must assume future values for each predictor variable. The latter method is called scenario-based forecasting. Scenario-based forecasting includes developing possible trajectories for the predictors in the model. Usually, this is done by determining future percentage changes for each predictor based on certain assumptions for the time span of the forecast. With scenario forecasting, decision makers participate in the generation of scenarios. While this may lead to some biases, it can ease the communication of the scenario-based forecasts and lead to a better understanding of the results (Hyndman & Athanasopoulos, 2021).

3.4 Motivation for a Dynamic Regression Model

The method review section established that ARIMA models are widely used to forecast demand for gas in power sectors and gas consumption. Despite the evolvement of sophisticated machine learning and artificial intelligence models, autoregressive methods are still being used to forecast energy demand (Kalimoldayev et al., 2020). Furthermore, deep theoretical development, outstanding empirical results, and simplicity make autoregressive methods highly recommended for experimental studies (Kalimoldayev et al., 2020).

Power generation from gas is expected to be exposed to the seasonality of lower power generation during warmer months and higher generation during colder months and to the intermittency patterns of renewable energy sources (see section 2.5.2 and 2.5.3). For seasonal time series forecasting, the SARIMA proposes a quite successful variation of the ARIMA model (Box, Jenkins, Reinsel, & Ljung, 2015; Hipel & McLeod, 1994). In addition, the ARIMA model is popular mainly due to its flexibility to represent several varieties of time series with simplicity (Box et al., 2015; Hipel & McLeod, 1994; Zhang, 2003). ARIMA models fit the middle-range area of being simple enough to not overfit and at the same time being flexible enough to capture some of the types of relationships visible in the data. Furthermore, the Box-Jenkins methodology for optimal model building process is another reason for the widely use of the ARIMA model.

In an experimental study, the researcher changes the exogenous variables and notes the changes in the response variable (Peter, 2021). Ideally, one wants to allow for the inclusion of relevant information from predictor variables, and at the same time allow for the subtle time series dynamics that can be handled with ARIMA models. The dynamic regression model provides the opportunity to do so. As this thesis seeks to answer the research question by building a model that captures the linear patterns in the data and can be used to forecast gas-generated power in response to changes in predictor variables, a dynamic regression model is considered an appropriate choice of method.

Another model which is a potentially suitable method for this thesis would be an ANN model. The previously mentionedstudy by Yusecan et al. (2021) comparing the ANN model to the ARIMA, found the ANN model to be more accurate when forecasting gas consumption (see 3.1 Method Review). However, there are some advantages of the ARIMA model compared to the ANN model. The results of an ANN model are far more challenging to interpret than those of an ARIMA model. In addition, the ARIMA model provides prediction intervals reflecting the uncertainty of the point forecasts, which the ANN model does not. This implies that although the ANN model may deliver the more accurate forecast values, a statistical analysis is mandatory if measures of uncertainty, either in parameter estimates or forecasts, are desired (Allende, Moraga, & Salas, 2002). The prediction provided by an ANN model delivers no explanation of how and why it obtains these results, thus it is often described as a black box (Mijwel, 2018). The measure of uncertainty and the interoperability of what is driving the prediction is, in this thesis, considered to be more important than the accuracy of the point forecasts. The dynamic regression model allow one to participate in the generation of scenarios and thus lead to better understanding of the results. Therefore, a dynamic regression model is the chosen method in this thesis.

4 Data

The time series data for this thesis were provided for by Rystad Energy and is not open to the public. However, Rystad Energy retrieves a large proportion of their power generation data from the open-source website of the European Network of Transmission System Operators for electricity (ENTSO-E). The data given by Rystad Energy are daily electricity generation (GWh) per energy source in both Germany and the UK. For Germany the time series are of daily observations from the 1st of January 2016 to the 2nd of October 2021 and for the UK from the 1st of January 2016 to the 4th of October 2021. Rystad Energy is one of the leading independent energy research and business intelligence companies providing data analytics and consultancy services to clients exposed to the energy industry across the globe. Thus, Rystad Energy is considered a reliable data source.

The data handling and the model building of the dynamic regression models was done in the open-source software tool RStudio (R). All observations following the 27th of June 2021 have been removed from the time series data for both countries. The reason behind this decision is the unprecedented European energy crisis in 2021. Therefore, the models in this thesis will be built using data from January 2016 up until the date the European energy crisis became unparalleled, which is set to the 27th of June 2021 (see Figure 2.2).

Finally, the data have been transformed from daily to weekly observations due to better fitted models.

5 Analysis

The following chapter will begin by describing the steps of building the dynamic regression models and use the models to produce simple forecasts of gas-generated power in Germany and the UK. Then there will be developed three different scenarios to forecast gas-generated electricity in each country over the next two years. Finally, the results of the scenario forecasts will be discussed in relation to Norwegian exports of gas to Germany and the UK.

5.1 Building the Dynamic Regression Model

The stepwise procedure to build the dynamic regression models is derived from a tidy workflow process of producing forecasts for time series data proposed by Hyndman & Athanasopoulos (2021). The different steps of the process are the following: (1) model specification, (2) seasonal variations and trends in the data, (3) stationarity, (4) define model structure, (5) residual diagnostics, and (6) forecasting. Each of these steps will be the subheadings in this section of the analysis chapter. The findings of each step are essential in building models that are appropriate for forecasting gas-generated power in Germany and the UK. In addition, this structure allows for an interesting comparison of both the data and the models of the two countries.

5.1.1 Model Specifications

Dynamic regression models are a single equation model in which a variable is explained in terms of its past and the present and/or past of other variables related to it (Hyndman & Athanasopoulos, 2021). Consequently, this type of model involves different relationships between variables and so may represent many real situations in economics, business, power generation, and other fields dealing with time series data. The background chapter has provided insights into different variables potentially influencing gas-generated power in Germany and the UK. One can be certain that gas-generated power is likely to correlate with coal-generated power and that both gas and coal correlate with the power generated by wind and solar. Furthermore, the gas market dynamics suggest that economic growth, temperature, the price of gas, and even the growth in LNG trade affect the electricity generation from gas. Therefore, this section aims to discuss variables that may influence gas-generated power and determine if these variables should be included as predictors in the dynamic regression models.

When deciding which exogenous variables to include in a regression model, it is usually important to avoid omitting determinants of the dependent variable that correlate with the exogenous variables. This issue is known as omitted variable bias (Hanck, Arnold, Gerber, & Schmelzer, 2019). Furthermore, the same phenomenon may be explained by one variable and if two highly correlated variables are included it can lead to multicollinearity. The regression coefficients of models with omitted variables bias and multicollinearity will be highly unstable as it causes large variance of the estimators and large standard errors (Hyndman & Athanasopoulos, 2021; Wooldridge, 2015). Therefore, inference will not be valid, but these issues are not necessarily a problem for prediction. This is because when forecasting, the objective is to build a model with good fit and trustworthiness, and interpreting the coefficients is not important (Stock, Watson, et al., 2012).

In both Germany and the UK, gas-fired power is used to deal with the intermittency of wind and solar. As a result, one should expect a negative correlation between power generation from these energy sources. Furthermore, coal is also expected to correlate with gas for mainly two reasons. First, both countries have to some extent used gas to substitute coal. Second, gas and coal are used to balance the intermittent power generation by renewable energy sources. Due to these relationships, one would want to control if coal-, wind-, and solar-generated electricity have predictive power for gas-generated electricity. In addition, electricity generation from nuclear, hydro, and biofuels may have some predictive power for gas-generated power, thus controlling for them is a good idea.

Furthermore, the average temperature in Germany and the UK is expected to influence gas-generated electricity, as temperature impacts electricity consumption (IEA, 2020a). In addition, the gas price influences the quantities of gas used in power generation, and one should therefore control for gas price. Another price variable of interest is the EU ETS price, as one knows from the background chapter that it has been an important driver for coal-to-gas switching and expansion in renewables in both countries. Therefore, it seems to be a good idea to control if the gas price and the ETS price add predictive power to the models.

As the aim of the models is forecasting, the most important is the predictive performance of the models. Hence, the AICc and BIC are essential measures to validate which exogenous variables to include as predictors. The values of the AICc and BIC indicate the models' fit to the data (Hyndman & Athanasopoulos, 2021). To determine which variables to include as predictors, one first make a model without predictors to be used as reference. Next, separate models are made for each of the potential predictors. If the AICc and BIC values are lower than those of the model without any predictors, the variable should be included as a predictor, as the model outperforms the reference model. However, if the added variable does not improve the AICc or BIC values, it may still have a lagged influence. For example, the ETS price and gas price can be variables with potential lagged effects. This makes sense considering how people react to price changes. Consumers are likely to change their behaviour today due to a price change the previous day, one week ago or even one month but longer lags seems unlikely.

The AICc and BIC values are lowest for the models that include coal-, nuclear-, wind-, and solar-generated power for Germany. The same is the case for the UK. Therefore, the ETS price and gas price should not be included in the further process as these variables' models indicate lesser fit to the data. The influence of these two variables may not be instantaneous; therefore, one controls for lagged terms. Including past values of the two price variables, as well as for some of the power generation technologies, does not appear to justify adding any lagged variables to the models. Consequently, the ETS price and gas price are excluded. Both the German and the British dynamic regression model end up including the following four predictors:

1. Coal-generated power
2. Nuclear-generated power
3. Wind power
4. Solar power

5.1.2 Seasonal Variation and Trends in the Data

Based on the insights provided by the background chapter, one expects seasonality in the time series data from Rystad Energy. Weekly data is relatively high frequency data and thus expected to exhibit more complicated seasonal patterns. Therefore, visualizing the data is an essential step in understanding the data as it allows identification of these patterns.

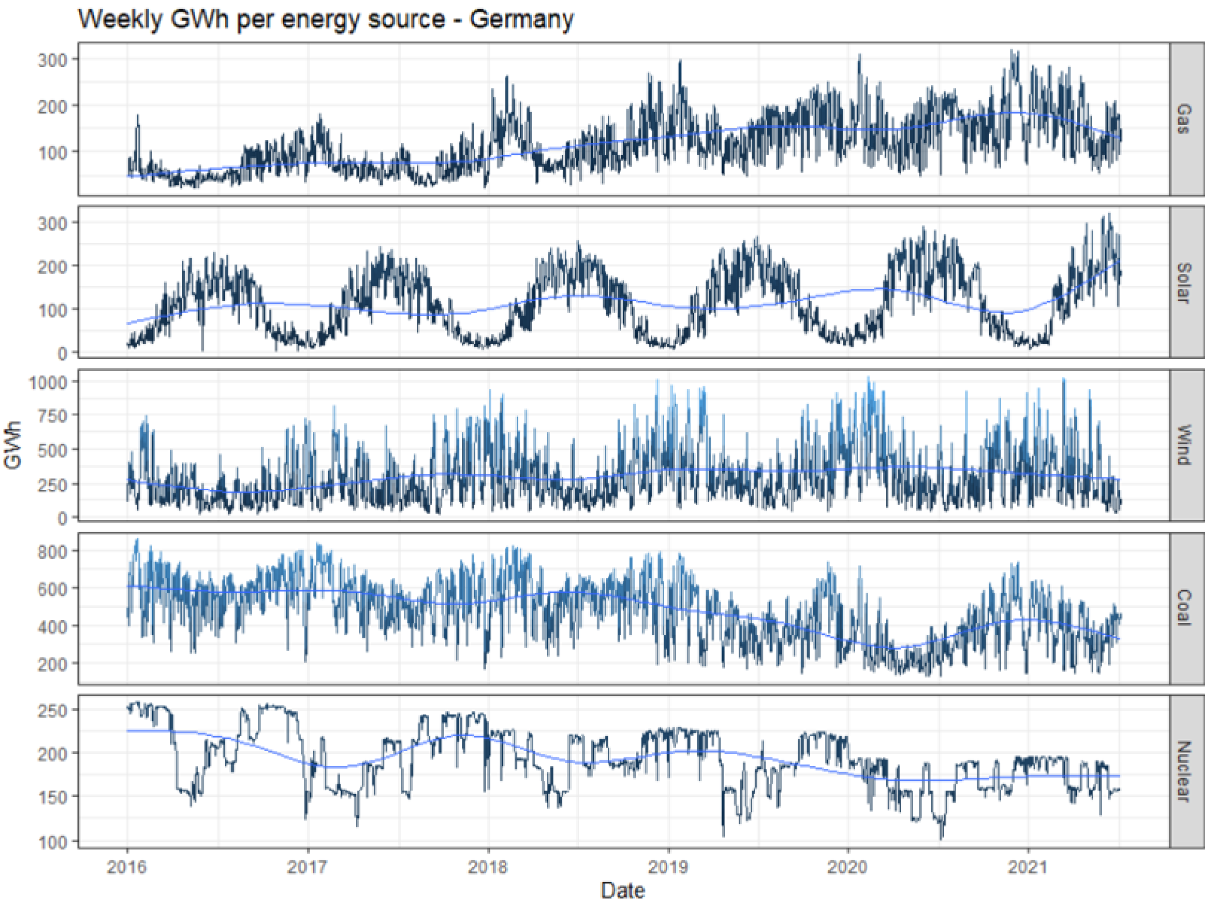


Figure 5.1: Gas, Coal, Nuclear, Solar and Wind in Germany January 2016 – June 2021

The first time series displayed in Figure 5.1 displays the electricity generation from gas in Germany. The range of the observed values fluctuates between 25-300 GWh per week. Further, the time series of gas exhibits annual seasonality, with power production plunging during summer months and peaking during winter months. In addition, there is an increasing trend until about January 2021. One can also note that more gas was used for power generation from January to May in 2021 compared to previous years. The reason for this was the bitter winter and spring leading up to the gas shortage and energy crisis in Europe. The second time series displays coal-generated power. Coal exhibits the same annual seasonality as gas, plunging in the summer and peaking during the winter. There is a clear trend of decreasing coal-generated power from 2016 to 2020. In comparison, nuclear-generated electricity seems relatively stable throughout the period; however, the trend is falling. Wind power distinguish from all other technologies due to the large fluctuations in power production. The graph displays a clear seasonal pattern for wind power with higher generation in autumn and winter months than during spring and summer. This is due to the natural cycles of changing weather in-between the seasons, which leads to more heavy and frequent wind in autumn and winter months. Electricity generation by wind has a trend of increasing production for almost the whole period of data. Lastly, solar power exhibit low production during late autumn and winter and high output during late spring and summer. Again, this is as expected due to changing seasons with less sun in late autumn and winter months. Electricity generation by solar has an upward trend. It is interesting to observe how the plotted time series of power generation by solar and wind illustrate the intermittency of these two renewable energy sources.

The time series for British power generation are also expected to be influenced by seasonality.

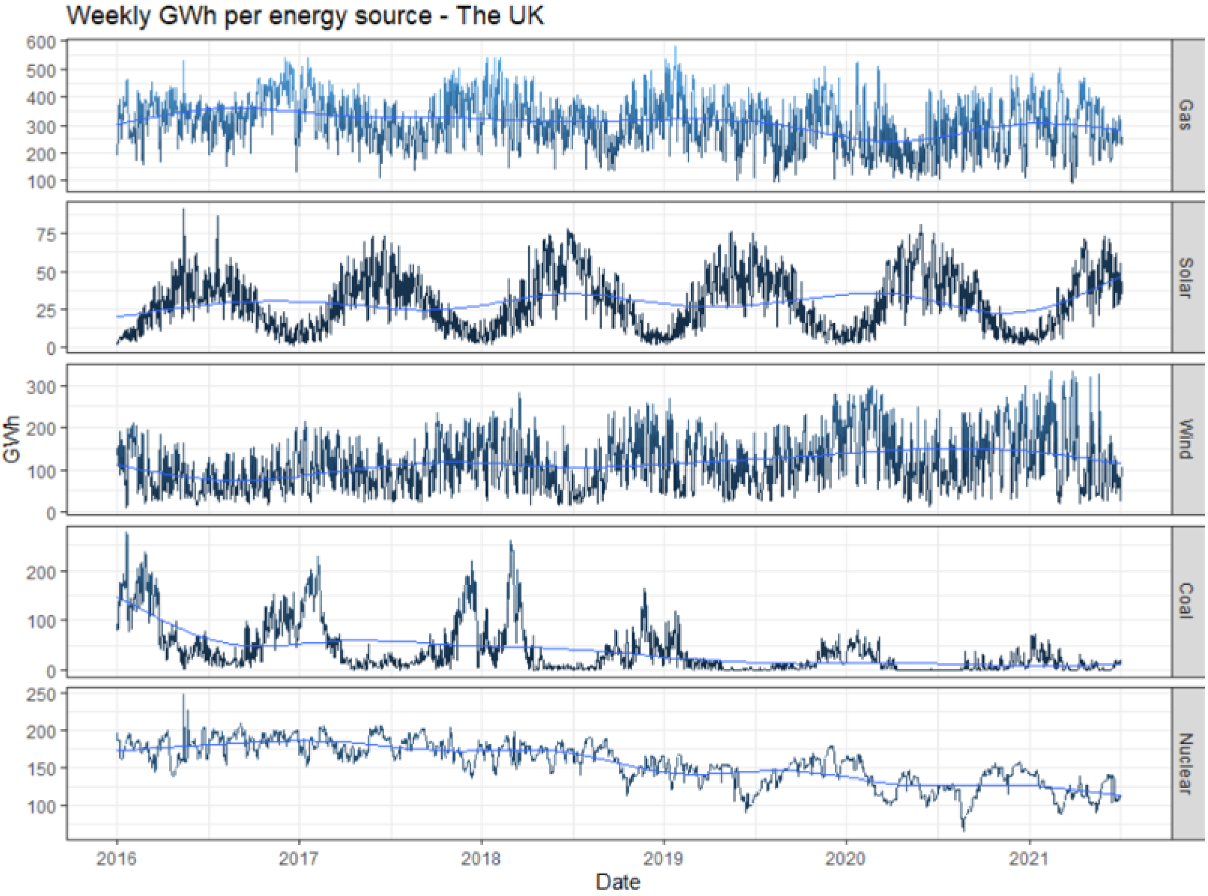


Figure 5.2: Gas, Coal, Nuclear, Solar and Wind in the UK January 2016 – June 2021

The first graph in Figure 5.2 displays that weekly gas-generated power varies between about 750-3,500 GWh over the five and a half years, which is a considerably higher range than in Germany. Further, the seasonal pattern for gas-generated electricity displays higher generation in colder months and lower in warmer months, as in Germany. However, the trend of decreasing gas-generated power in the UK is the opposite of the trend observed in Germany. Despite the downward trend, one can observe that the weekly power generation in 2021 have been higher than in the previous years of data. As in Germany, this is likely to have been caused by the prolonged European winter of 2021. There has been a rapid decrease in coal-generated power since 2018 and the coal phase-out is almost completed. However, the seasonal pattern of coal-fired power is similar to that of gas-fired power, as in Germany. Power generated by nuclear plants is relatively stable over the five-and-a-half-year period of data, but the trend is falling. As in Germany, British wind power fluctuates more than any other technology. Wind power exhibits strong seasonality, which is as expected due to more wind in autumn and winter months than in spring and summer months. For solar power, the graph exhibits low generation during late autumn and winter and high during summer. The upward trend for both wind and solar power is in accordance with the surge in renewables in the UK.

After identifying it exists seasonality and trend in the data, it is necessary to make seasonal adjustments to handle the complex seasonality in the time series. Times series can be split into components: seasonality, trend, and cycles. One usually combines the trend and cycle into a single trend-cycle component. Consequently, a time series ends up consisting of the following three components: (1) a trend-cycle component, (2) a seasonal component, and (3) a remainder component (Hyndman & Athanasopoulos, 2021). Time series of higher frequencies can have more than one seasonal component, each corresponding to the different seasonal periods. Weekly data may display monthly patterns, a quarterly pattern, as well as an annual pattern.

To determine the seasonal components, one can plot the different components of the time series. The trend plot should display as little cyclical trend as possible. This is because the aim is to withdraw the seasonality in the data and capture it in seasonal components. By smoothing the trend lines of each time series, the time series are split into the appropriate components.

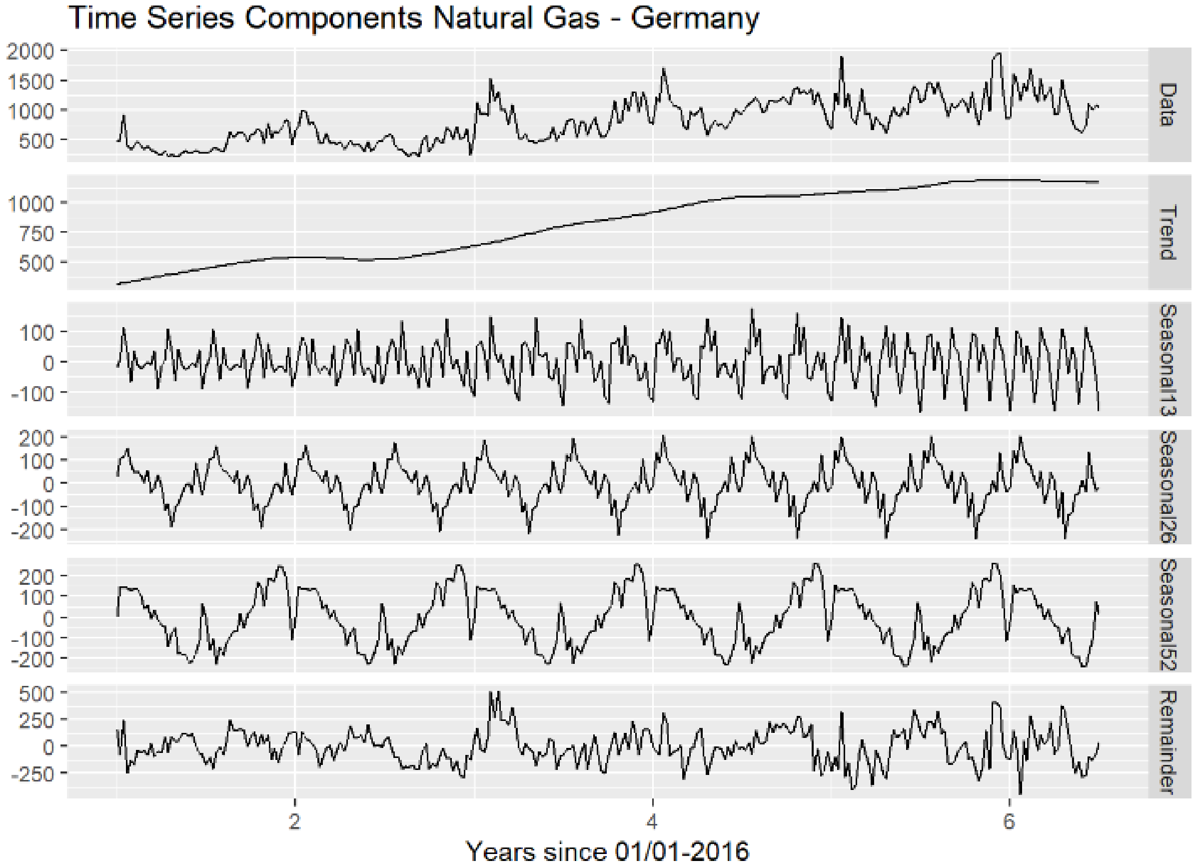


Figure 5.3: Gas time series' components in Germany

Figure 5.3 displays the time series of German gas-generated power split into the following five components: (1) a smooth trend component, (2) a quarterly seasonal component, (3) a six-month seasonal component, (4) an annual seasonal component, and (5) a remainder component. The chosen seasonal components reflect the seasonality identified when visualizing the time series of gas. This implies gas-generated power varying in-between the four seasons, between winter and summer and autumn and spring, and peaking in winter months and plunging in summer months. The same approach is used to adjust for the seasonality in the time series of the other energy sources. The same three seasonal components are chosen for all power generation technologies.

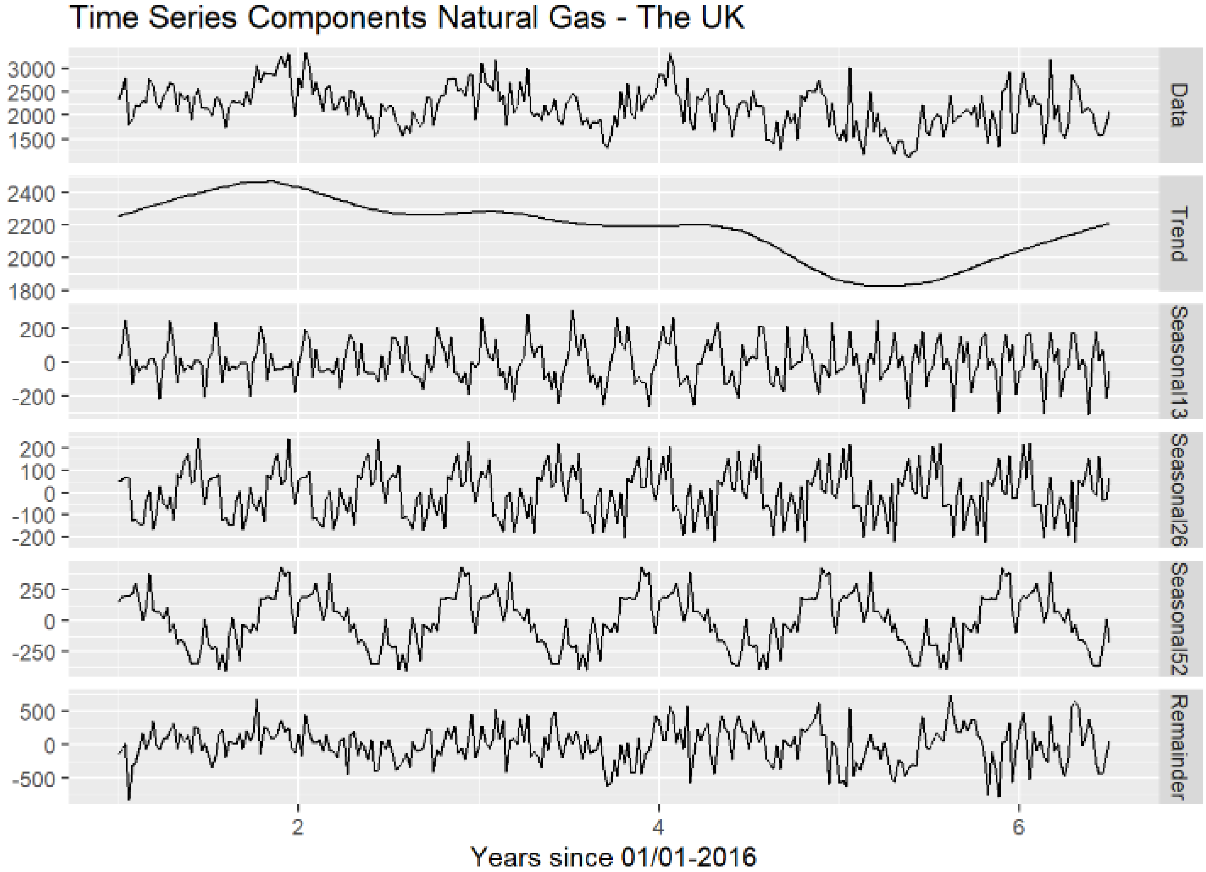


Figure 5.4: Gas time series' components in the UK

Smoothing the trend lines of each of the British power generation time series, results in the same three seasonal components for the British time series as for the German. This has a logical explanation in the UK and Germany having similar temperatures and seasons during the year. Therefore, it is not expected to observe distinct differences in seasonal variations for the power generation technologies, despite the technologies stipulating different shares of the two countries' total power generation.

5.1.3 Stationarity

To proceed with building models to forecast weekly gas-generated power, the time series of all variables should be stationary for the model's estimated coefficients to be consistent estimates. A stationary time series' statistical property does not depend on the time at which the series is observed. Thus, time series with trends or seasonality are not stationary (Hyndman & Athanasopoulos, 2021). Visualizing the data can help determine if the time series is stationary. However, the Augmented Dickey-Fuller (ADF) test, which is explicitly designed for determining the stationarity of time series data, is a better option. The null hypothesis of the ADF test is that the time series is non-stationary (Hyndman, 2014).

	Gas	Coal	Wind	Nuclear	Solar
German model	.048	.01	.067	.01	.054
British model	.014	<.01	.078	<.01	.044

Table 5.1: ADF-test results for the times series for Germany and the UK

Table 5.1 displays the P values of the ADF test statistics for the time series in the German and British models. The test statistics of the time series for German wind and solar power have P values that are higher than .05. Accordingly, the null hypotheses of these time series being non-stationary cannot be rejected. For the other variables, one rejects the null hypotheses and assumes stationarity. For the UK, the test statistics of the time series of British wind power returns a P value of .078. For all other British time series the P values are below .05. Thus, one can reject the null hypotheses and assume stationarity.

5.1.4 Define Model Structure

After the time series have been visualized, adjusted for seasonality and checked for stationarity, an algorithm made by Hyndman and Khandahar (2008) will pick the best dynamic regression model. The algorithm combines unit root tests, minimization of the AICc and maximum likelihood estimation (MLE) to obtain the best fitted regression model with ARIMA errors.

<table>
<tr><th colspan="11">Germany – Regression with ARIMA(3,1,1)(0,0,1)$_{52}$ errors</th></tr>
<tr><td></td><td>Ar1</td><td>Ar2</td><td>Ar3</td><td>Ma1</td><td>Sma1</td><td>Drift</td><td>Coal</td><td>Wind</td><td>Nuclear</td><td>Solar</td></tr>
<tr><td>Coefficient</td><td>0.737</td><td>-0.006</td><td>0.058</td><td>-0.964</td><td>0.015</td><td>4.390</td><td>0.209</td><td>-0.042</td><td>0.017</td><td>-0.144</td></tr>
<tr><td>S.e</td><td>0.068</td><td>0.077</td><td>0.065</td><td>0.033</td><td>0.072</td><td>1.341</td><td>0.018</td><td>0.012</td><td>0.062</td><td>0.036</td></tr>
<tr><td colspan="11">The UK – Regression with ARIMA(1,0,1)(0,0,1)$_{52}$ errors</td></tr>
<tr><td></td><td>Ar1</td><td>Ma1</td><td>Sma1</td><td>Intercept</td><td>Coal</td><td>Wind</td><td>Nuclear</td><td colspan="3">Solar</td></tr>
<tr><td>Coefficient</td><td>0.826</td><td>-0.162</td><td>0.219</td><td>3755.014</td><td>0.215</td><td>-1.122</td><td>-0.420</td><td colspan="3">-1.259</td></tr>
<tr><td>S.e</td><td>0.051</td><td>0.085</td><td>0.068</td><td>205.084</td><td>0.094</td><td>0.045</td><td>0.160</td><td colspan="3">0.255</td></tr>
</table>

Table 5.2: Model structure

For Germany, the fitted model is a regression with ARIMA(3,1,1)(0,0,1)$_{52}$ errors. This implies a model with three AR-terms (p), one degree of differencing (d), and one MA-term (q). In addition, the model has a seasonal MA-term which implies that the model uses the error one year ago (52 weeks) to predict the next observation. Due to the first differencing of the data, the German model is called a “model in differences”. In addition, there is a drift term, which is the constant for an ARIMA model with first difference (Hyndman & Athanasopoulos, 2021). For the UK, the algorithm by Hyndman and Khandahar (2008) chooses a regression with ARIMA(1,0,1)(0,0,1)$_{52}$ errors. This model has one AR-term, no degree of differencing, and one MA-term. Furthermore, the British model has the same seasonal MA term as the German model. The fitted model also has an intercept and its estimate will be close to the sample mean of the time series of gas-generated power (Hyndman & Athanasopoulos, 2021).

Surprisingly, the algorithm does not take first difference of the British time series. This is because the model has stationary error terms according to the Kwiatkowski–Phillips–Schmidt–Shin (KPPS) test. The determination of stationary error terms is also conducted with the ADF test and the Phillips-Perron (PP) test, which both deliver the same conclusion. As the time series of wind is the only non-stationary time series and the fitted model’s error terms are stationary by three different stationarity tests, one proceeds with the model picked by the algorithm of Hyndman and Khandahar (2008).

The objective of both models is to be used for prediction and not causal interpretation. It may not be correct to give a causal interpretation to the coefficients of the models as they can be biased by unmeasured correlation in the model. However, they can still be interpreted in terms of the dynamics and correlations of the variables in the models (Seber & Lee, 2012). In the German model, coal- and nuclear-generated power have positive coefficients, which implies that a one unit (first difference) increase in one of these variables is associated with an increase in gas-generated electricity, all other variables kept equal. This makes sense as power generation from coal and from gas have the same seasonality (cf. Figure 5.3) and that coal only partially has been replaced by gas. The coefficient for coal is significantly different from zero at the 1% significance level, implying that the estimated effect is significant. Nuclear power has a positive coefficient; however, the coefficient is not significant at any significance level, reflecting a weak relationship. The coefficients of wind- and solar power are negative, implying that a one-unit increase in one of these variables is associated with a decrease in gas-fired power, everything else equal. This seems plausible as gas-generated power, in conjuction with coal, is used to deal with the intermittency of wind and solar power (Figure 2.6). Both coefficients are significant at the 1% level.

For the British model, the coefficient for coal-generated power can be interpreted as a one-unit increase in coal-generated power (GWh) is associated with an increase in power generation from gas, all else equal. This makes sense due to coal-fired electricity having the same seasonality as gas. However, the reduction in coal-generated power has been replaced by gas to a significant degree, but this is at the yearly level, and the data are weekly observations. Therefore, this negative relationship is not captured by the model.

The coefficient for coal is significant at the 5% level. There is a negative relationship between gas- and nuclear-generated electricity, and this estimated effect is significant at the 1% level. The coefficients of wind and solar power are negative, implying that a one-unit increase in one of these variables is associated with a decrease in gas-fired power, all other variables constant. This is as expected, knowing that gas is used to stabilize the intermittent power generation from renewable energy sources in the UK (Figure 2.9). Both these estimated effects are significant at the 1% level.

5.1.5 Residual Diagnostics

It is necessary to examine the residual diagnostics of both models to check whether the models have adequately captured the information in the data. The residuals in a time series model exhibit what is left over after fitting a model. The residuals are equal to the difference between the observations and the corresponding fitted values (Hyndman & Athanasopoulos, 2021). The fitted values are the forecasted values of each observation in a time series using all previous observations. If patterns are observable in the residuals, the models can probably be improved.

A good model for forecasting will yield residuals with the following properties: (1) the residuals are uncorrelated. If there are correlations between residuals, then there is information left in the residuals that should be used in computing forecasts. (2) The residuals have zero mean. If they have a mean other than zero, then the forecasts are biased. In addition to these essential properties, it is useful for the residuals to have the following two properties, as they can make the prediction intervals more precise: (3) The residuals have constant variance, known as homoscedasticity, and (4) the residuals are normally distributed (Hyndman & Athanasopoulos, 2021).

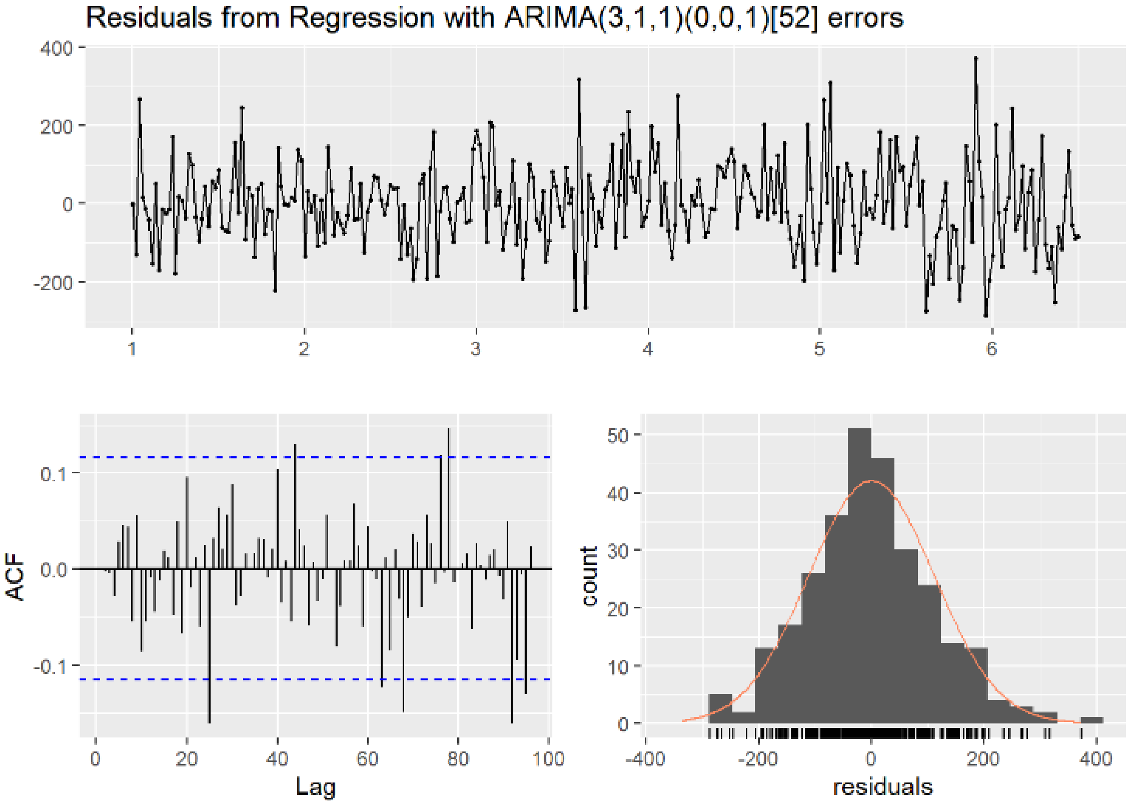


Figure 5.5: Residuals for the German model

Figure 5.5 displays the residual diagnostic plots for the German model. The top graph plots the residuals of the model. Ideally, the plotted residuals should look like white noise, and they do not seem that far off. There is some evidence of heteroscedasticity with a repeating pattern of higher variance in January and February. The significant spikes in the AutoCorrelation Function (ACF) plot indicate that there may be some autocorrelation left in the residuals. However, most spikes are within the required limit. The histogram of the residuals looks normally distributed as it is quite symmetric and the tails of the distribution are about the same length (the right tail being slightly longer).

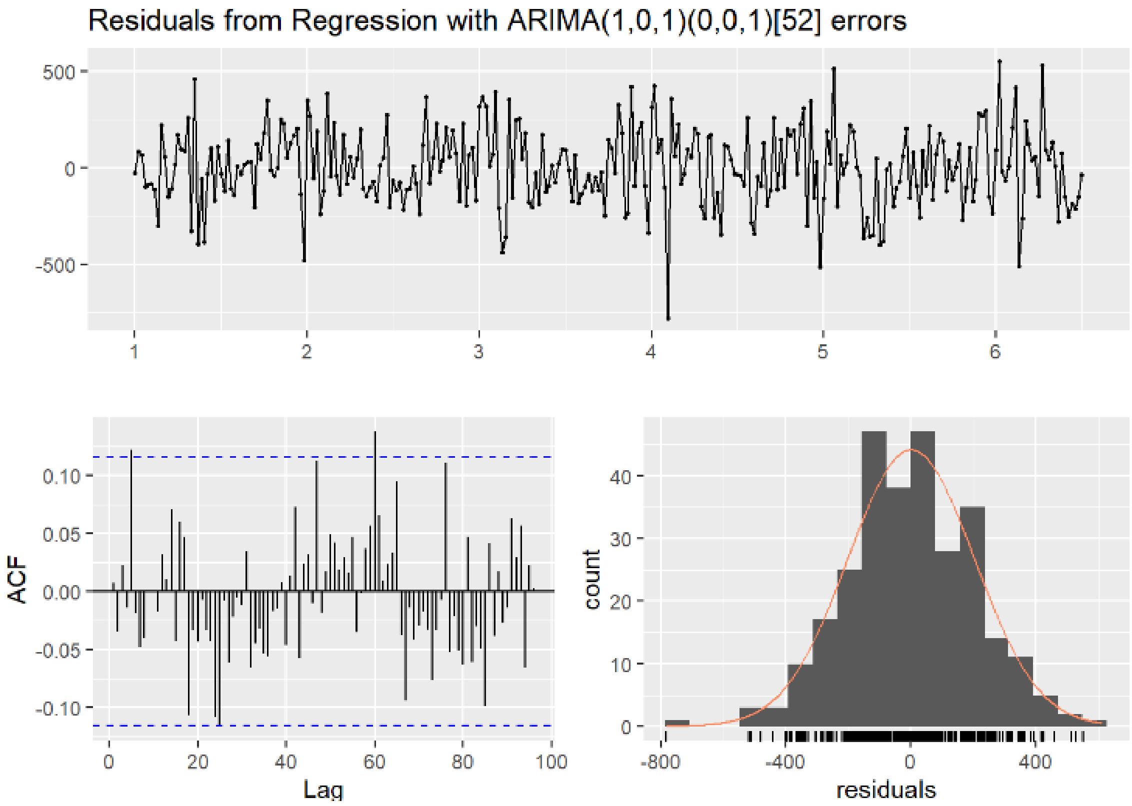


Figure 5.6: Residuals for the British model

The same method is used to check the British model's residuals and determine whether the model is a good fit and captures all the information in the data. From the first plot, the residuals look similar to a white noise time series. However, there seems to be higher variance from about November to February. The ACF plot only displays two significant spikes, and all other spikes are within the required limit, which indicates that there seems to be little autocorrelation left in the errors. Furthermore, the histogram looks roughly normally distributed, despite several peaks and a highly probable outlier to the far left.

In addition to looking at the ACF plots, there exists more formal tests for autocorrelation in the residuals of a model. When looking at the ACF plot to determine if each spike is within the required limit, one is implicitly carrying out multiple hypothesis tests. Many such tests increase the likelihood of at least one test giving a false positive, which can lead to the conclusion of the residuals having some remaining autocorrelation, when in fact they do not (Hyndman & Athanasopoulos, 2021). The Ljung-Box test checks if the residuals from a time series model resemble white noise. The null hypothesis of the Ljung-Box test is that the autocorrelations come from a white noise series, while the alternative hypothesis is that the autocorrelations do not come from a white noise series (Hyndman & Athanasopoulos, 2021). Running the Ljung-Box test for the German model's residuals returns a P value of 0.44. For the British model, the Ljung-Box test returns a P value of 0.73. Both of the obtained P values imply that the null hypotheses cannot be rejected, and one can assume that there is no serial correlation left in the models' residuals.

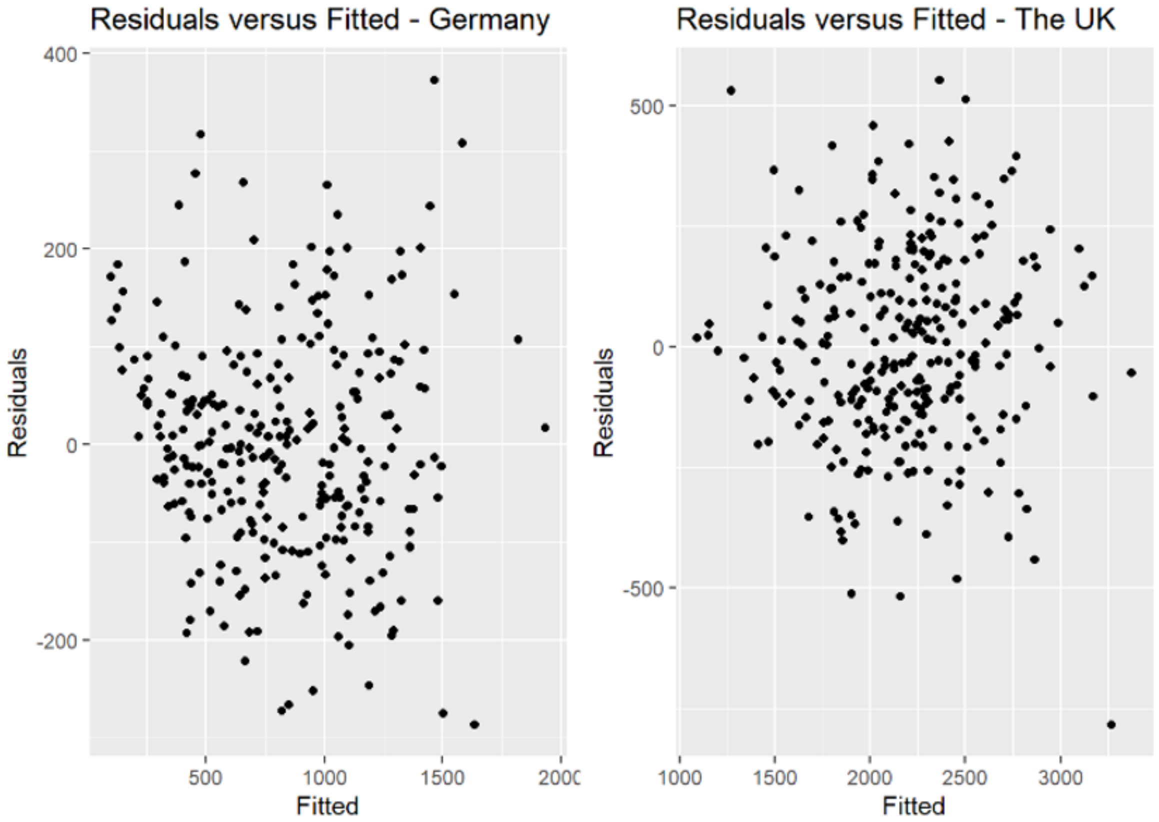


Figure 5.7: Residual plots

Lastly, by plotting the residuals against the fitted values, one can determine if the mean of the residuals is zero. The plot should show patterns approximately symmetric around zero, which indicates that the residuals are uncorrelated. Looking at the plots it does not seem to exhibit a clear systematic, asymmetrical pattern deviating from zero. Although the left side of the residuals for the German model may suggest some asymmetric deviation from zero, the rest of the plot seems acceptable. The British model's residuals look satisfying. The pattern is symmetric on both sides of the horizontal zero reference line and there is not much that suggests that the zero-mean assumption is violated. Therefore, it seems reasonable to assume that the zero mean assumption holds for both models.

To conclude for the German model, (1) the assumption of uncorrelated errors seems to hold, and (2) there is no clear evidence that the zero-mean assumption is violated, despite that there may be some asymmetric deviation on the left side of the plot of the residuals versus fitted values. These properties are the two most essential properties of the residuals to use the model for forecasting. In addition, (3) the residuals render a white noise process, which means one accepts the assumption of homoscedasticity, and (4) the residuals also seem to be normally distributed. As all four assumptions hold, despite some flaws, the model is considered satisfying in capturing the information in the data.

In conclusion for the British model, (1) the residuals are assumed to be uncorrelated, and (2) the zero-mean assumption holds. In addition, (3) the plotted residuals look like white noise, despite some traits of homoskedasticity. Lastly, (4) one can assume that the mean of the residuals is zero. The British model's residuals yield all four properties and seems to do a good job in capturing the dynamics of the data. Thus, both models are considered fit for forecasting.

5.1.6 Forecast

With two appropriate models specified, structured, and checked, one can proceed to produce forecasts. To confirm whether the dynamics captured by the models is satisfying, it is helpful to plot a simple forecast for both countries. In order to obtain forecasts, one first needs to forecast the predictors of the models. For simplicity, all predictors are set to their values in the past two years in the two-year forecasts (104 weeks). The forecast is called the "No Change scenario" and begins on the 26th of June 2021.

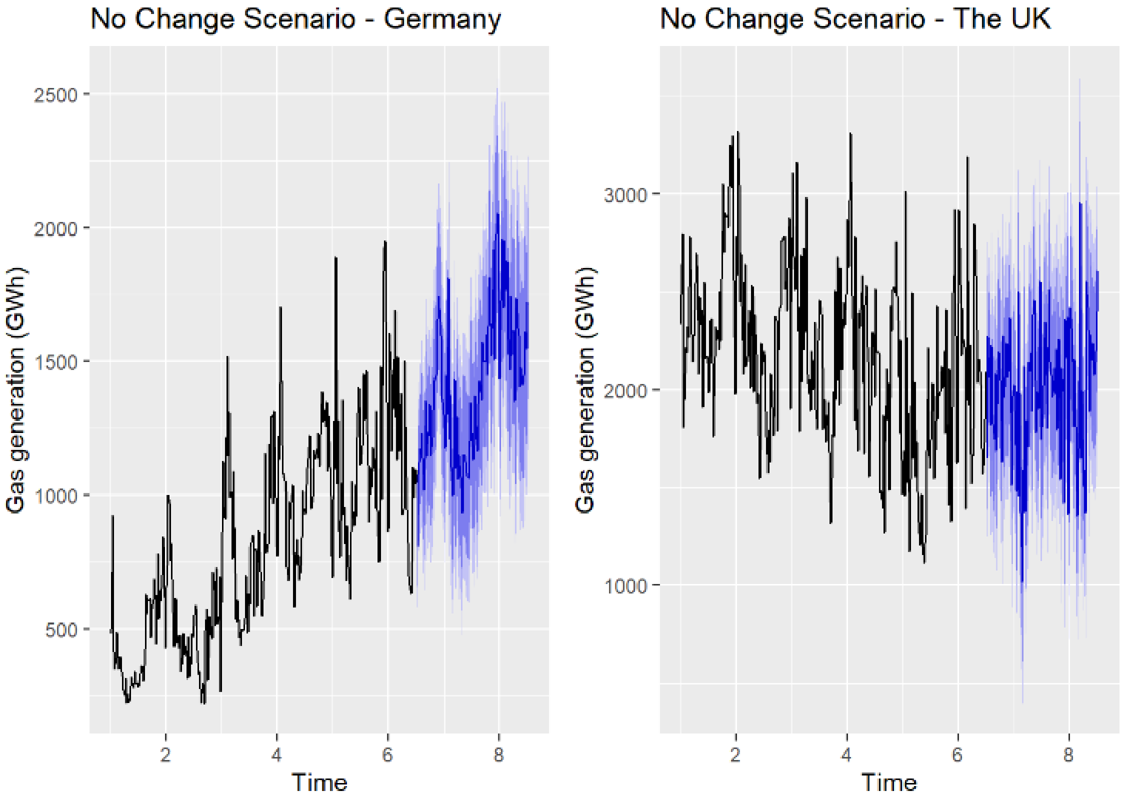


Figure 5.8: Forecasting natural gas - No Change scenario

The forecast for German gas-generated power seems to capture a lot of the dynamics in the data, especially the seasonal patterns. Furthermore, the model predicts increased gas-generated power, which is continuing the trend even though the trend seems to stabilize more in the forecast. The No Change forecast for the UK also seems to capture the seasonal variations in gas-generated electricity. In addition, the forecast does not display a clear trend, which seems to correspond with only the past year of the times series. For both forecasts, one can note that the point forecasts have a narrower amplitude than the historical observations. However, it is the prediction intervals, reflecting the uncertainty in the forecasts, that have most value. The dark blue bands represent an 80% prediction interval, and the light blue bands represent a 95% prediction interval.

5.2 Scenario-based Forecasting

The following section will present three different scenario forecasts for Germany and the UK. The forecast period begins on the 26th of June 2021 and ends two years later (104 weeks). The first scenario is a realistic scenario for the next two years. The second will be a scenario where the transition from fossil fuels to renewables progresses faster than expected. The third scenario accelerates the transition even more. For both countries, the three scenarios assume growth in solar and wind power and a decline in coal-generated power, which is in accordance with the German and British governments' plans (see section 2.5.2 and 2.5.3).

5.2.1 Realistic Scenario

In the "Realistic scenario", the German predictors have been given annual exponential growth rates based on the BMU's climate action plan. The assumed growth rate for each predictor is the exponential percent growth in each energy source's power generation capacity to meet their targeted capacity by the stipulated year. To illustrate, the German coal-fired power capacity in 2020 was 43.50 GW and the target is 0 GW by 2030 (the coal phase-out), which implies a negative constant growth rate in coal power generation capacity of -36.10% per year.[1] Therefore, the growth rate for coal-generated power is -36.10% annually. The assumed growth rates for nuclear-, wind-, and solar power have been computed using the same approach (Table 5.3). Nuclear-generated electricity also has a strong negative growth rate due to the planned nuclear capacity phase-out by the end of 2022. It is worth noting that the growth rates are based on installed power generation capacity for each energy source and not their actual power outputs.

	Capacity 2020 (GW)	Target (GW)	Target year	Growth rate (%)
Coal	43.50	0	2030	-36.10
Nuclear	8.10	0	2022	-75.64
Wind	62.10	91.00	2030	3.91
Solar	53.80	100.00	2030	6.36

Table 5.3: Realistic scenario Germany

A similar approach have been used to develop the Realistic scenario in the UK. The exponential growth rates are based on an outlook on electricity capacity in the UK by source for 2020 to 2040 (Alves, 2021) and an analysis by Rystad Energy (2020) on developments in British renewable energy capacity through 2030 (Table 5.4). Again, to

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[1] Capacity 2020 x $(1 + r)^t$ = Capacity target, where: r = constant growth rate and t = years until target. Solving the equation for r gives the exponential growth rate.

illustrate, British coal-fired power capacity amounted to 5 GW in 2020 and in accordance with the UK's phase-out plan, coal will be retired by the end of 2024. This implies that the annual exponential growth rate for coal power generation capacity will be -44.10%, and thereby also the assumed growth rate for coal-generated power.

	Capacity 2020 (GW)	Target (GW)	Target year	Growth rate (%)
Coal	5.00	0	2024	-44.10
Nuclear	8.10	6.00	2030	-2.84
Wind	21.00	60.00	2030	11.07
Solar	8.50	12.00	2030	4.34

Table 5.4: Realistic scenario the UK

The growth rates for the predictors in Table 5.3 and Table 5.4 lead to the following forecasts (Figure 5.9).

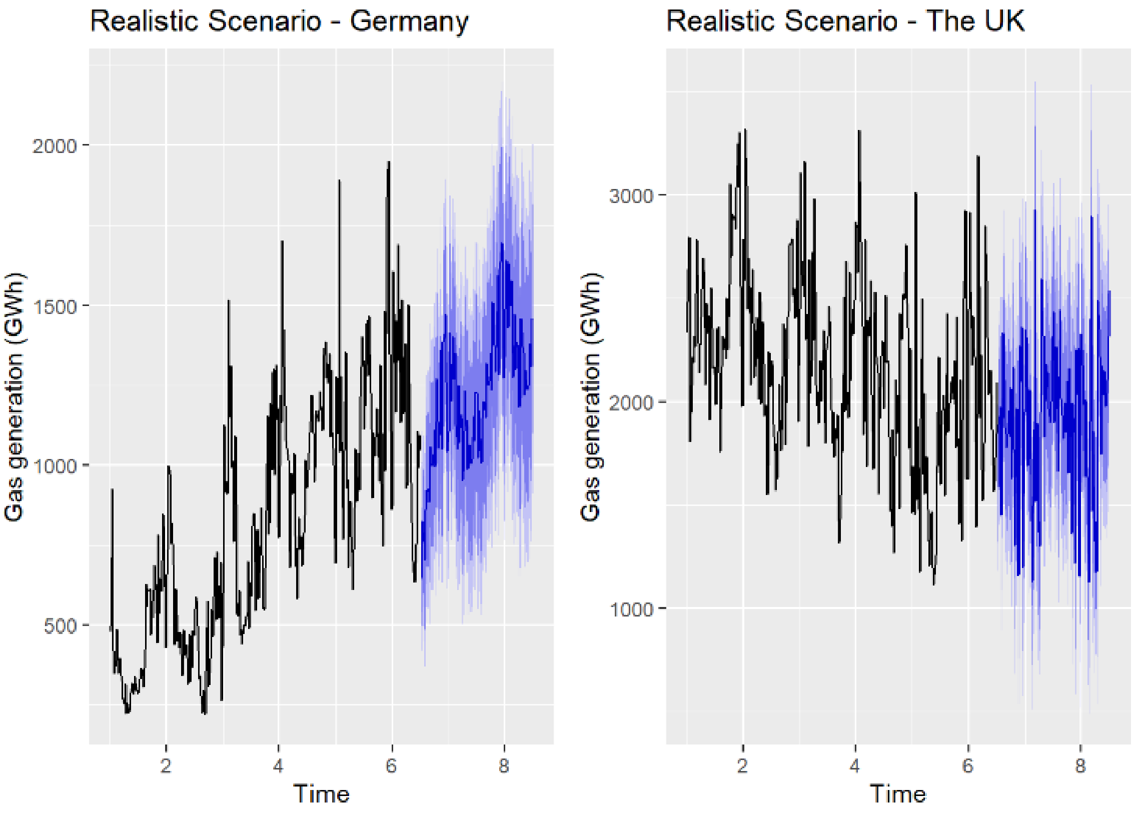

Figure 5.9: Forecasting natural gas - Realistic scenario

The Realistic scenario forecast for Germany predicts that gas-generated power will be relatively stable compared in the first year and then increase in the second year (see A3). Furthermore, one can note that the amplitude of the point forecasts is lower than in previous years throughout the forecast period, implying less fluctuation. It is interesting to compare the Realistic scenario with the gas-generated power of the past two years and quantify the predicted change. The Realistic scenario predicts an increase in gas-generated power of 7.72% in Germany. The Realistic scenario forecast for the UK predicts that gas-generated electricity will decrease at the beginning of the forecasted period and then stabilize more. The amplitude of the forecasted values also seems narrower compared to the historical values. When comparing the point forecasts of the Realistic scenario to the two previous years, British gas-fired electricity declines by 2.23%.

Dynamic regression models combine time series elements with classical regressions. To understand what is driving the forecasts one needs to understand the dynamics and relationships captured in the models. The AR terms attempt to predict the future by extrapolating the recent past, and the MA terms give the models the ability to correct course by allowing it to consider the magnitudes and directions of its errors (Hyndman & Athanasopoulos, 2021). This implies that the AR and MA components are both derived from gas-generated power's past values. The ARIMA errors should make almost no difference to the longer-term forecasts as they will be controlled entirely by the predictors. The purpose of the ARIMA errors is to account for the serial correlation that remains in the residuals from the regression and to improve the very short-term forecasts (Hyndman & Athanasopoulos, 2021). Therefore, the predictors and their seasonal patterns are the dominant drivers of the forecasts. Coal-, wind-, and solar-generated electricity are the most important drivers for the German model. As the relationship between coal- and gas-generated power is positive and coal decreases, gas will decrease in the scenario forecasts. Furthermore, gas-generated electricity will decrease as wind and solar power increase due to their negative influence on gas-generated power captured in the model. However, the drift term continues the increasing trend of the time series and thus works as a counterweight by driving the trend of gas-generated power upwards. In a similar way as the German model, the British model captures a positive relationship between coal and gas, and therefore gas decreases as coal-generated electricity decreases in the forecasts. However, nuclear-generated power and especially solar and wind power are much more important drivers of gas-generated electricity in the British model. These three technologies have a negative influence on power generation from gas. Therefore, it expected that the increase in renewables will lead to gas-fired electricity decreasing further in the Rapid I and Rapid II scenario forecasts. In addition, the intercept in the British model indicates that there is no clear trend in the data and it can be considered the mean of the times series. This implies it does not drive the forecasts in any direction, but rather stabilizes them.

5.2.2 Rapid I Scenario

The Rapid I scenario includes a faster transition from coal to renewable energy sources in the power sector. This scenario assumes a 20% increase in the exponential growth rates for coal-, nuclear-, wind-, and solar-generated power in the Realistic scenario (Table 5.5). In the German model, the growth rate for nuclear-generated electricity is kept unchanged from the previous scenario, as it seems highly unlikely that the phase out of nuclear will proceed faster than planned.

Rapid I Germany				
	Target (GW)	Target year	Change in growth rate from Realistic Scenario (%)	Growth rate (%)
Coal	0	2030	20.00	-43.32
Nuclear	0	2022	0.00	-75.64
Wind	89.00	2030	20.00	4.69
Solar	98.00	2030	20.00	7.63
Rapid I the UK				
	Target (GW)	Target year	Change in growth rate from Realistic Scenario (%)	Growth rate (%)
Coal	0	2024	20.00	-52.92
Nuclear	6.00	2030	20.00	-3.41
Wind	60.00	2030	20.00	13.28
Solar	12.00	2030	20.00	5.21

Table 5.5: Rapid I scenario

Given the growth rates of the predictors in Table 5.5, the model produces the following forecasts of gas-fired power.

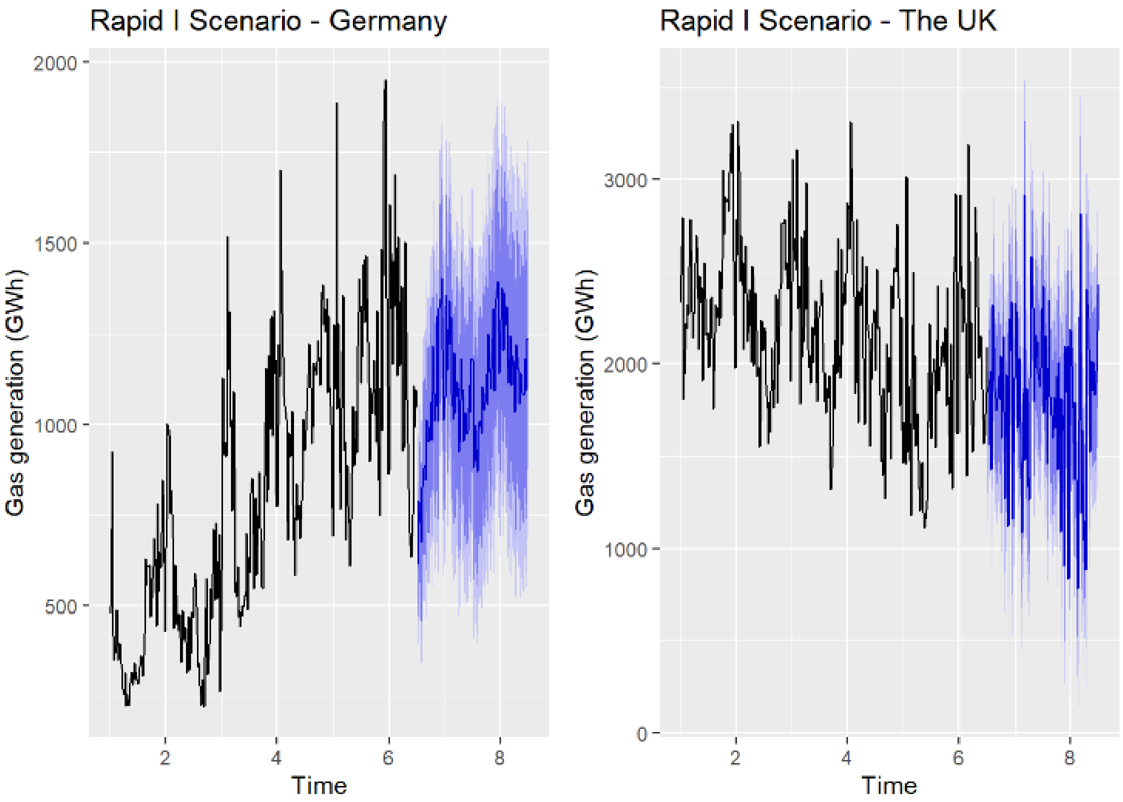

Figure 5.10: Forecasting natural gas - Rapid I scenario

For Germany, the Rapid I forecast predicts lower gas-generated power compared to the prediction in the Realistic scenario. The biggest change is the second year of the forecast and is due to the predictors driving the longer-term forecast and the continuous growth rates which amplifies the values of the predictors in the second year. Comparing the Rapid I scenario to the past two years, gas-generated power is reduced by 3.32%. According to the model, more solar and wind power and less coal-generated electricity lead to a decrease in power generated from gas in the German power sector. For the UK, the plot of the forecasted values of the Rapid I scenario looks similar to the Realistic scenario in the first year. It then predicts a greater decrease, which again is explained by the changes in the predictors driving the forecast. In percent, there is a change of -7.87% from the past two years. According to the British model, increased electricity generation by solar and wind, occurring while the coal phase-out accelerates leads to a slight decrease in electricity generated by gas in the British power sector.

5.2.3 Rapid II Scenario

The Rapid II scenario is based on an even faster clean energy transition in the German and British power sectors. In this scenario, the constant annual growth rates for the generation capacities of coal, nuclear, wind and solar increase by 35% compared to the Realistic scenario (Table 5.6). The growth rate for German nuclear-generated electricity is again unaltered.

Rapid II Germany				
	Target (GW)	Target year	Change in growth rate from Realistic Scenario (%)	Growth rate (%)
Coal	0	2035	35.00	-48.74
Nuclear	0	2022	0	-75.64
Wind	89.00	2030	35.00	5.28
Solar	98.00	2030	35.00	8.59
Rapid II the UK				
	Target (GW)	Target year	Change in growth rate from Realistic Scenario (%)	Growth rate (%)
Coal	0	2022	0	-59.54
Nuclear	6.00	2025	0	-3,83
Wind	60.00	2030	35.00	14.94
Solar	12.00	2030	35.00	5.86

Table 5.6: Rapid II scenario

Based on the growth rates of the predictors in Table 5.6, the models produce the forecasts displayed below (Figure 5.11)

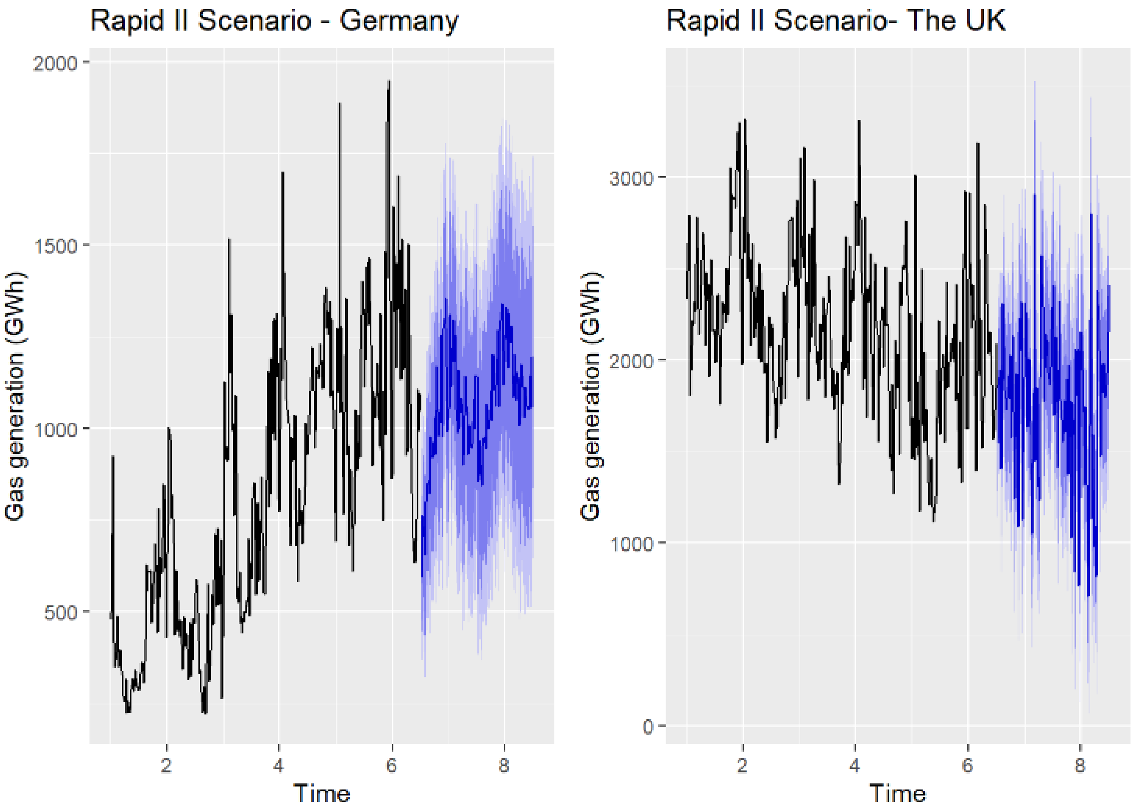

Figure 5.11: Forecasting natural gas - Rapid II scenario

Compared to the Realistic forecast, the Rapid II forecast predicts a further decrease in gas-generated power. Again, it is the change in the predictors which is driving the change, especially in the longer-term of the forecast period. The Rapid II forecast predicts a reduction of 6.18% in German electricity generated from gas compared to the past two years. According to the model, the changes between all three scenarios imply that, when the clean energy transition accelerates in Germany, gas-fired power will decrease further. For the UK, the Rapid II forecast is not much different from the Realistic scenario in the first year, while in the longer-term of the forecast gas-generated electricity decreases further due to the influence of the predictors. The predicted reduction in gas-fired power is of 9.46% compared to the past two years. Similar to the German model, the British model predicts that a faster green energy transition will lead to a decrease in gas-generated electricity. This dynamic is captured in both models and represents what one may possibly expect to see in the future.

5.3 Scenario Impacts on Norwegian Natural Gas Exports

The following section will describe how the different scenarios could potentially affect Norwegian exports of gas to Germany and the UK. This section will primarily focus on the Realistic scenarios as the Rapid I and Rapid II scenarios are considered highly unlikely. The reason being that Germany has moved the coal phase-out forward by eight years while the wind power installations are at risk (see 2.5.2) and that the UK has one of the most ambitious climate policies globally (see 2.5.3). These elements of uncertainty are already part of the Realistic scenario. It is important to emphasize that the forecasts are for gas used in the power sector, not in other sectors or industries.

It is necessary to make some assumptions to give the predicted changes in the scenarios a monetary value. First, the share of Norwegian gas in the countries' overall gas-generated power is assumed to be the same share that Norwegian gas comprises for the combined domestic production and imports of gas. To illustrate, the total production and imports in 2020 for Germany was 159,493 million m^3 and their total import of Norwegian gas was 50,000 million m^3, equivalent to a share of approximately 32.00% (Ceitdata, 2021). Consequently, 32.00% of the amount of used in the German power sector is assumed to be Norwegian gas. The total amount of gas used for power generation in Germany in the past two years was 10,644 million m^3 and thus 3,407 million m^3 is assumed to have been Norwegian gas (Rystad, 2021). The second assumption is a gas price set to EUR 2.75 per MMBtu, which was the spot price at the beginning of the forecast period, the 27th of June 2021. (Trading Economics, 2021).[2] However, this is somewhat inaccurate, as both countries import a substantial amount of Norwegian gas on long term-contracts (see 2.3). Therefore, the gas price used in the following calculations may be somewhat exaggerated. Furthermore, the third assumption is an exchange rate from EUR to NOK of 10.14, which was the exchange rate on the 27th of June 2021.

Overview Scenarios – Germany				
	Last two years	Realistic	Rapid I	Rapid II
Total generation in GWh	118,293	127,426	114,597	110,983
Change from last two years %	-	7.72%	-3.32%	-6.18%
Upper 95% prediction interval	-	48.63%	37.79%	34.73%
Lower 95% prediction interval	-	-33.18%	-44.03%	-47.09%
Norwegian share in m^3	3,406,841,807	3,669,869,008	3,300,385,130	3,196,325,994
Total change in NOK	-	258,987,059	-104,821,485	- 207,282,255

Table 5.7: Overview scenarios Germany

Table 5.7 presents the differences between the scenarios for Germany. Compared to the last two years, a change within the interval of -33.18% and 48.63% is observed for the Realistic scenario. This implies that an increase in gas-fired power is the most likely. The point forecasts add up to an increase of 7.72% for the forecast period. Based on the assumed gas price of EUR 2.75 per MMBtu and the exchange rate from EUR to NOK of 10.14, this is equivalent to a monetary value of NOK 258,987,059. Interestingly, there is a decrease in gas-generated power when the clean energy transition is accelerated in the scenarios. However, these decreases seem plausible, as the capacity gaps due to the nuclear and coal phase-outs are expected to be primarily filled by renewables development (Appunn, 2021). As a result, gas-fired electricity is expected to be relatively stable until

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[2] 1 MMBtu = 28.26 m^3

the German phase-outs are completed, and an increase or decrease is expected to be conditional on Germany's success with relying on expanding renewables to cover the retired capacities, which is in line with the scenario forecasts. To summarize, in the next two years, the German model predicts that the change in Norwegian exports of gas to Germany is conditional on the pace of the clean energy transition, and if Germany follows its planned developments within the power sector, Norwegian gas exports will most likely increase.

Overview Scenarios - The UK				
	Last two years	Realistic	Rapid I	Rapid II
Total generation in GWh	203,103	198,567	187,110	183,897
Change from last two years %	-	-2.23%	-7.87%	-9.46%
Upper 95% prediction interval	-	29.78%	24.14%	22.56%
Lower 95% prediction interval	-	-34.24%	-39.89%	-41.47%
Norwegian share in m3	5,761,985,875	5,633,309,208	5,308,283,681	5,217,112,626
Total change in NOK	-	- 126,700,171	- 446,733,252	- 536,503,904

Table 5.8: Overview scenarios the UK

In UK, the total production and imports of gas in 2020 was 84,433 million m^3 and their total import of Norwegian gas was 26,300 million m^3, equivalent to a share of 31,52%. In the last two years, the UK used 18.280 million m^3 of gas in power production, where 5,762 million m^3 is assumed to stem from Norway (Rystad, 2021). In Table 5.8, one can observe a change in the interval of -34.24% and 29.78% in gas-generated power for the Realistic scenario compared to the two previous years. The point forecasts predict a fall of 2.23% in gas-fired electricity in the UK. As a monetary value, this decrease in Norwegian exports over the next two years is calculated to NOK 126,700,171. As for Germany, the model predicts a further decline in gas-generated power when coal-generated power declines and renewable-generated power increases. As gas has already had the substitution role as a transition fuel and is the only fossil fuel left in the British power sector, the predicted fall in gas-fired electricity fits well with future expectations. To summarize, the British model predicts a likely decrease in Norwegian exports of gas to the UK over the next two years, a prediction which decreases further if the UK accelerates its pathway to renewables.

6 Discussion

The background chapter has presented how gas can serve as a transition fuel in two main ways: (1) by substituting more polluting fuels and (2) by stabilizing the intermittency of renewable energy sources. Furthermore, the background chapter provided an overview of the past developments within the German and British power sectors. It was established that Germany has only partially used gas as a substitution fuel for coal and used gas, in combination with coal, to stabilize power production when renewables have been intermittent. The past developments in the British power sector have established that gas has been used to both substitute coal and stabilize intermittent renewables. The past role of gas is certain; however, this thesis aims to provide insights into the uncertain future role of gas as a transition fuel in the German and British power sectors.

Based on the predictions of the three scenario forecasts, the expectation for gas-generated power in Germany is ambiguous, as gas-generated power in the next two years is conditional on the pace of the clean energy transition. The expectation for the UK is unambiguous as all three scenarios predict a decrease. Furthermore, for all three scenarios, the amplitudes of the point forecasts for Germany are smaller than the amplitudes of the point forecasts for the UK. The findings mentioned in this paragraph may indicate what role gas will have as a transition fuel in the two countries. Therefore, the two potential roles of gas as a transition fuel will be discussed in relation to the forecasts and the future developments stipulated in the German and British climate action plans.

Gas has a large potential as a substitution fuel for coal in Germany. In the Realistic scenario forecast for Germany, gas-generated power increases as power generation from coal declines and renewables rise. However, when the clean energy transition is accelerated in the Rapid I and Rapid II scenarios, gas-generated electricity declines in response. As the Realistic scenario predicts an increase in gas-fired power when coal and nuclear power plants are phased out, the model predicts that gas will play a role as a substitution fuel in Germany. However, the BMU's Climate Action Plan 2030 has reserved no place for gas as a substitute for the retired coal and nuclear capacities. The German government plans to replace the needed capacities with power generated by renewable energy sources (Federal Ministry for the Environment, Nature Conservation, and Nuclear, 2020). It is therefore interesting that the model predicts that gas-generated power declines when the clean energy transition proceeds faster as this is in accordance with the German government's ambition of expanding renewables. However, several authors suggest that, in the short run, it is unlikely that renewables will be able to replace the capacity gap alone due to coal and nuclear power being phased out simultaneously (Claußner, Linkenheil, & Göss, 2021; IEA, 2020c). This corresponds with the predicted increase in gas-generated power in the Realistic scenario forecast, suggesting that gas will be partially used as a substitute for coal and nuclear power. Furthermore, this expectation is supported by the enhanced phase-out of coal by 2030 as it increases the chance of gas being used as a substitution fuel. In addition, the prospect of gas-generated electricity rising will improve if the minimum distance law for onshore wind is passed.

In the UK, the potential of gas as a substitution fuel is limited. The British forecasts predict that gas-generated power will likely decrease over the next two years and that a faster transition from fossil fuels to renewables will lead to a further decrease. The model thus does not predict that gas will be a substitution fuel in the UK. This corresponds with the country's coal generation capacity almost being phased out and there being no plan for the country to retire its nuclear capacity, entailing that there are no fuels left for gas to substitute. The fact that gas will be the only fossil fuel left in the British power mix in 2024 further strengthens the expectation that gas will decrease, as it is next in line to be replaced. In addition, this decrease is in accordance with the short-term trajectory of gas-generated power in the UEPs 2019.

Furthermore, gas is used to deal with both the intermittency of renewable power generation and periods of colder temperatures in both Germany and the UK. Therefore, gas-generated power fluctuates throughout the year. It is more challenging to use the two models' forecasts to understand how gas will be used as a stabilizing fuel in the short term. One could look to the fluctuation of the point forecasts; however, quantifying the variation seems to have limited value as both models predict point forecasts with less fluctuation than the fluctuations of the historical data. This is a finding itself, as it may indicate that Germany and the UK will use less gas to stabilize power production. The discussion of gas as a transition fuel, this time as a stabilizer, widens to include the climate action policies of the two countries. Germany uses both coal and gas to stabilize the power supply (see Figure 2.6). The simultaneous phase outs of coal and nuclear have implications for gas as a stabilizing fuel. The German government plans to replace coal and nuclear with renewables. However, in the short term, renewables will not provide enough and flexible electricity due to their intermittency (Federal Ministry for the Environment, Nature Conservation, and Nuclear, 2020). As renewables constitute an increasing share of the power mix, the German power sector is becoming increasingly intermittent itself. Thus, German energy security is expected to be tied to gas security in the short term. In combination with the lack of an alternative backup fuel (due to limited hydropower and the phase-out of nuclear), the stabilizing role of gas is expected to become increasingly important. Consequently, the German model most likely underestimates the future fluctuations of gas. In the UK, gas has a vital role in backing up intermittent renewables (see Figure 2.9). However, the combination of a planned phase-out of gas and nuclear becoming the most important backup technology for renewables (Shankleman & Morison, 2021), leads to the expectation that gas has reached its height as a stabilizing technology in the British power mix. However, the intermittency of renewables will still be a problem in the years to come. Therefore, the UK has no plans to phase out gas in the short term (Department for Business, Energy and Industrial Strategy, 2020a).

The impact of gas-generated power's predicted role in the transition to renewables in Germany and the UK on Norwegian gas exports have been monetized in the previous chapter. It would be interesting to discuss which of the two transition roles gas can play that dominates the total change in gas-generated power. Focusing on the Realistic scenarios, the discussion in the previous paragraphs have led to the following expectations for the role of gas in the short term: (1) In Germany, gas will play an increasing role both as a substitution fuel and as a stabilizing fuel, while (2) in the UK, gas will play a declining role as a substitution fuel and continue its role in balancing intermittent renewables. According to the point forecasts, the total effect of gas as a transition fuel leads to an increase of 7.72% in German gas-generated power and a decrease of 2.23% in British gas-fired power, despite less future fluctuations. This suggests that gas's role as a substitution fuel, according to the models, is the dominant effect and thereby the most important for Norwegian gas exports. This makes further sense as the substitution of other fuels implies larger and more stable power production in contrast to ramping gas-fired power up and down in response to intermittent renewables. Therefore, Norwegian exports of gas can be expected to increase among trade partners with similar power mixes as Germany- that is, where coal is being phased out - and to decrease among trade partners with similar power mixes as the UK, where gas is the last fossil fuel to replace. In addition, LNG can increase the reach of Norwegian gas to new markets, for example the growing gas demand in Asia due to coal-to-gas switching, and thus increase exports in the short term.

Even though gas's role as a stabilizing fuel may not be as important as its role as a substitution fuel, gas's role as a stabilizing fuel is also expected to have a significant influence on Norwegian exports. In periods of low wind and high demand for electricity, Germany and the UK draw gas from their storages to ramp up power production from gas. These storages need to be refilled, and as more countries need backup capacity for renewables, gas prices may rise in response. The European energy crisis in 2021 has demonstrated such a situation. If a greater share of the European countries' power mixes had been renewables in the summer of 2021, when there were record-low winds, the crisis would have had more dramatic consequences. The largest market for Norwegian gas is Western Europe. These countries have committed to clean energy transitions that they plan to reach by replacing coal and heavier polluting fuels with renewable energy sources. As a result, the market may be more vulnerable to demand and supply shocks causing gas prices to become more volatile in the future (Baker, Stapczynski, Murtaugh, & R, 2021). The European energy crisis has had a major effect on Norwegian exports, resulting in historically high revenues from gas exports (Sættem & Grønli, 2021).

In the longer term, it seems inevitable that gas's role as both a substitution fuel and a stabilizing fuel will decline and eventually be phased out in both Germany and the UK. The German government has announced a phase out of gas by 2040, and the British government has announced that the power sector will be fossil free by 2035. These ambitious targets for both countries are interesting as their power mixes are at very different stages. The UK has chosen a pathway to renewables through gas, while Germany plans to skip coal-to-gas switching and transition directly to renewable power generation. In addition, these two countries have chosen completely different paths concerning nuclear power. Gas's future is in large part dependent on the pace of the capacity increases and the technology-driven breakthroughs for storage of renewable energy sources. Additional renewable capacity and new storage solutions could potentially lead to days with almost no power produced by gas in the long term, as renewables and stored electricity from renewables are able to fill the power demand. This was demonstrated when the UK had its first coal free month in May 2020, due to a particularly sunny period (Ambrose, 2020). Furthermore, CCS and hydrogen production are important climate actions in both the Energiewende in Germany and in the Ten Point Plan for the Green Industrial Revolution in the UK. Therefore, CCS and production of blue hydrogen will be essential measures for reaching the German and British climate commitments, and they will in turn prolong the lifespan of gas, and thus Norwegian gas exports.

7 Critique

This chapter will discuss the limitations and robustness of the dynamic regression models used to produce the forecasts. In the stepwise procedure of building the models, some potential issues have been identified for both models. The following section will discuss some of the issues and potential ways to deal with them.

Chosen Predictors

According to the approach used to choose predictors, the ETS price and gas price were not included in the model, nor lagged terms for these variables. However, based on economic theory of market supply and demand, there is a strong argument that the ETS price and gas price influence gas-generated power. This is further underlined by the fact that it would make little sense to convince an economic theorist or a gas market expert that the gas price does not influence gas for power production. Therefore, it can be argued that at least the gas price should have been included. Furthermore, one can argue similarly for including the ETS price as a predictor. The ETS price has increased rapidly from 2018 and one can be certain it will influence the balance between fossil fuels and renewables in the EU in the time to come.

Another potentially important predictor for gas fired power is temperature. There seems to be a strong correlation between gas-fired electricity and temperature, thus one can argue that this variable should have been included in the model. However, finding weekly temperature data for a country has proved challenging, and extensive efforts have fell short in obtaining representative data.

The Properties of the Models' Residuals

Any forecasting method that does not satisfy the four properties can be improved. However, that does not mean that forecasting methods that satisfy these properties cannot be improved (Hyndman & Athanasopoulos, 2021). It is possible that there exist models that would be a better fit to the data than the models obtained in this thesis. Both the German and the British models had some traits of homoscedasticity. Sometimes applying a Box-Cox transformation may assist with ensuring that the residuals have constant variance and a normal distribution, but otherwise there is usually little that one can do to ensure these properties.

ARIMA Models Capture Only Linear Relationships Between Variables

The severe limitation of ARIMA models is the pre-assumed linear form of the associated time series which becomes inadequate in many practical situations. This implies that the models do not capture the non-linear relationships in the data. To overcome this drawback, various non-linear stochastic models have been proposed in literature (Zhang, 2003, 2007). However, from the implementation point of view, these are not as straightforward and simple as the ARIMA model.

European Energy Crisis

Autoregressive models implicitly assume that the future will resemble the past. As a result, they can prove inaccurate under certain market conditions, such as crises or periods of rapid technological change (Fernando, 2020). In 2021 Europe has experienced a perfect energy storm. A cold winter sent gas demand rising and gas storages plummeting. These reserves would normally have been replenished over the summer of 2021. However, gas imports decreased due to several major producers catching up with maintenance postponed during Covid-19 lockdowns. Meanwhile, calm weather reduced the amount of electricity generated by wind. As a result, wholesale gas prices more than quadrupled throughout 2021. Therefore, the data from the period after the energy crisis has been removed to avoid inaccurate forecasts, which might have rendered little value for the aim of the thesis. However, this comes at a cost as the short term forecasts are likely to be far from the real values.

Assumptions With No Uncertainty

It is important to realize that the prediction intervals for scenario-based forecasts do not include the uncertainty associated with the future values of the predictor variables. They assume that the values of the predictors are known in advance. Therefore, the prediction intervals should be interpreted as being conditional on the assumed future values of the predictors. These future values are also uncertain with an accompanied uncertainty band which is challenging to model. As a result, the more exogenous variables one adds to the model, the more uncertain the forecast becomes. Although the growth rates added to the predictors are based on viable sources, the uncertainty is still high, even beyond the prediction intervals presented in previous figures (see 5.2 Scenario Forecasting). Furthermore, the growth rates added to the predictor variables were constant for every week of the forecasted period, which is unrealistic.

8 Conclusion

This thesis has intended to answer the following research question:

What role will natural gas serve in the transition to renewable energy sources in the German *and British power sectors, and what will be the implications for Norwegian natural gas exports?*

To answer the research question two dynamic regression models have been built to forecast the gas-generated power in Germany and the UK. Other power generation technologies were chosen as predictors based on their predictive power for gas power generation. These predictors were then given growth rates based on the official climate action plans of the German and British governments. In this way, one could create scenario forecasts for both countries. The purpose of these scenarios was to provide insight into the future role of gas as a transition fuel and observe how the use of gas might differ for the two countries. Furthermore, the predicted values for each scenario were monetized to discuss how the change would impact Norwegian exports of gas. Before answering the research question, it is important to emphasize that one always should treat forecasts sceptically because the future is inherently uncertain, and no amount of computing or data will ever change that fact

The German model predicted an increase in gas as the most likely trajectory over the next two years. In that case, gas will be a transition fuel through its ability to substitute other fuel types in Germany. The impact of the point forecasts on Norwegian export was an increase in revenue for all three scenarios. The British model predicted a decrease in gas. Consequently, gas' role as a transition fuel is unlikely to be used as a substitution fuel. This will likely lead to a decrease in Norwegian export of gas to the UK. In both countries gas will continue to stabilize for renewables and thus be used as a transition fuel for its reliable nature. However, it was more challenging to use the models' forecasts to understand how gas will be used as a stabilizing fuel, as quantifying the variation seemed to have limited value due to both models' point forecasts had less fluctuation than the fluctuations of the historical data. In Germany, the predicted increase in gas combined with a decrease in coal and nuclear will potentially lead to gas bearing a greater share of the stabilizing role and thus fluctuate to a further extent. In the UK, the use of gas as a stabilizer was harder to anticipate, but gas will undoubtedly continue to be an important part of the British power mix in the short term. The effect of gas becoming an important backup fuel, combined with increasing share of renewables could potentially cause the gas price to fluctuate to a further extent in the future. This effect has been demonstrated by the European gas crisis in 2021.

Finally, the discussion of the potential future of gas is an important question for decision makers that need to be addressed carefully. If countries decide to rely more on gas, the long-lived and expensive nature of the infrastructure may cause a crowd out of investments from renewables and thus a carbon lock-in. As such, the decisions made by governments regarding gas does not just affect the countries' residents but also lead to global externalities that may affect future generations. The transition to renewables will undoubtedly affect Norwegian export of gas and oil. The decreasing trend of gas in the UK combined with Germany and other western European countries prioritizing emission reductions in their power sectors, should motivate Norwegian decision makers to incentivize large scale investments in CCS and blue hydrogen production, to prolong the lifespan of gas in Norwegian export markets.

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Appendix

A1 Trade Movements

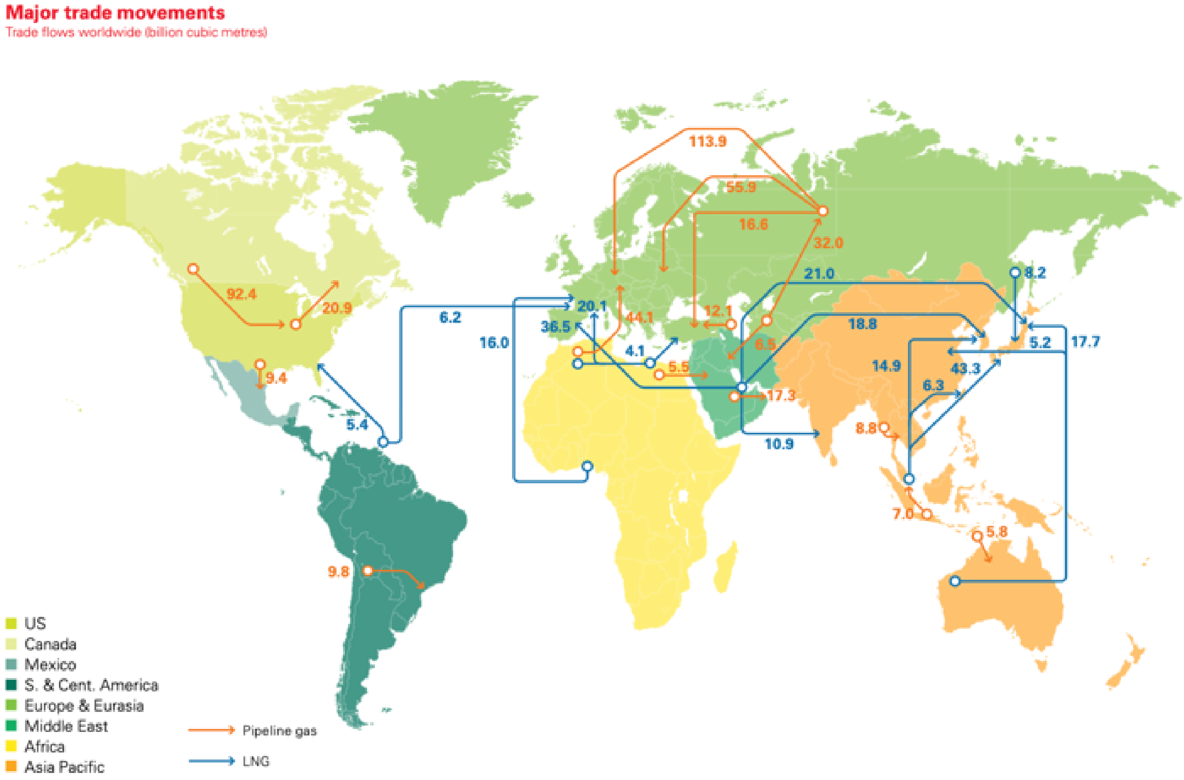

Figure A1.1: Global gas trade 2010

Compared to Figure 2.1 the growth in LNG trade is significant.

A2 Gas Prices Convergence

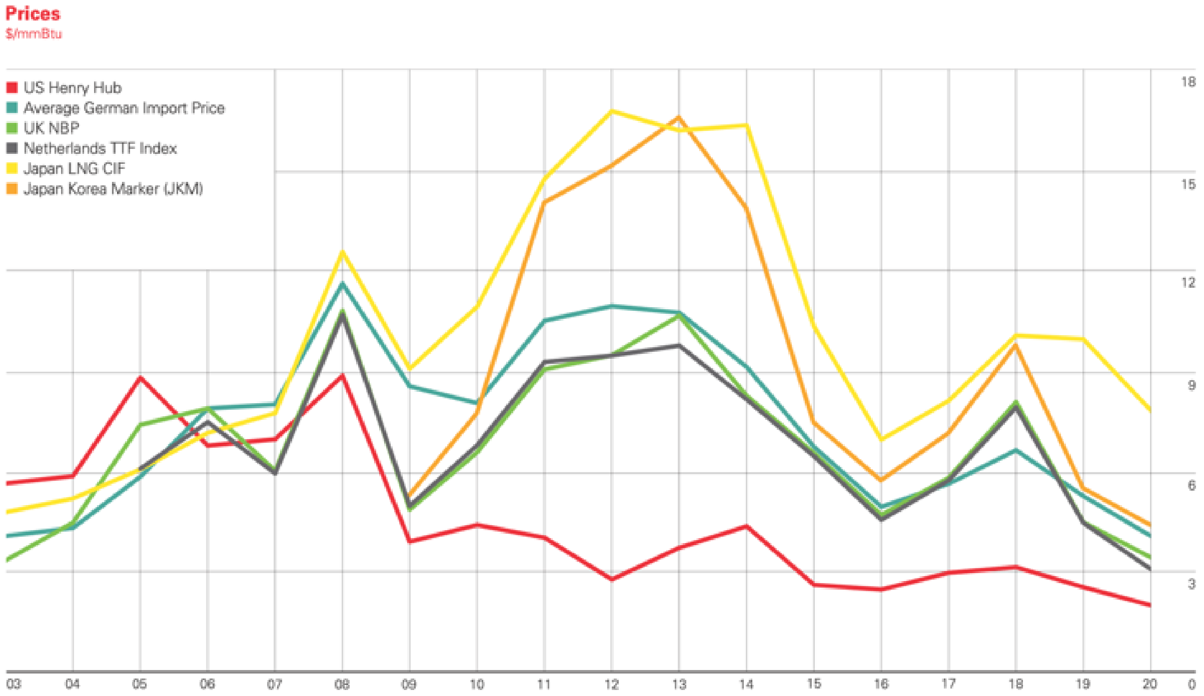

Figure A2.1: Gas price convergence

A3 Closer Inspection at the Forecasts

A3.1 Germany

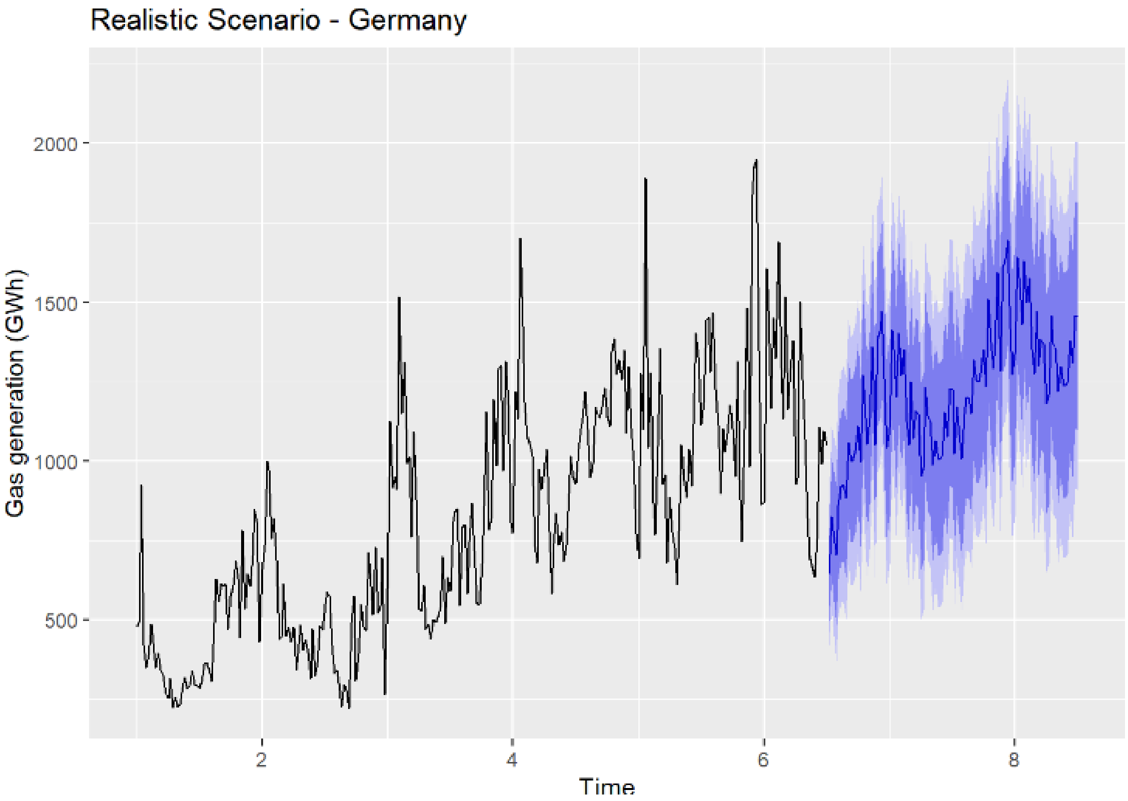

Figure A3.1: Forecasting natural gas - Realistic scenario Germany

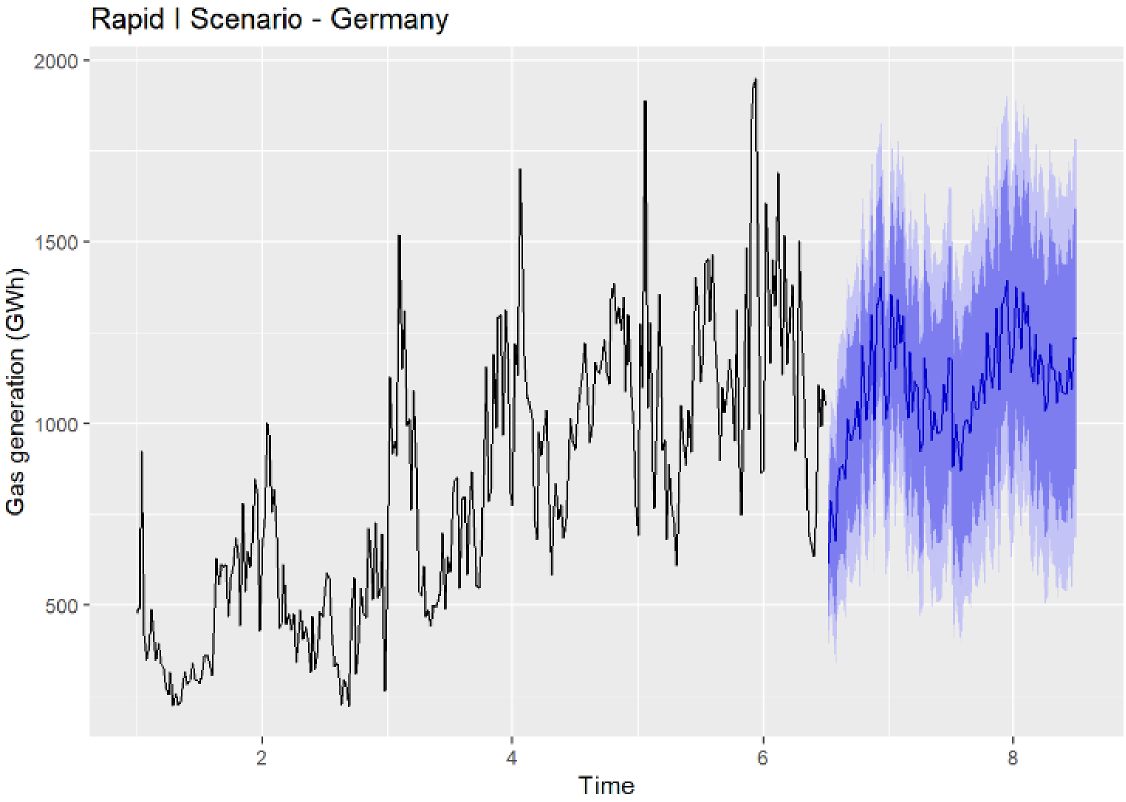

Figure A3.2: Forecasting natural gas - Rapid I scenario Germany

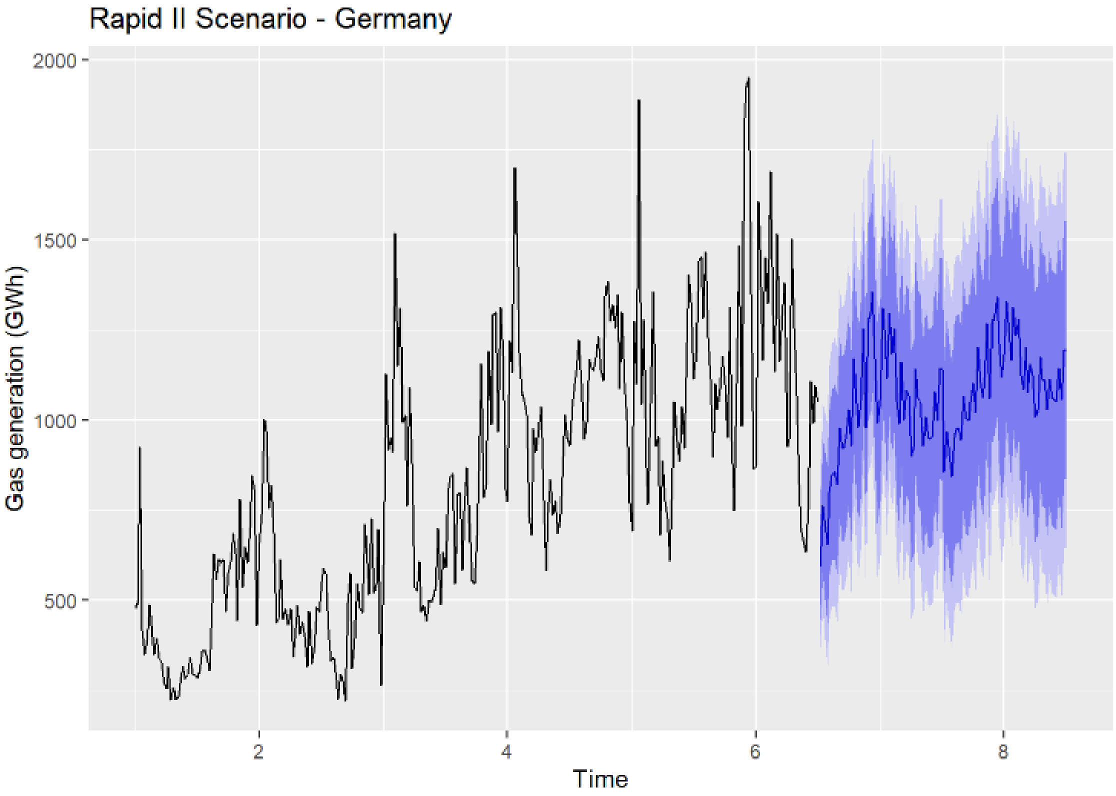

Figure A3.3: Forecasting natural gas - Rapid II scenario Germany

A3.2 The UK

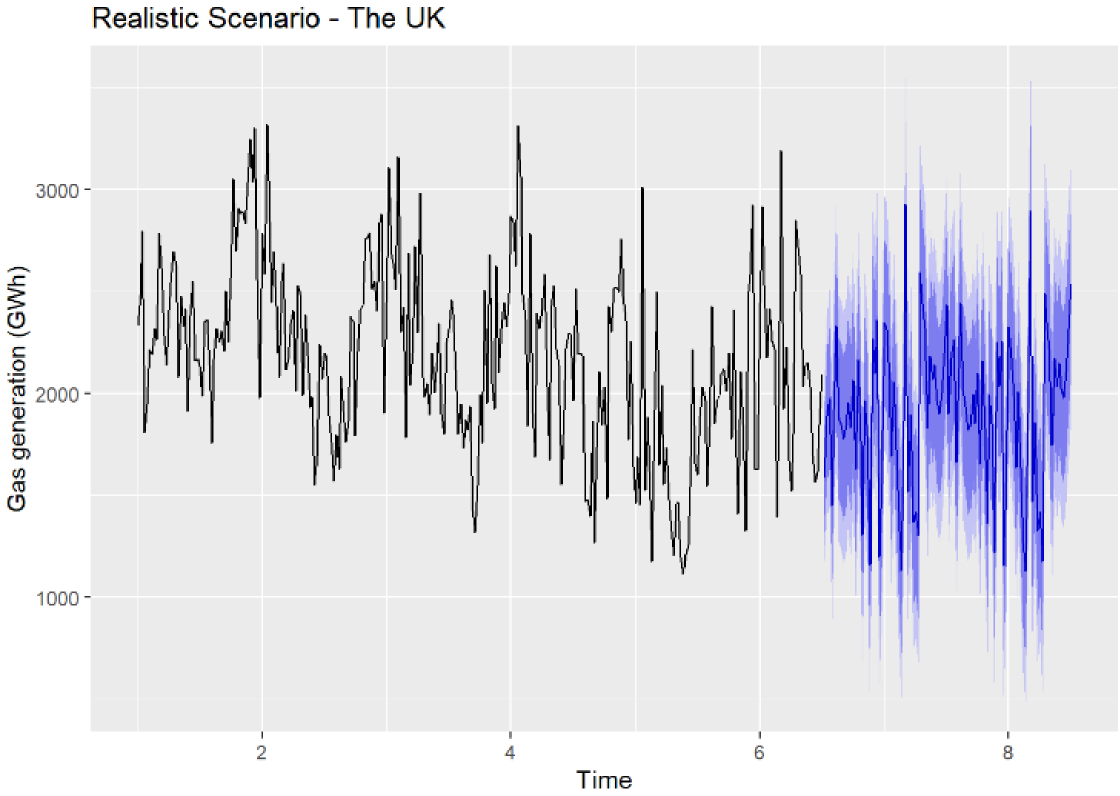

Figure A3.4: Forecasting natural gas - Realistic scenario the UK

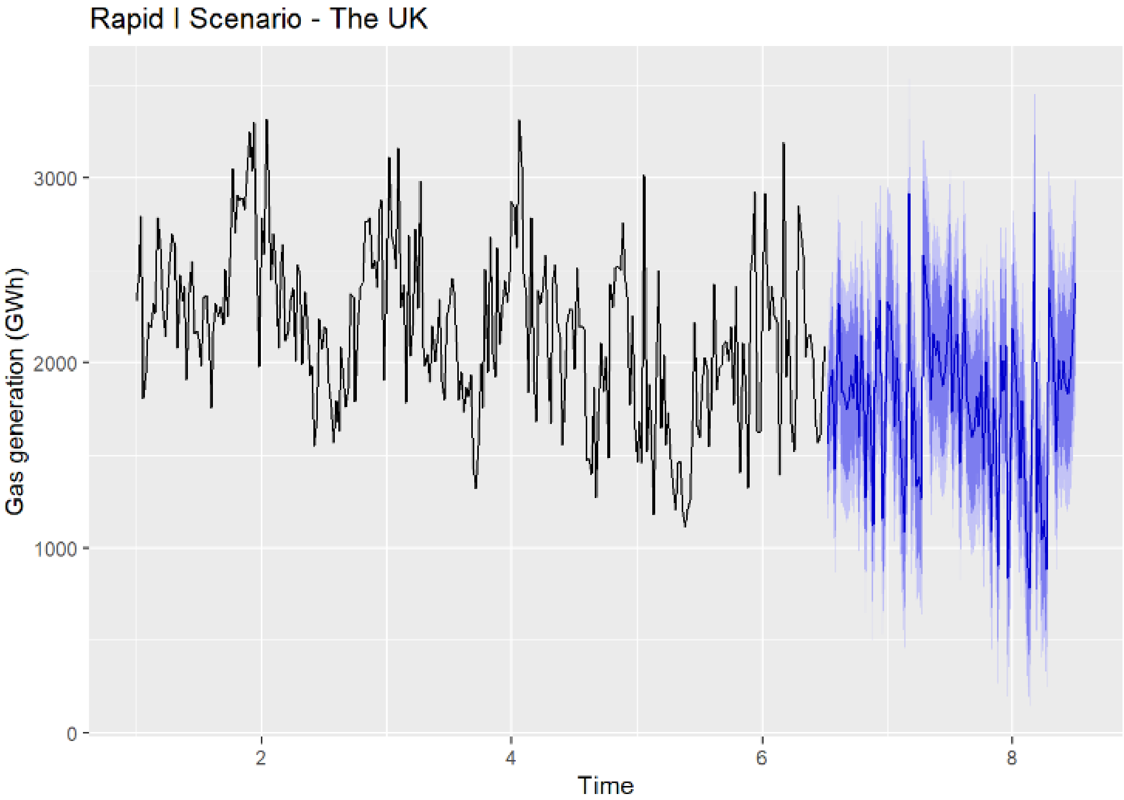

Figure A3.5: Forecasting natural gas - Rapid I scenario the UK

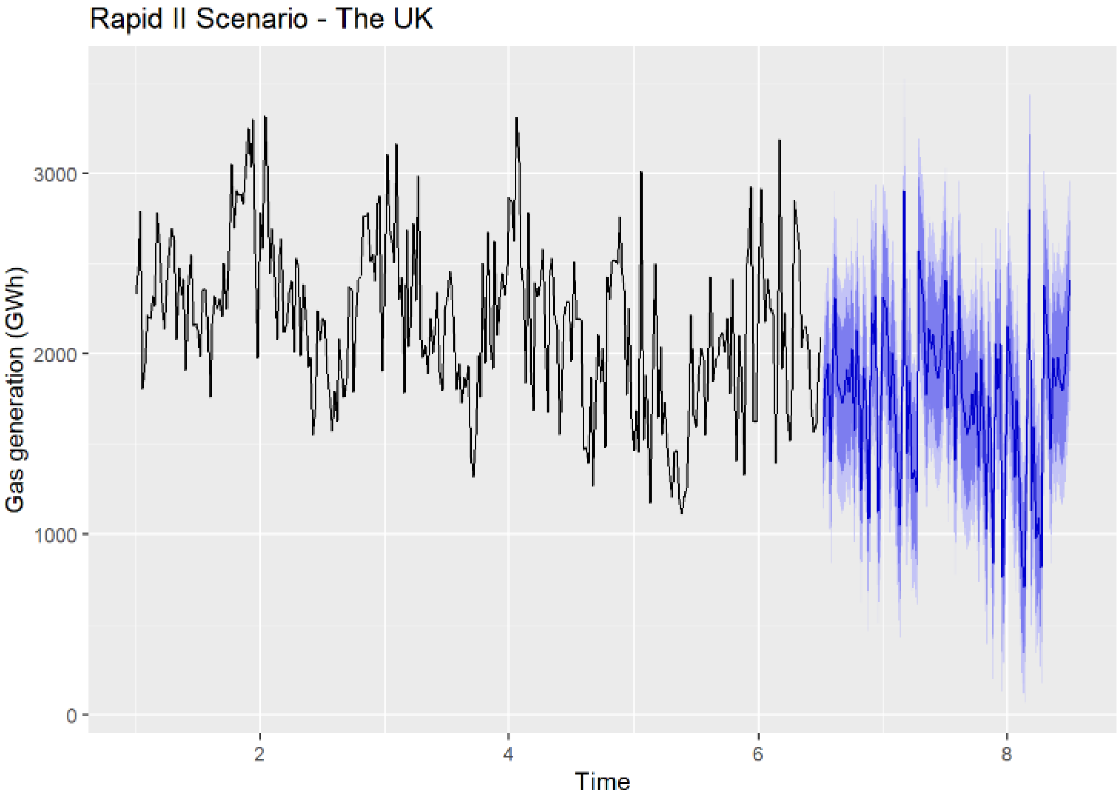

Figure A3.6: Forecasting natural gas - Rapid II scenario the UK