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Sustainability and Energy Policy: The Case of Germany's Natural Gas Supply Chains

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Abstract

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Climate change presents a global challenge. Despite the environmental concerns associated with fossil fuels, they remain vital for global economies. This is a particularly important topic for Germany, as the country is highly reliant on natural gas (NG) - a crucial component for its economic growth and stability, as well as for its ambitious energy transition policy, Energiewende. The central research question probes the impact of the energy crisis on Germany's energy transition and its potential consequences on achieving the country's sustainability targets. The thesis begins with an analysis of the dynamics of Germany's natural gas supply chains, scrutinizing the nexus between sustainable energy practices and the policies that underpin them. Thereafter, a mathematical model is developed that connects the overall emission levels with changes in the Primary Energy Consumption (PEC) mix and this model is used to test the impact of changes in the future PEC caused by changes in NG supply conditions on future emission levels. The results of the analyses show that Germany needs to keep focusing on renewable energy sources development instead of moving its focus to LNG supply chains development if it hopes to reach the ambitious goals set out in its energy transition policy.

Keywords: Energy Policy, Germany, Natural Gas, Sustainability, Supply Chains

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Glossary

AGEB	AG Energiebilanzen (Energy Market Research Group)
AI	Artificial Intelligence
BMWK	Germany’s Federal Ministry for Economic Affairs and Climate Action
FSRU	Floating Storage Regasification Unit
GHG	Green House Gases
LNG	Liquified Natural Gas
LULUCF	Land use, land-use change, and forestry
NG	Natural Gas
PEC	Primary Energy Consumption
RES	Renewable Energy Sources

1 Introduction

Climate change is one of the biggest environmental challenges that cannot be ignored as it applies to everyone. Fossil fuels such as coal, oil, and natural gas play significant role in environmental pollution and climate change. When burning, fossil fuels emit to atmosphere huge amounts of greenhouse gases like carbon dioxide. This results in ozone depletion, air and water pollution and global temperature rise (Bertrand 2021).

However, it is not possible to stop using fossil fuels immediately despite rising environmental concerns. This is because they have played a crucial role in the global economy for many decades. Fossil fuels have been the primary source of energy in industrial, transportation, and residential sectors. They provide the energy required for electricity generation, heating, and serve as a fuel for vehicles and machinery. In addition, exports and imports of fossil fuels influence global trade dynamics. Countries with significant fossil fuel reserves often play a key role in international trade negotiations. Nations rich in resources may hold geopolitical influence due to their capacity to supply or withhold energy resources (International Renewable Energy Agency 2023).

Nevertheless, countries engaged in fossil fuel export and import activities are increasingly aware of the negative environmental and climate impacts associated with these fuels. Efforts to decrease these negative impacts include a combination of policy measures, technological advancements, and international cooperation. Participating in international agreements, such as the Paris Agreement, and cooperating on climate and environmental initiatives can encourage a collective effort to reduce global emissions (Volcovici, Abnett & Green 2020). Energy transition policy pursued by governments plays a significant role in climate action by providing a pathway towards a more sustainable and low-carbon future. One of its primary objectives is to shift from fossil fuels, which contribute to greenhouse gas emissions, towards cleaner and renewable alternatives of energy sources (S&P Global 2023). However, the transition to renewables faces several challenges, making it a complex and

gradual process. The wind and solar energy are not stable and dependent in weather condition. There is need to invest into technologies development and infrastructure construction. Public acceptance also plays an important role in this process. A key question is how countries can continue to reduce emissions during this shift to renewables. A solution was found to have natural gas as a principal source of energy during transition process. Among fossil fuels, natural gas (NG) is considered the cleanest source of energy as it emits less carbon dioxide compared to coal and oil. Since 2010, the transition from coal to gas has saved atmosphere from 500 million tons of CO2 (IEA 2019). Natural gas is essential for electricity generation globally. Gas-fired power plants are known for their flexibility, providing a reliable source of energy (Agora 2017). Finally, NG can balance intermittent production from renewable energy sources like wind and solar, thus increasing security of energy systems operation.

In this thesis the complex dynamics of Germany's natural gas supply chains are studied with the focus on exploring the connection between sustainable energy practices and the policies that govern them. As will be later discussed, Germany is highly dependent on NG supplies as this resource is crucial for normal functioning of the country’s economy and stability. At the same time, Germany is well-known for its sustainable practices and energy transition policy – Energiewende, where NG plays a key role. The country has set ambitious goals, one of which is to become climate neutral by 2045. However, the changes on global arena after February 2022 impacted a lot on Germany’s natural gas supplies. Due to military actions in Ukraine, Germany announced about accelerated termination of NG supplies from Russia – its main NG supplier. However, to ensure energy security, the country had to take unprecedented and costly measures such as transition to liquified natural gas (LNG) and the construction of its first LNG terminals. As an additional security measure, it was also decided to start generating energy from mothballed coal powered plants. These plants are, however, considered among the biggest air polluters. The actions that Germany took to secure its energy supplies call into question the country’s sustainability targets fulfilment.

The main research question is how strong the current energy crisis affected the Germany energy transition and whether it will have impacts on reaching the country's sustainability targets on time.

The first part of this thesis is dedicated to understanding the NG role in the Germany's economy. It draws a broad picture of Germany's NG consumption and imports for the period 2000-2022 based on analyses of reports prepared by BMWK (The Federal Ministry for Economic Affairs and Climate Action) and AGEB (Energy Market Research Group set up by several major German energy industry associations and economic research institutes). After this, PESTEL analysis is provided to assess the natural gas industry in Germany through macroeconomic prism. The results indicate that drastic political changes had a significant bullwhip effect on the gas supply chains and exacerbated major risks for the country's economy affecting also country's social, technological, environmental and legal aspects.

The second part of the thesis delves into researching Germany's energy policy and its sustainability targets and analyses challenges that Germany may be facing in an attempt to decrease its dependence on Russian natural gas supplies. These challenges might include over investments into LNG terminals, prolonged use of NG in PEC, and shifting focus from sustainable development and transition to renewables in favour of energy security.

To address the research question, a simplified model which links primary energy consumption to annual emission levels was developed in this thesis. The model allowed for evaluating the total CO2 emissions level in Germany based on changes in PEC mix. To estimate future emissions pathways that match sustainability targets, the scenario of PEC development prepared by Germany's analytical agency Agora was used. Following this, the methods of sensitivity analysis were applied to understand the impact of changes in major PEC components such coal, gas and renewables on prognosis emissions. The findings suggest that changes in renewables level have particularly strong impact on prognosis emissions in Germany. An alternative scenario where

renewables development is stagnated due to lower investments caused by shifting focus on LNG terminals expansion in Germany. It was found that if such a scenario occurs, Germany might deviate upward from its sustainable targets 2045 by more than two times and might see about a 5-year delay in becoming climate neutral.

2 The role of Natural Gas in Germany's economy

Germany is the seventh largest country in Europe with a total land area of 357,168 sq. km (World Atlas 2020). It is one of the strongest economies in the EU and in the world. A driving force for Germany's economy stability and development is the industrial sector. The country's dominant industries are: the automotive, mechanical engineering, chemical and electrical (Orth 2023). There is strong correlation between the country's GDP growth and industry value-added growth. In case of Germany, the manufacturing industry's share of gross value added is around 23% and this number remains stable for about 20 years (BMWK 2023).

Germany is also the third populated country in the EU with a population of 83 286 971 people according to 2023 data (Worldometer 2023). Most of the Germany's population (77.54%) lives in cities and the urbanization level is constantly growing (O'Neill 2023).

High population and extensive economic activities require a lot of natural resources, for instance, fossil fuels for electric and heat energy generation. Thus, Germany was the seventh country in the world in terms of its primary energy consumption in 2020 (U.S. Energy Information Administration 2020). Energy is needed not only for the industry but also for fulfilling basic human needs. However, Germany's domestic resources are largely depleted and their extraction requires a lot of investments. The country has no other choice but to import fossil fuels from other countries to support its population and economy (Meza 2021).

According to BMWK (2022) among imported fossil fuels natural gas (NG) plays a significant role for Germany after petroleum and coal.

NG is mainly used for electricity generation, heating, industrial processes, and as a fuel for vehicles:

- In 2016 Germany accounted 866 gas filling stations for gas powered vehicles and it was expected that this number will increase to 2000 by 2025 (BMWK 2022a).

- For the period from 2016 till 2021 the construction of gas heated houses was constantly growing (AGEB).

Another reason why NG is so important for Germany is due to the country's efforts towards transition to a more sustainable and low-carbon energy system. According to different statistics, natural gas is considered as one of the cleanest sources of energy. This is justified by the least number of carbon dioxide emissions. The table below illustrates carbon dioxide emission comparison by type of fuel.

Table 1. Carbon dioxide emissions by type of fuel. (Volker Quaschning 2021)

Fuel type	**Emission, (CO2)/GJ**
Hard coal	94,6
Diesel	74,1
Crude oil	73,3
Gasoline	69,3
Natural gas	55,82

It is possible to see that compared to hard coal, natural gas produces half as much carbon dioxide, that makes it the most sustainable source of energy among fossil fuels. Therefore, Germany uses NG as a transitional fuel that will help reach it sustainability goals.

2.1 Overview of Germany's Gas Consumption during the period between 2000-2022

In this subsection the natural gas import situation for the period from 2000 till 2022 is analysed to see the trends and tendencies during this timeline. The graph below illustrates natural gas consumption for the period from 2000 till 2022.

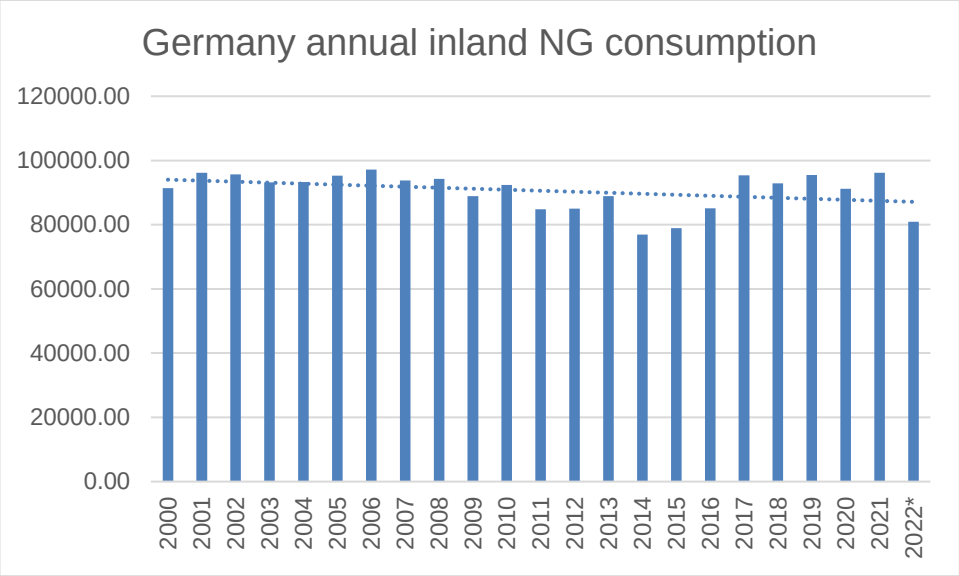

Figure 1. Germany annual inland NG consumption in bill. cubic meters for the period from 2000 till 2022.

It is possible to see that the NG consumption was unstable for the given timeframe. According to Statista (2022) for the period from 2000 till 2014 there was a gradual decline in the annual NG consumption to 76.897 bill. cubic meters. One of the main reasons was the country's interest towards renewable energy sources and sustainable development initiatives. In 2000 Renewable Energy Act (EEG) was issued that replaced the law on feeding electricity from renewable resources. The EEG was aimed to provide long-term support for electricity generated from renewable sources, such as wind, solar, biomass, and hydropower via a tariff subsidy system (Appunn 2021).

However, despite to the declining tendency, the figures of 2005 and 2006 showed higher numbers in consumption. This is due to the rising NG price

competitiveness as well as gradual phase-out of Nuclear Power Plants. In these circumstances NG served as a transitional fuel (BMWK 2022b).

Another reason was that Germany's economy experienced a significant growth in 2005 - 2006, leading to increased industrial activity and energy consumption. The graph below illustrates Germany's GDP for the period from 2000 till 2006.

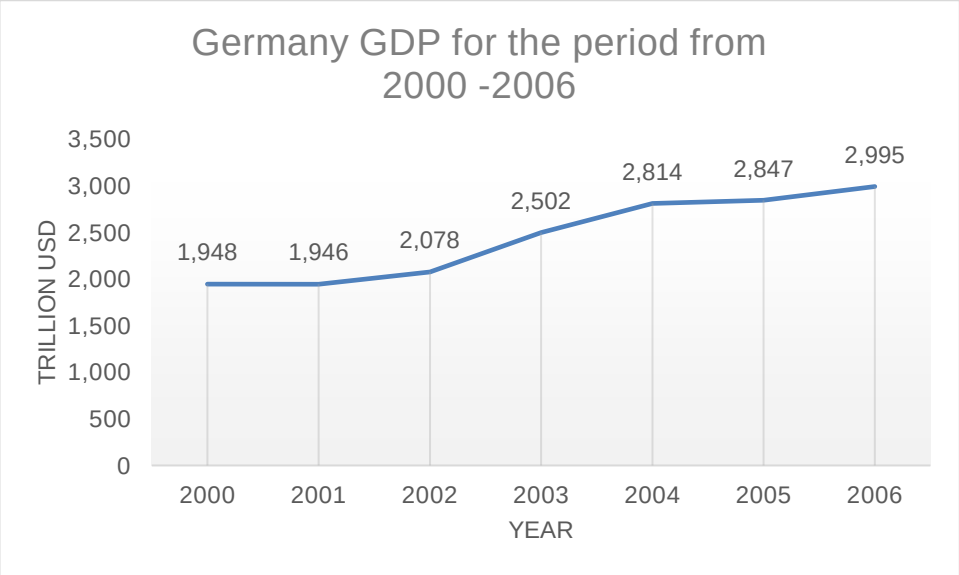

Figure 2. Germany's GDP for the period from 2000 till 2006.

Germany's GDP in 2005 accounted for 2,847 trillion USD, GDP in 2006 accounted for 2,995 trillion USD compared to previous years. In this period, the use of NG in many industrial activities, such as manufacturing, heating, and power generation significantly increased (Deutsche Welle 2007).

The figures for the period from 2015 till 2021 show gradual increase in NG consumption. Based on analysed AGEB reports the main reasons were:

- Colder temperatures during heating season compared to the previous years.
- Replacing heat generation systems with gas powered inside older houses.
- Construction of new houses with gas powered heat generation systems.

- Liberalization of energy market and growing number of gas supply enterprises.
- NG prices were more competitive compared to other sources of energy. The figure below illustrates gas prices (Eurostat 2023).

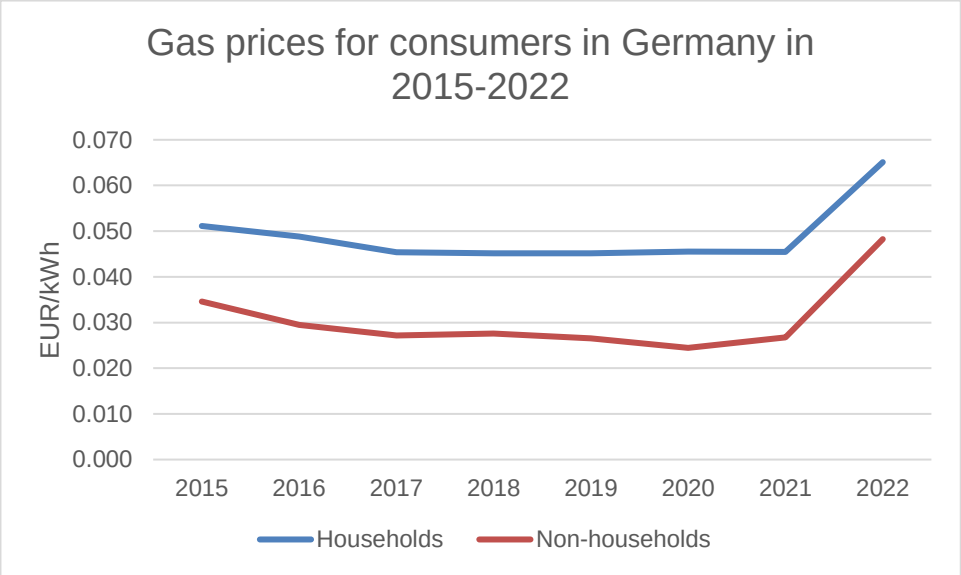

Figure 3. Gas prices for consumers in Germany in 2015-2022.

However, there was a noticeable NG consumption decline in 2018 due to warmer weather conditions during the heating season as well as a significant reduction of NG demand in the chemical industry. The chemical and pharmaceutical industries are the biggest contributors to Germany's GDP. Their consumption of NG accounts for 29.1% from the total country's NG consumption (Fraunhofer cited in Halser & Paraschiv 2022:2a). In other words, lower industrial NG consumption has a direct effect on overall country's NG consumption.

Another noticeable decline in NG consumption took place in 2020 due to global the pandemic COVID-19 causing an industrial production shut down and the country's lock down when most of the units such as schools, offices, shops were closed. Nevertheless, in 2021 the country gradually restored after pandemic, and the levels of NG consumption significantly increased again

reaching 95.5 mill. cubic meters per year which was as high as it was last recorded in 2005 - 2006.

In 2022, a noticeable decrease in NG consumption occurred. This has several reasons listed below:

- Milder weather conditions, the average temperature during the heating season was 1.1 °C above the annual average of the last four years.
- The gas prices have significantly increased since March 2022, reaching a temporary record high (€315.9/MWh) – that was four times more compared to NG prices before the military actions in Ukraine.
- The lack of NG supplies from Russia (Bundesnetzagentur 2023a)
- Obligatory filling gas storage facilities to prevent NG shortage during wintertime.

According to Germany's Federal Network Agency (Bundesnetzagentur 2023b) NG consumption by industry was down by 23% and the consumption by private consumers and businesses was down by 21% compared to the previous years.

Despite Figure 1 showed mixed trendline during researched period from 2000 till 2022, it was possible to see that Germany's NG consumption was relatively high. This is mostly due to Germany's economy growth and sustainability initiatives. At the same time, over the periods 2000-2022 the consumption showed periods of decline caused by milder weather conditions, due to which less NG was used for heating purposes in households' sector. With this, extreme declines occurred in 2020 and 2022 and they were caused by exceptional and unpredictable situations in the world such as global COVID pandemic and war in Ukraine.

2.2 Germany's Import Overview for the period from 2000 -2022

Germany is highly dependent on NG import as domestic production is constantly falling. According to BMWK (2022) in 2016 domestic production of NG in Germany covered only 6% of country's consumption, 94% of the

country’s consumption were covered by NG import. Russia, the Netherlands and Norway were the largest exporters of natural gas to Germany (Energy Information Administration 2020a). ICIS analysis showed that in December 2021 Russian NG imports accounted for 32%, Norwegian 20% and Dutch 12% (BMWK 2021a). Being highly dependent on NG imports, Germany needs to ensure the security of gas supply (BMWK 2022c).

To increase the gas supply security, the country developed and applied the following measures:

- providing support for NG domestic producers
- diversifying supply sources and transmission routes
- establishing stable relationships with supplier countries
- concluding long-term gas supply contracts
- investing and developing supply infrastructure including underground storage facilities and LNG (liquefied natural gas) terminals (BMWK 2021b).

To have a broader understanding of Germany’ NG import situation, the volumes of gas import the period from 2000 till 2022 were analysed and presented on figure below.

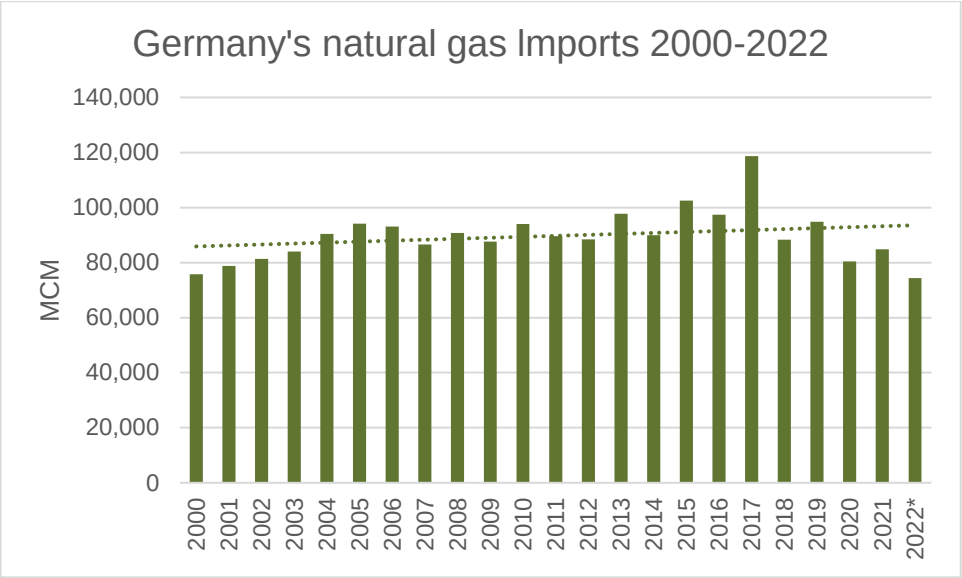

Figure 4. Germany's natural gas import for the period 2000 – 2022 MCM (*2022 estimated value. (Bundesnetzagentur 2023c)

It is possible to see that NG import was not stable during the mentioned period from 2000 till 2022 and overall import situation has mixed trend.

In recent years, declining NG import amounts are explained by the falling NG demand due to increasing interest to alternative energy sources: the country implemented the Energiewende - a policy to transition to renewable energy sources and reduce greenhouse gas emissions. Another reason was technical progress and the energy conservation (BMWK 2022d).

However, in earlier periods an increasing trend is observed, for instance, for the period from 2000 till 2005 due to the country's expanding industrial sector and increasing demand for natural gas in power generation and heating. This NG import increase was also due to Germany sought to diversify its energy sources to reduce dependence on coal or nuclear power (BMWK 2021c).

The highest import value is observed in 2017. This is due to Germany’s gradually phasing out nuclear power generation since the Fukushima nuclear disaster in 2011. This resulted in increasing reliance on alternative energy sources, including natural gas. Germany has also been implementing policies to

reduce coal-fired power generation as part of its efforts to transition to cleaner energy sources. In these conditions, NG served as a backup to ensure a stable and reliable power supply when renewable sources are not generating enough electricity. Another reason was that NG prices were relatively low in 2017, making it an attractive option for import (BMWK 2021d).

In 2022 NG imports comprised 1,449 TWh (2021: 1,652 TWh). The largest volumes came from Norway (33%) and Russia (22%; the share was 52% in 2021). Gas imports from Russia were constantly declining during 2022. Until the middle of June around 1.7 TWh were still being delivered daily through Nord Stream 1. Nord Stream 1 numbers decreased by 60%, then by 80% and finally fell to 0 TWh at the beginning of September 2022. Germany managed to partially replace falling Russian NG imports by additional imports from the Netherlands, Belgium, Norway, and other countries (Bundesnetzagentur 2023d).

2.3 NG Infrastructure and Logistics in Germany

Historically, being heavily reliant on gas, Germany has developed a wide and well interconnected NG grid with a total length of 511,000 km (BMWK 2022e). Before 2022 NG to Germany was imported mainly through the gas pipelines and road transport. The pipelines were used to deliver NG to Germany from its biggest suppliers such as Russia, Norway and Netherlands*.

The list of pipelines for transporting NG from Russia and Norway included:

- Nord Stream 1 for transporting Russian NG, which started operating in 2011 with 55 billion cubic meters per year.
- New Nord Stream 2 pipeline for Russian NG supplies was completed in 2021 and was expected to be in use in 2022, with annual capacity 55 billion cubic meters per year (Medlock et al 2022)
- Norpipe, Europipe I and II for Norwegian gas import with a total capacity of 54 billion cubic meters (EIA 2020).

*The import from the Netherlands was decreasing due to earthquakes resulting in NG production in the Groningen gas field. This impacted negatively to the environment and safety. Germany stopped NG import from the Netherlands in 2022 (Energy Information Administration 2020c).

However, the changes that 2022 brought to Germany's NG supply affected also on the country's NG import infrastructure. In June 2022, Gazprom announced a planned reduction of NG supplies via Nord Stream I due to pipeline technical problems. Planned supplies went down from 167 to 100 million cubic meters per day initially. Shortly after this, the pipeline flow decreased to 67 million cubic meters per day as Gazprom proclaimed about turbine weakening conditions and impossibility to use them for gas transportation without due maintenance. The required maintenance could have been done only in Canada which has blocked delivery of turbines due to the sanctions (Halser & Florentina 2022b). In autumn 2022 the Nord Stream I and II were destroyed by explosions.

After losing a significant part of the import volume that was coming from two Russian pipelines with a total annual capacity of 110 billion cubic meters, Germany had to take steps to secure its energy supply. In attempt to diversify its NG supplies, in Spring 2022 Germany announced about investing into construction of its first LNG terminals in Brunsbüttel and Wilhelmshaven. Transition to LNG will be discussed at a greater length in chapter 3.

2.4 Analysing Germany's Natural Gas Industry

It was possible to see from the previous subsections that being highly dependent on NG gas Germany is encountering many challenges. The situation inside the NG industry has a direct effect on Germany's prosperity. Political and economic stability, social harmony and innovation are key factors for the country's welfare. These factors are interconnected and changes happening with one of them can have ripple effects across the others. This thesis applies PESTEL analysis to reflect the environment of the natural gas industry in Germany from the macro factors perspective. PESTEL analysis was originally

known as PEST, before environmental and legal aspects were included in the 1980s. It serves for analysing industrial or business environment through macroeconomic prism (Debourdeau et al 2023). This will provide a comprehensive overview of the current situation in Germany and in the industry before deepening into the country's sustainability issues that will be described at a greater length in the following chapter 3.

Political

The natural gas industry is highly affected by the changes that may happen in the political arena. For instance, it may be affected by geopolitical factors, political tension, termination of international agreements and relations (International Renewable Energy Agency 2023). Germany's NG imports are dependent on supplies from Russia and other countries. For the industry it means that establishing and developing strong supplier relations is one of the key points especially when it comes to a country's energy security. However, military actions in Ukraine that started in 2022 significantly changed international relations between Russia and Germany. In this consequence Germany is aiming to reduce NG supplies from Russia, its main NG supplier, to 10% by 2024 (Ting, Galen & Zhou 2022:4a). This endangers Germany's energy security. In order to overcome this crisis situation, the country must look for the options to diversify its energy sources. This can be done by contracting new NG suppliers, use of alternative sources of energy and investing into research and development of new infrastructure and technologies. However, the country's economy may suffer from such significant changes.

At the same time, this crisis situation requires political decisions on regulation of NG use. According to the International Monetary Fund (2022), Germany's Federal Network Agency developed the NG rationing plan that takes into account non-economic aspects such as social, technical, legal, and environmental. In addition, the entity has collected crucial information on firms' gas usage needs to help develop plans for gas distribution in a crisis (Ting, Galen Zhou 2022:4b).

Another political factor that affects industry is the country's policies that are applied internally. For instance, since 2011 Germany follows its energy transition policy called "Energiewende", according to which, the country's main goal is to reduce its GHG emissions and become climate neutral by 2045. In order to comply with these set of goals, NG was chosen as a temporary solution or so-called bridge fuel. However, it is expected that NG will be gradually substituted by cleaner options in the future. This will potentially be negatively impacting the demand for natural gas.

Economic

According to the research prepared by the International Monetary Fund team in 2022, the shut downs of NG supplies from Russia could contribute to a decline in Germany's GDP by about 1.5 percent in 2022, 2.7 percent in 2023 and 0.4 percent in 2024. Other factors contributing to GDP decline were considered: reduced supply of intermediate goods and services to downstream firms and reduced economic activity due to rising uncertainty. The associated rise in wholesale gas prices could increase inflation by about 2 percent on average in 2022 and 2023.

The overall economic health effects on energy consumption in industrial and residential sectors. Since NG is the main energy resource in Germany, energy prices correlate with NG prices. When NG prices increase this makes energy prices higher and therefore the cost of manufactured goods will increase too. At the same time this creates complications for the households that use NG, for instance, for heating purposes. In case of cold winters, the household owners may appear to be unable to pay energy bills if the family income is insufficient.

Another factor is investment into facilities to secure NG supplies. After February 2022 Germany announced about investment into construction of LNG terminals. The cost of this investment was €3 billion ($3.25 billion) according to the DW report in 2022. However, recently it was published that the Bundestag lower house of parliament has approved 9.8 billion euros ($10.40 billion) for the 2022-

2038 period (Eckert 2023). For Germany's taxpayers this will possibly mean that taxes increase or less will be spent for other sectors such as for instance schools, medical system etc. This is also because Germany's government partially subsidizes the costs of LNG terminals from the federal budget (Ting, Galen & Zhou 2022).

It is also expected that new NG suppliers for Germany will be US and Qatar. U.S was planning to deliver 15 billion cubic meters of fossil fuels (Shonhardt & Waldman 2022). At the same time, Qatar announced its NG shipments to Germany from Texas' Gulf Coast where it has LNG terminals (Sal 2022). The deliveries of LNG in these cases are organized via sea going vessels tanked by diesel oil. This will mean that prices for oil can affect on LNG prices as well. There is also environmental concern, as vessels are polluting air, water and harmful for sea flora and fauna.

Social

Factors such as population, urbanization trends and social awareness may influence different fields and industries, and NG is not an exception. NG demand correlates with the population of the country. According to the Worldometer July 2023 update, Germany's population comprised 83 286 971 people that makes it the third most populated country in Europe. More than a half of the country's households (41 mil) are equipped with gas powered heating systems. Growing population will potentially increase this number and therefore demand for NG in household's sector. At the same time Germany has a growing urbanization trend with 1.2% increasing annually. Urbanization stimulates energy consumption and in the case of Germany where NG is the main source of energy it will also increase its demand.

As it was mentioned before Germany follows Energiewende policy that sets certain sustainability goals. However, to achieve these goals joint actions of the whole country are required. For the government it sets the task to raise social awareness of sustainability problems among people. Since NG gas is a part of

Energiewende policy and serves as a bridge fuel while the country is transitioning to alternative sources of energy. This may potentially have an effect on re-equipping the households with new NG powered heating systems as well as people could switch on electricity suppliers whose energy facilities are also powered by NG. However, in contrast, the sustainability policy and social awareness can decrease NG demand in case more households will be using heat generated from alternative sources.

It is necessary to mention also how changes in relations between Germany and Russia after 2022 affected the social aspect of the analysis. Due to a sharp decrease in NG supplies from Russia, Germany had to take emergency measures to secure NG storage. According to Monetary Fund team research (2022), by reducing households' heating temperature by about 2 degrees while heating is needed could save about 10% of gas consumption. However, these measures were voluntary for household's owners.

Technological

NG Industry creates opportunities for development of technologies. For instance, AI was used for drilling and optimization operations. Growing demand for NG made companies invest into R&D in terms of the NG fields exploration and production sector. More examples can be found also in transportation technologies for LNG. In addition, there is a growing number of gas-powered vehicles and therefore gas stations. This is also a good contribution to environmental protection and sustainability.

In the case of Germany, the technologies are aimed at the development of effective distribution grids and network infrastructures. In addition, as it was mentioned previously, there is a growing number of houses that are equipped with gas powered heating systems.

With the changes after February 2022, there is a new set of tasks for Germany in technological aspects. In its attempts to diversify NG supplies, the country invested into its first FSRUs that are required for LNG deliveries. This

technology requires experienced specialists and developing knowledge, as FSRUs were not used before in Germany and there is no expertise in this field.

The smart meters installed in houses could help to track gas consumption in a NG crisis environment. This could help the house owners to monitor gas consumption in real time. However, this is not widely used technology in Germany and another solution could be found in providing up-to-date, online gas usage statistics (Ting, Galen & Zhou 2022:4c).

Environmental

One of Germany's main sustainability targets is to complete climate neutrality by 2050. In order to achieve that, NG was chosen as a bridge fuel when transitioning to renewables. This makes NG an important tool that will help the country to achieve its sustainability goals. However, it is necessary to mention that despite the current importance of NG, Germany will gradually reduce its consumption and NG will be substituted by alternative sources of energy in the future.

Political tension between Germany and Russia, effected a lot on the country's sustainability goals. The NG shortage led to a crisis situation. The country's government had to take immediate measures to secure its NG reserves and supplies. The measures led to the consequences as listed below:

- Coal-exit Law underwent some changes - for instance, two lignite power plants that were supposed to be decommissioned in 2022 will be operating until 2024 to generate additional power (Kylmann 2022).

- Investment to LNG terminals (FSRU) – negative effect on local environment and focus from climate action towards recovering cost of this investment.

- Diversifying suppliers by contracting Qatar and USA – LNG deliveries by sea-going tankers that emit carbon dioxide.

However, due extensive shut downs of NG supplies from Russia, Germany invested into LNG facilities with total capacity 3.5-5 billion cu m/year. This potentially means that the consumption of NG may continue to increase that would undermine energy transition.

Legal

The licensing requirements must be complied by NG companies if they want to continue their operations. Each country has its own rules and laws that control the whole industry. For instance, in Germany, it is controlled by the Federal Network Agency (Bundesnetzagentur) (BNetzA) and the federal-state regulatory authorities on national regulations level. The country also applies international environmental regulations such as the Paris Agreement, Kyoto Protocol, Montreal Protocol, European Union Emissions Trading System (EU ETS), The Renewable Energy Sources Act (EEG). Germany recently joined the Global Gas Flaring Reduction Partnership (GGFR) that aims to reduce the environmental impact of gas flaring in the oil and gas industry, which includes natural gas production.

The current geopolitical environment also affects the legislation system in Germany. Due to gas shortages some amendments in Germany's legal system were made. Firstly, the government took control of critical energy infrastructure that is currently under private control. Secondly, new legislation is aimed to help energy companies stay solvent by allowing more flexibility in retail prices. According to the International Monetary Fund report (2022), Germany's government plans to support firms' liquidity with loans through KfW (Green Climate Fund). This activity includes loans to energy producers to post margins on their hedging contracts. And thirdly, discretionary income support for vulnerable households through one-off energy relief payments or housing benefits (Ting, Galen & Zhou 2022:22).

2.5 Conclusions to Chapter 2

The data analysed in chapter 2 demonstrated the imminent role of gas in Germany’s economy. However, analysis also showed that Germany is heavily dependent on natural gas imports. In 2016, Germany’s imports covered 94% of the total country’s’ gas consumption and this number remained quite stable in the following years. The in-land gas consumption is found to be influenced by factors such as economic growth, competitiveness of NG prices, and climate conditions. Peaks and declines in consumption correlate with economic activities and external factors like the COVID-19 pandemic. There is also a strong correlation between Germany's GDP growth and the growth of the manufacturing industry - the second largest gas consumer of the country - which accounts for about 23% of gross value added. In addition, Germany's commitment to sustainability also supports strong demand for natural gas in the years to come as the country sees natural gas as a transitional fuel to achieve its climate neutrality and environmental targets.

However, the changing geopolitical landscape and energy crisis that erupted during 2022 have influenced consumption levels and led to reconsideration of the country’s NG supply chains. Sharp deterioration of relations between Germany and Russia, which was the biggest NG supplier for Germany, has negatively affected the country's GDP and overall economic health. Challenges, such as disruptions in NG supplies from Russia, have led to emergency measures and sharp increase of investments in new LNG terminals. With all these changes it is impossible not to consider their negative impacts on environment targets and social aspects.

Ultimately, NG plays a multifaceted role in supporting Germany's economy, meeting the energy needs of its industries, and serving as a transitional fuel on its way towards sustainability. The challenges and adaptations reflect the dynamic nature of the energy landscape, requiring strategic measures for security, efficiency, and environmental considerations.

3 Analysis of Germany’s Energy Policy and Sustainability

This chapter analyses Germany's energy policy and the country’s sustainability targets. The energy transition towards renewable sources such as wind, solar, and biomass will be discussed. The challenges that Germany faces on its way towards sustainability goals will be analyzed. This includes, for instance, a phasing out of natural gas, that remains an important resource for Germany's energy mix. The discussion extends to the country's shift towards Liquified Natural Gas (LNG) as part of a crisis plan for maintaining energy security. With this, concerns about the economic and environmental implications of this transition, including potential conflicts with climate targets and sustainability goals, are discussed at a greater length in this chapter.

3.1 Germany’s efforts towards sustainability in energy sector

Energy and climate policy are crucial issues for Germany due to the country's strong industrial base, which historically has been energy-intensive. Transitioning to more sustainable practices often requires substantial investments and adjustments for industries deeply rooted in traditional methods. Optimization of the energy sector operation and energy supply chains in order to decrease emissions that are harmful for climate and environment is critical for Germany (European Commission 2019). Germany has set ambitious targets to support its sustainable development. The table below illustrates some of Germany’s steps towards sustainability.

Table 2. Germany sustainability targets.

Year	Description of activity
By 2030	• Greenhouse gas decrease by at least 55% compared to 1990 • Share of renewable energies in gross final energy consumption 30% compared to 2008 • Reduction of energy consumption and increase of energy efficiency by 30%
By 2038 at the latest	• Gradual reduction and phase-out of coal-fired generation
By 2045	• Climate-neutral energy system
By 2050	• Limiting global temperature rise to well below 2 degrees Celsius above pre-industrial levels, with efforts to limit it to 1.5 degrees Celsius.

The plan described above is enshrined in different policies, acts and international agreements of the country. Thus, in 2019 the German Federal Government has passed the Climate Action Program 2030 that sets the country's sustainability goals by 2030. According to the program, the country is going to implement a national emissions trading system for the heating and transport sectors. Additionally, there is The Renewable Energy Sources Act (EEG) 2030, according to which it is expected that the share of gross electricity consumption that is met by renewable sources production must comprise at least 80% by 2030. The EEG 2023 is often considered as the biggest amendment to energy legislation in decades since it lays the foundations for Germany to become climate neutral (Bundesregierung 2022).

Climate neutrality by 2045 is enshrined in the Climate Change Act (Klimaschutzgesetz), which is on a national law level. For the country it means an almost complete phase out of coal, oil, and gas. In other words, Germany has to diversify its energy mix and to pursue transition policy. The shift towards renewable energy sources such as wind, solar, and biomass, as well as efforts to improve energy efficiency in various sectors is promoted in the energy transition policy "Energiewende". The "Energiewende" is the policy adopted by Germany's government that represents complex, long-term sustainability activity that includes decarbonization of the energy sector, reduction of greenhouse gas emissions, and obtaining sustainable energy supply. It also

implies an ecological strategy that takes into account scientific insights and ethics with far-reaching economic and societal impacts (Agora Energiewende 2023). The “Energiewende” policy was officially launched in the early 2000s and has become a prominent and influential approach to addressing climate change and promoting a more sustainable energy landscape.

It is also necessary to mention Germany’s participation in the Paris Agreement with a target to limit global temperature to 1.5 degrees Celsius. As part of the Paris Agreement, each member country is required to submit Nationally Determined Contributions (NDCs), outlining their climate action plans. Germany has submitted its NDCs, specifying the measures it intends to take to contribute to the global climate goals (UN Climate Change 2023). This is aligned with its domestic policy initiatives, particularly the “Energiewende”. Germany actively supports transition to renewables and works on increasing the share of renewables in its energy mix. Overall, Germany's participation in the Paris Agreement reflects its dedication to combating climate change and transitioning towards a low-carbon, sustainable future.

In April 2021 Germany amended its Climate Act setting more ambitious targets regarding CO2 reduction. The new plan includes achieving greenhouse gas neutrality by 2045. It has also set the preliminary goals to reduce emissions by at least 65 percent by 2030 compared to 1990 levels, and 88 percent by 2040 (Appunn, Eriksen & Wettengel 2023).

3.1.1 Phasing out coal and natural gas

In an attempt to achieve climate neutrality, Germany has recognized the necessity to transition away from its carbon-intensive energy sources, particularly coal. Coal is known among the most air-pollutant sources of energy. Phasing it out is essential to reduce greenhouse gas emissions and mitigate climate change. In 2018, Germany established The Coal Exit Commission (Kommission Wachstum, Strukturwandel und Beschäftigung) (Wehrmann 2018). Its primary purpose was to develop guidelines for the country's phase-

out of coal mining and coal-fired power generation. Another important task was to ensure a just transition for affected regions and workers. The Coal Exit Commission initiated a specific goal to exit coal entirely by 2038 (Wehrmann 2018). However, in 2021 Germany's government announced about speeding up actions towards termination of coal use and set a new goal with the complete phasing out of coal by the year 2030. Necessary to mention that phasing out coal initiatives brought positive results already in 2020. Thus, according to the BMWK Monitoring Report 2021, in 2020, a large decrease in energy production generated by coal-fired plants was observed. It showed around 25% less electricity generated from hard coal and around 20% less electricity generated from lignite (Bundesnetzagentur 2021).

Despite achievements in phasing out coal described above, phasing out natural gas looks more complex because it is used as a transition fuel aimed to substitute dirtier energy sources while renewable energy sources are expanded. Regardless of the fact that NG plays an important role according to "Energiewende", it remains a fossil fuel that negatively impacts environment and climate change. There are several reasons why NG use should be mitigated. Firstly, it still produces carbon dioxide (CO2) when burned. Secondly, its production and distribution can result in methane emissions. Methane is a potent greenhouse gas that has a much higher heat-trapping potential than CO2 over a short time frame. Leakage of methane during extraction and transportation can significantly contribute to global warming. It means that phasing out natural gas reduces methane emissions (Center for Climate and Energy Solutions 2013). And finally fossil fuels including natural gas are finite resources that will eventually be depleted therefore mitigating reliance on them is also a crucial issue for energy security (Holechek et al 2022).

The New Climate Institute (2022) provided comprehensive research showing that in order to achieve climate neutrality by 2045, Germany must reduce its NG consumption in 2030 from 20% to 30% compared to 2021 levels. The research also offered three scenarios for reduction of NG consumption if Germany wants

to achieve its climate neutrality goal by 2045. It is advised that NG must drop according to the schedule below:

- by half from 2021 levels by 2035
- by four-fifths by 2040
- to nearly zero by 2045

Phasing out natural gas is consistent with the Paris Agreement commitments and demonstrates Germany's dedication to addressing climate change.

3.2 Analysing Germany's energy consumption through the sustainability prism

Germany's energy system is supplied from fossil fuels as its primary source, followed by renewables such as solar, wind, biomass (Lafrance & Wehrmann 2023). The figure below illustrates Germany's primary energy consumption for the period from 2000 till 2022. The figure also shows government sustainability targets by 2030 and 2050 according to the Energy Concept and the Energy Efficiency Strategy 2050 of the Federal Government.

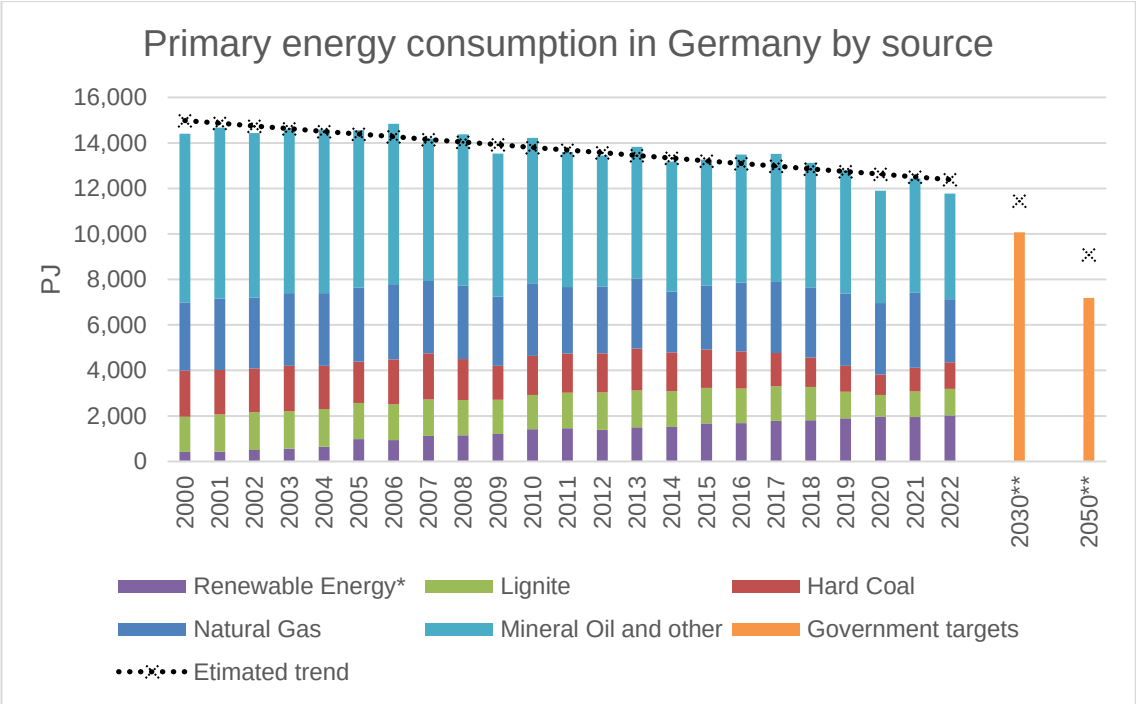

Figure 5. Germany's primary energy consumption.

The figure 5 shows that the country persistently follows its sustainability goals described in the previous chapter. Thus, for example, there was a noticeable decline in hard coal and lignite use for the period from 2000 till 2020. At the same time, primary consumption from renewables grew constantly. However, NG primary consumption does not demonstrate a significant decline. Nevertheless, the overall primary consumption shows steady decline, which can suggest Germany’s commitment to its sustainability targets and international climate agreements.

As can be seen from figure 5, 2022 brought vast changes that influenced the energy consumption of the country. The hard coal and lignite-based consumption increased in 2022 by 7.3 %. At the same time NG primary consumption showed a significant decline of 15.4%.

Electricity sector in particular was strongly affected by changes in gas supply conditions. According to Statista, despite Germany’s government has previously agreed to stop using coal by the year 2030, this fossil fuel made a comeback in 2022 due to the global energy crisis and attempts to save as much gas as

possible. In 2022 about 30% of electricity in Germany will be generated from lignite and hard coal power plants. The increased use of hard coal and lignite for power and heat generation increased emissions in the power sector (Statista 2022). For reference, burning lignite produces 0.36 kg of carbon dioxide per kilowatt-hour of electrical energy, while hard coal produces 0.34 kg of carbon dioxide (Uniper 2023). Germany owns ten coal-fired power plants, seven of which are considered the most polluting power plants in the EU. For instance, the Neurath plant produced 22 million metric tons of CO_2 equivalent in 2021 alone. The total CO2 emissions from the energy sector in 2022 were about 250 MtCO2, about 4.5% increase from 2021 levels. Similar CO2 emission level in the energy industry of Germany was seen in 2019 (Umwelt Bundesamt 2023). Reduction of primary energy consumption from gas was also caused by lowered gas demand from industry, facing high gas prices.

Nevertheless, it should be mentioned that primary energy consumption from renewables also increased by 4% in 2022, mainly due to higher renewables in the power sector. The proportion of electricity generated from renewable sources in 2022 comprised 48.3% compared to 42.7% in 2021. Among all types of renewables, wind power, including both onshore and offshore installations, contributed significantly with a share of 25.9%. Solar constituted 11.4%, while biomass accounted for 8.2%. The remaining 2.8% comprised hydropower and other renewable sources. The total renewable energy generation in 2022 amounted to 233.9 terawatt-hours (TWh), marking an increase of approximately 8.5% from the 215.5 TWh recorded in 2021. Specifically, onshore wind generation reached 100.5 TWh, representing a substantial 12.4% surge compared to the 89.4 TWh reported in 2021 (Enerdara 2023).

Figure 5 also shows primary energy consumption levels for 2030 and 2050 if current fossil fuels usage and renewable growth trend continue. It can be seen that in that case primary energy consumption in Germany may stay above the governmental targets for 2030 and 2050. According to our estimates, the primary energy use could remain 14% and 26% above expected levels in 2030 and 2050 correspondingly if additional sustainability measures are not in place.

Figure 6 shows the levels of total emission in Germany in thousand tons of CO2 equivalent over the period 2000-2022 by source, the overall trend and expected emission levels in 2030 and 2050 if current emissions trend continues.

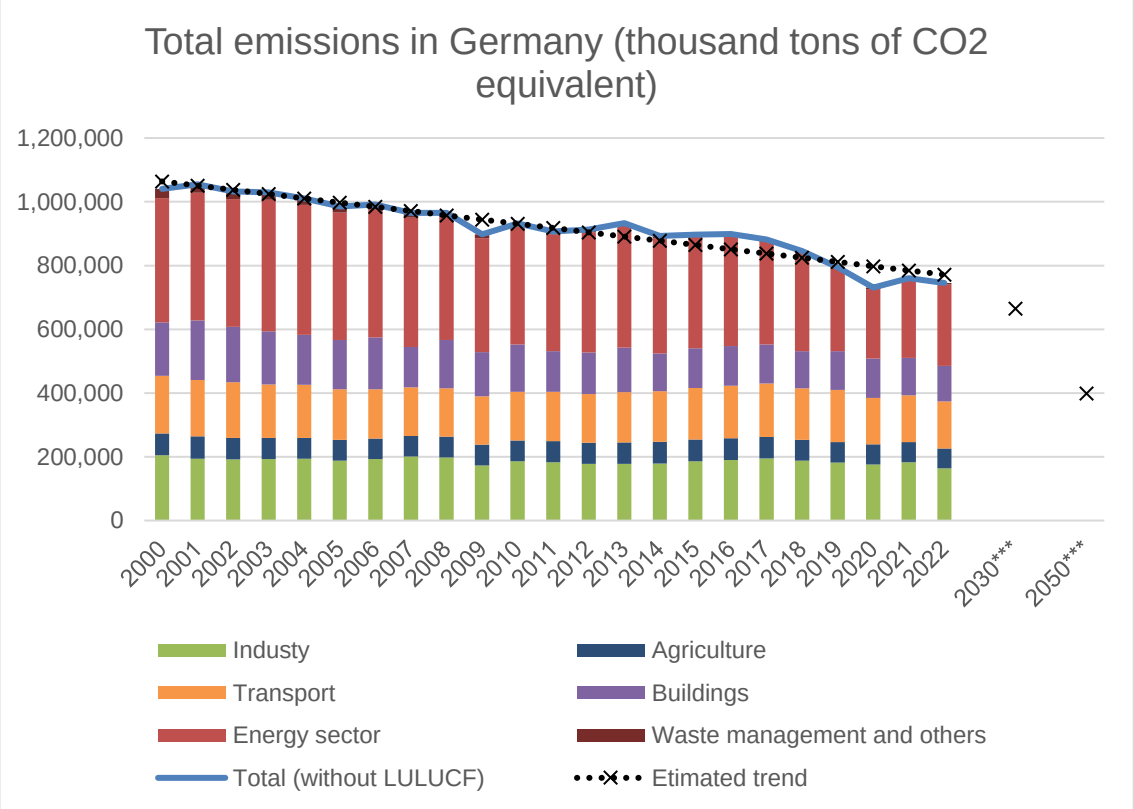

Figure 6. Total Emissions in Germany.

It is possible to see from the figure that the most significant influence on emission levels is caused by the energy sector. However, a declining trend in energy sector emissions is observed that is compliant with Germany's sustainability initiatives and policies. The total emissions level in Germany decreased by 28.3% between 2000 and 2022, from 1,040,191.8 Mt CO2e to 745614.4 Mt CO2e. With this, preliminary analysis suggests that if the current emissions trend continues total emissions in 2030 and 2050 may reach 665,106.8 Mt CO2e and 399,202.4 Mt CO2e respectively, which is likely to be higher than governmental targets for these years.

3.3 Environmental Consequences after changes in NG supply chains and infrastructure

The paragraph 3.3 focuses on Germany's crisis plan and shift towards LNG supplies as an alternative to Russian pipeline NG supplies. LNG presents a promising opportunity to secure the country's energy supply, however, there are concerns such as significant investments into LNG infrastructure and development of relations with new LNG suppliers. In addition, sustainability impacts caused by transition to LNG are discussed.

3.3.1 Shifting towards Liquified Natural Gas supplies

In the beginning of May 2022 Berlin announced the preparation of a crisis plan for stopping NG supplies from Russia (O' Donell 2022). It includes the following measures:

1. LNG import and use of non-Russian pipeline gas from Norway, Algeria and Azerbaijan.

2. Replacing NG by other energy sources such as renewables, including other dirtier alternatives such coal and oil.

3. Energy conservation and efficiency actions (Umbah 2022).

Germany's main focus shifted towards LNG supplies in order to improve its energy security. LNG – is liquefied natural gas, that has been cooled (−162°C) to a liquid state that makes it easier in storage and transportation in thermally insulated reservoirs. Compared to gaseous form, liquified NG has 600 times less volume (Waldholz, Wehrmann & Wettengel 2023). However, LNG solution creates challenges for Germany. Firstly, LNG undergoes re-gasification at LNG terminal before it is fed into existing gas grids and pipelines. This requires to adjust the gas network to be able to receive LNG from new directions. Secondly, the country has to find and build strong relations with new LNG suppliers (Kedziersky 2023a). Thirdly, even though the supplier relations are

established and infrastructure is built, it will take time for LNG supply to become stable. And lastly, it is yet to be seen how LNG affect the achievement of sustainability targets.

In February 2022 Germany announced its intention to build the first LNG terminals in Brunsbüttel and Wilhelmshaven. However, shortly the plan was extended to eight floating terminals, also known as Floating Storage and Regasification Units (FSRU) and three onshore ports. The figure below illustrates the plan of FSRU construction.

	Location	Type*	Operator	State support	Capacity per year, bcm		Start	Lifetime	Comment
					Min	Max			
1	Brunsbüttel	FSRU	RWE	X	5	5	2022	4	Chartered for 10 years
2	Wilhelmshaven	FSRU	Uniper	X	5	7,5	2022	10	Application for permanent operation
3	Lubmin	FSRU	Deutsche ReGas		4.5	6,5	2022	5	Application for permanent operation
4	Wilhelmshaven	FSRU	Tree Energy Solutions	X	5	5	2023	2	Chartered for 5 years
5	Lubmin	FSRU	RWE/Stena Power	X	5	7	2023	15	
6	Lubmin	FSRU	Deutsche ReGas		7	9	2023	5	Duration of charter unknown, conservative estimate
7	Stade	FSRU	Hanseatic Energy Hub	X	5	5	2023	3	Chartered for 15 years
8	Hamburg	FSRU	Hamburger Energiewerke	X	3.2	4	2023	10	
9	Wilhelmshaven	Onshore	Tree Energy Solutions		20	25	2025	20	
10	Brunsbüttel	Onshore	RWE/Gasunie	X	8	8	2026	20	
11	Stade	Onshore	Hanseatic Energy Hub	X	13	13	2026	20	

The maximum total capacity will be reached at the end of 2026. The sum of the average of the minimum and maximum capacity of the plants operating at that time is around 73 bcm.

Figure 7. FSRU construction plan. (Höhne, Marquardt & Fekete 2022a)

The country's primary importers such as RWE, Uniper and EnBW took proactive measures to diversify their LNG supplier portfolios and managed to sign new long-term contracts. Thus, RWE entered into contracts with the American Sempra Infrastructure company for an annual supply of 3 bcm starting from 2027. Uniper ensured agreements with the Australian Woodside company for an annual supply of 1 bcm from 2023. EnBW finalized contracts with the American Venture Global company for an annual supply of 2.7 bcm, with deliveries starting from 2026. Additionally, the American ConocoPhillips

company announced a collaboration with QatarEnergy, outlining plans for the supply of Qatari gas to Germany amounting to 2.7 bcm annually starting from 2026 (Kedziersky 2023b).

It is expected that investment into LNG terminals will not only secure Germany's NG supplies, but will also give an opportunity to the country to become the gas hub for Central Europe and increase its NG exports inside EU (Kedziersky 2023c).

3.3.2 Discovering FSRU's environmental issues

Although it seems that LNG and FSRU can help to solve the country's problems with gas supplies and energy security, there are rising concerns regarding fulfilment of Germany's sustainability targets. Firstly, the planned capacity of LNG terminals in Germany is 73 bcm per year which is oversized. This is 50% more than annual NG import volume from Russia which comprised 46 bcm per year. This potentially means that the consumption on NG may continue to increase that would undermine energy transition and further breaches Climate Action Act. In addition, high investments into LNG terminals will move the focus from environmental situation improvement towards the need to reimburse the significant cost of LNG infrastructure and earn the profit on LNG operations. In other words, there is a risk that LNG terminals might not be used as a temporary solution to enable energy security but will hamper transition towards alternative energy sources which would violate Germany's sustainability goals. According to New Climate Institute research, achieving Germany's climate targets with full operation of the planned terminals would be nearly impossible (Höhne, Marquardt & Fekete 2022b).

The decision of developing FSRUs contradicts Germany's national climate targets such as, for instance, the Climate Action Programme 2030 and the goal enshrined in the Climate Action Act. In addition, it breaches national legislation and international commitments under the Paris Agreement (Höhne, Marquardt & Fekete 2022c).

3.4 Sensitivity analysis of potential emission levels to changes NG share in prognosis primary consumption

The previous subsections showed that Germany is actively working on transition towards renewables to support its Energiewende policy, reduction of NG dependency and coal phase-out. In order to evaluate the impact of these changes in Germany's energy mix on future CO2 emission volumes, we develop a simplified model which links primary energy consumption to annual emission levels.

The model connects total GHG emissions in Germany expressed in thousand tons of CO2e (equivalent) to changes in levels and structure of primary energy consumption (PEC) reported for each year between 2000 and 2022. According to definition of EuroStat (2023), primary energy consumption represents the total energy demand of a country and it includes consumption of the energy sector, losses during energy transformation and distribution, and the final end-user consumption of energy. Information about PEC by fuel types for each year of the 2000-2022 period was collected from AGEB annual reports and from Umwelt Bundesamt (2023a) and aggregated into 5 key categories. These categories are the primary energy consumption of natural gas, hard coal, lignite, renewable energy, and mineral oil and other. The latter includes the sum of mineral oil consumption, nuclear energy, electricity exchange balance and other.

In assessment of total GHG emissions we rely on a method of analysis of fuel input as outlined, for example in LowTEMP project report (2020). According to the method, GHG emission from a combustible source can be estimated by multiplying the units of activity (energy) into fuel-specific default emission factors. Using this method, it is possible to express the total GHG emissions through equation below:

$$GHG\ emissions\ (MtCO2e) = PEC_{gas} \times EF_{gas} + PEC_{coal} \times EF_{coal} + PEC_{lign} \times EF_{lign} + PEC_{res} \times EF_{res} + PEC_{oil} \times EF_{oil}$$

where

PEC_{gas} is primary energy consumption of natural gas in PJ

PEC_{coal} is primary energy consumption of hard coal in PJ

PEC_{lign} is primary energy consumption of lignite in PJ

PEC_{res} is primary energy consumption of renewable energy (solar, wind, biomass) in PJ

PEC_{oil} is primary energy consumption of mineral oil and other in PJ

For the present analysis we use the default values of effective CO2 emission factors for natural gas, hard coal and lignite as provided in IPCC guidelines (IPCC 2006). Our emission factor for the category “mineral oil and other” is based on average default values of effective CO2 emission factors for crude oil (73 300 kg/TJ) from IPCC guideline. However, we assume slightly higher value (74 000 kg/TJ) for this category to account for additional emissions from other sources included in this category. Information on used emission factors is shown in the table 3.

Table 3. Emission Factors by type of fuel.

Fuel type	***CO2 emission factor (kg/TG)***
Natural Gas	56100
Hard Coal	98300
Lignite	101000
Mineral Oil	74000

It should be acknowledged that emissions estimated with this simplified approach may under and overestimate the actual emission levels from different fuel types due to use of aggregated consumption data and lack of information about actual sources included in each consumption category. The use of reference emission factors values is also a simplification. In addition, the emissions that are not associated with fuel combustion are not considered in the model. However, the obtained total emission estimates may still be considered as reasonable approximation of the actual total emission levels as

shown in the figure 8, where we compare the estimated emission levels with actual GHG emission levels as provided by Umwelt Bundesamt (2023b).

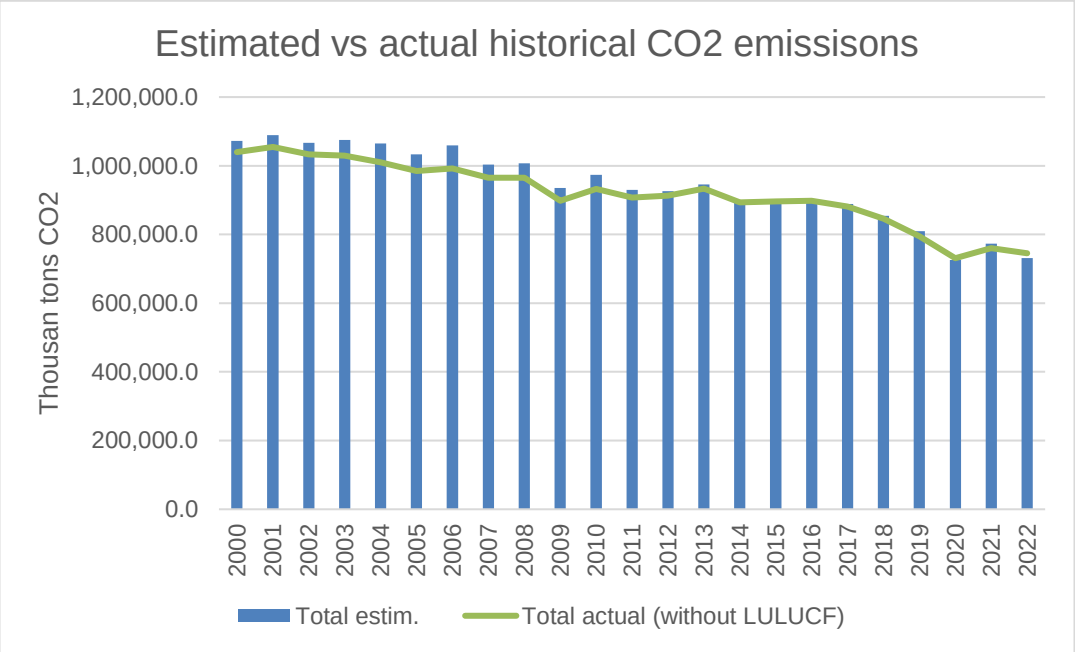

Figure 8. Estimated vs actual historical CO2 emissions

We rely on the prognosis of the development of primary energy consumption in Germany made by Agora Energiewende research "*Towards a Climate-Neutral Germany. Three Steps for Achieving Climate Neutrality by 2050 and an Intermediate Target of -65% in 2030 as Part of the EU Green Deal*". Agora Energiewende is an analytical center and policy institute based in Germany that focuses on the energy transition - "Energiewende". The research provides a scenario indicating that Germany has the potential to attain climate neutrality by 2050, along with a significant 65% reduction in emissions by 2030. This ambitious achievement depends on a substantial acceleration of Germany's climate initiatives. Agora Energiewende team describes the specific measures that Germany must undertake in its primary energy consumption sectors in order to realize its climate and sustainability objectives. Further in this paper we will refer Agora Scenario as base scenario.

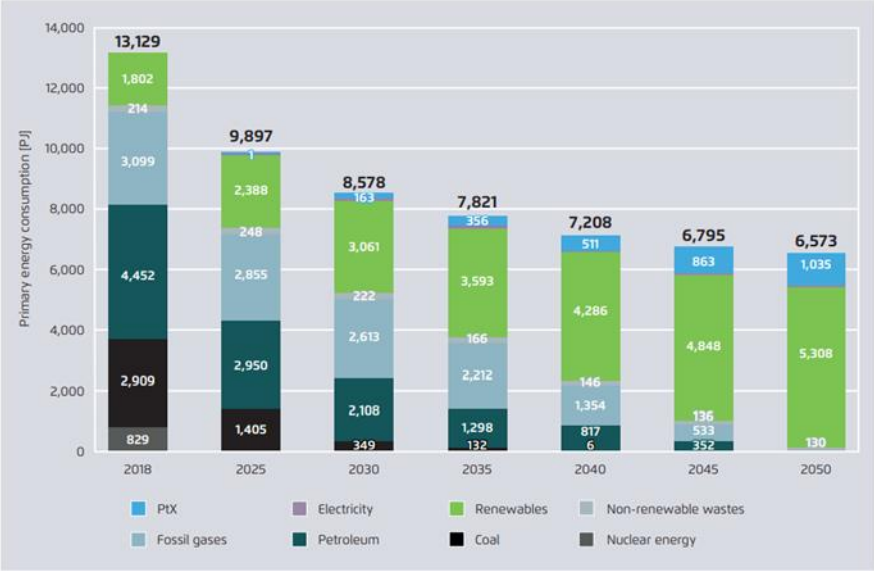

Figure 9. Base scenario for primary energy consumption development by Agora Energiewende.

Using the established connection between historical primary energy consumption and emission levels, we examine changes in prognosis emissions in Germany based on the base scenario primary energy consumption outlook. The figure below shows the estimated emissions between 2023 and 2050.

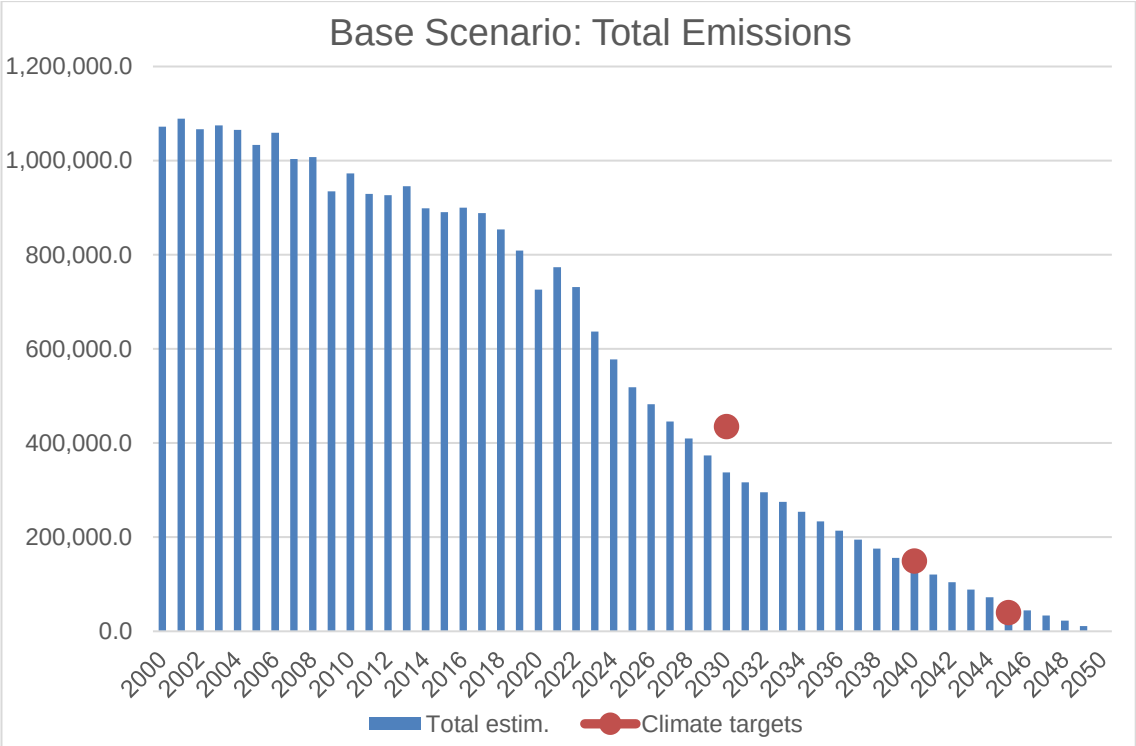

Figure 10. Base Scenario: Total Emissions.

As can be seen in the figure 10, Germany could reach its CO2 reduction targets if the base scenario is followed. The targets are: greenhouse gas neutrality by 2045, with intermediate targets of emissions reduction by at least 65 % by 2030 compared to 1990 levels, and 88 % by 2040.

However, it is important to note that emissions levels vary depending on type of fuel used in the energy mix. In order to see how sensitive prognosis emission levels are to changes in fuel use in primary energy consumption, we conduct a simplified sensitivity analysis.

One of the widely used definitions of sensitivity analysis belongs to Andrea Saltelli (2004). According to Saltelli sensitivity analysis is “the study of how the uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input” (Saltelli cited in Reed et al 2022). Sensitivity analysis involves studying how changes in the inputs of a system or model affect the outputs. The analysis helps to understand the sensitivity of the model's results to different factors and to identify which

variables have the most significant impact on the results and which ones are less influential. According to Pannel (1997), by conducting a sensitivity analysis it is possible to understand the behavior of the examined system under different circumstances. Sensitivity analysis includes two approaches such as local and global. Local sensitivity analysis zooms in on a specific point, providing detailed insights into local behavior, while global sensitivity analysis considers the broader picture, revealing the overall influence of input parameters throughout their entire range (Reed et al 2022).

In this work we apply the principles of local sensitivity analysis. We assume that total primary consumption and mineral oil and others remain unchanged and will follow a base climate action scenario, but we vary the amount of natural gas, coal (hard coal plus lignite) and renewables in the primary consumption mix. We tested 5%, 10%, 15%, 20% increase and 5%, 10%, 15%, 20% decrease in NG use in primary consumption over 2023-2050, assuming that coal and renewable energy sources would cover the residual primary energy consumption. Then we repeat the same percentage increase and decrease test for coal and renewables. We estimated changes in total CO2 emissions over 2023-2050 in each run. The results of sensitivity test are shown in the figure below.

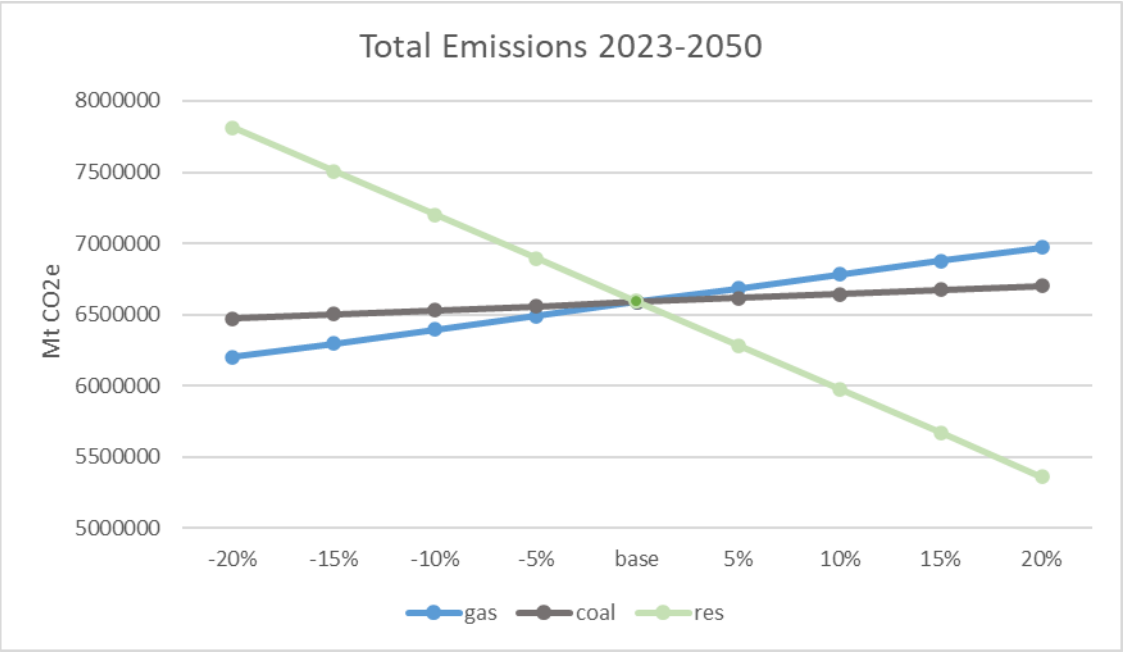

Figure 11. Sensitivity of emissions to changes in PEC assumptions.

After that we estimated sensitivities of changes in total CO2 emissions to changes in each parameter. Sensitivity index is estimated in accordance with Hoffman & Garder (1983) as the difference between maximum and minimum total emissions divided by maximum total emissions obtained in sensitivity test. The results are presented in the table below.

Table 4. Sensitivity analysis results.

Parameter	*Case*	*Total CO2 2024-2050*	*Sensitivity Index*
Gas	**Base**	**6,587,887.9**	**0.11**
	max	6,973,606.7	
	min	6,202,168.9	
Coal	**Base**	**6,587,887.9**	**0.03**
	max	6,702,168.5	
	min	6,473,607.2	
RES	**Base**	**6,587,887.9**	**0.31**
	max	7,812,217.2	
	min	5,363,558.5	

According to the results of sensitivity analysis the highest impact (highest sensitivity index 0.31) on emissions is caused by changes in renewables. At the

same time changes in coal do not have a significant effect on the total emissions level. It can be concluded that renewables amount is the most influential factor on prognosis emissions level.

3.4.1 Scenario Analysis of Germany's sustainability targets

We conducted alternative analysis to understand how deviations in primary energy consumption mix would affect the achievement by Germany of its sustainability targets.

In our scenario we assumed that Agora Energiewende scenario renewable growth rates are too optimistic and actual renewable rates will be lower. This assumption is motivated by results of The New Climate Institute team research, mentioned in chapter 3.3.2, concluding that transition to LNG and, as consequence, larger investments into construction of LNG terminals will cause increase in NG consumption and lower investment in renewables. In other words, Germany will move its focus from sustainable technologies expansion to LNG terminals development. Therefore, we continued the historical trend of renewables without accelerated increase. We assumed that missing primary energy consumption needs will be covered by gas over the entire forecast horizon. At the same time, the coal phase-out follows its initial plan – coal phase-out is completed mostly by 2038.

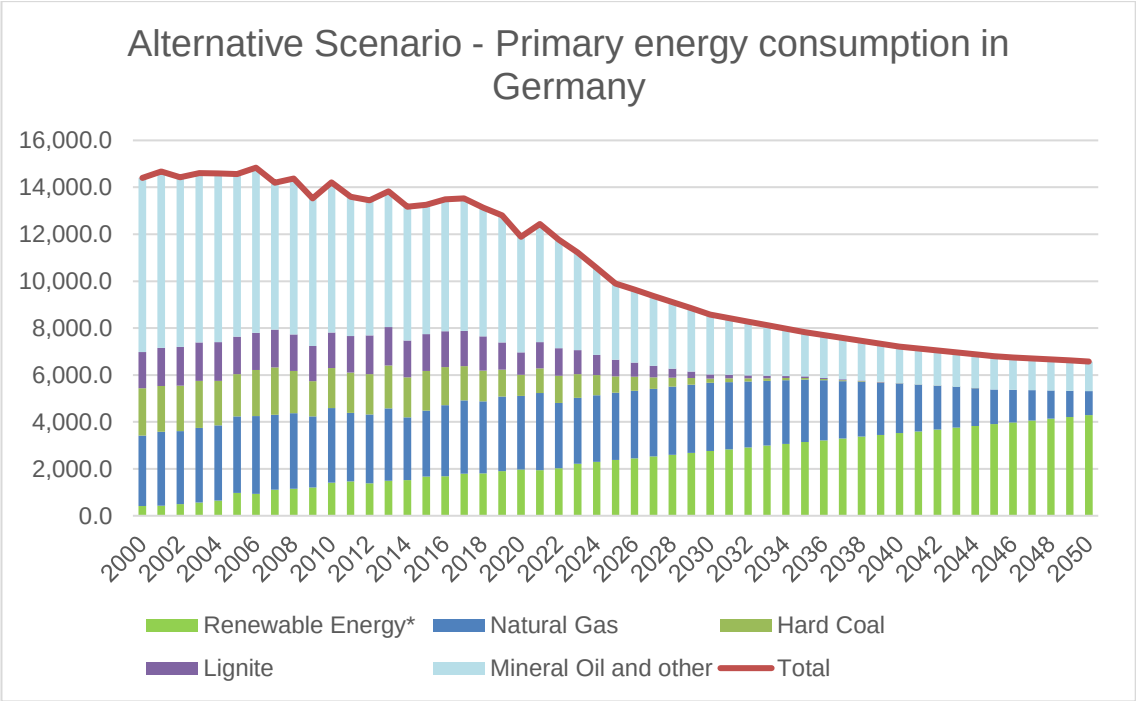

Figure 12. Primary energy consumption according to alternative scenario.

In the alternative scenario renewables reach 2757.6 PJ in 2030, and in 2045 they will reach 3904.4 PJ. This is 10% and 19% lower than proposed by the basic scenario. The resulting NG consumption grows to 2,916.4 PJ in 2030 and it will remain about 1,476.6 PJ in 2045 which is nearly three times higher than suggested by Agora Energiewende in its 2045 climate neutral scenario. This means that Germany continues using NG longer than expected and this would result in higher level of future emissions. The table below shows estimated emissions level in the alternative scenario.

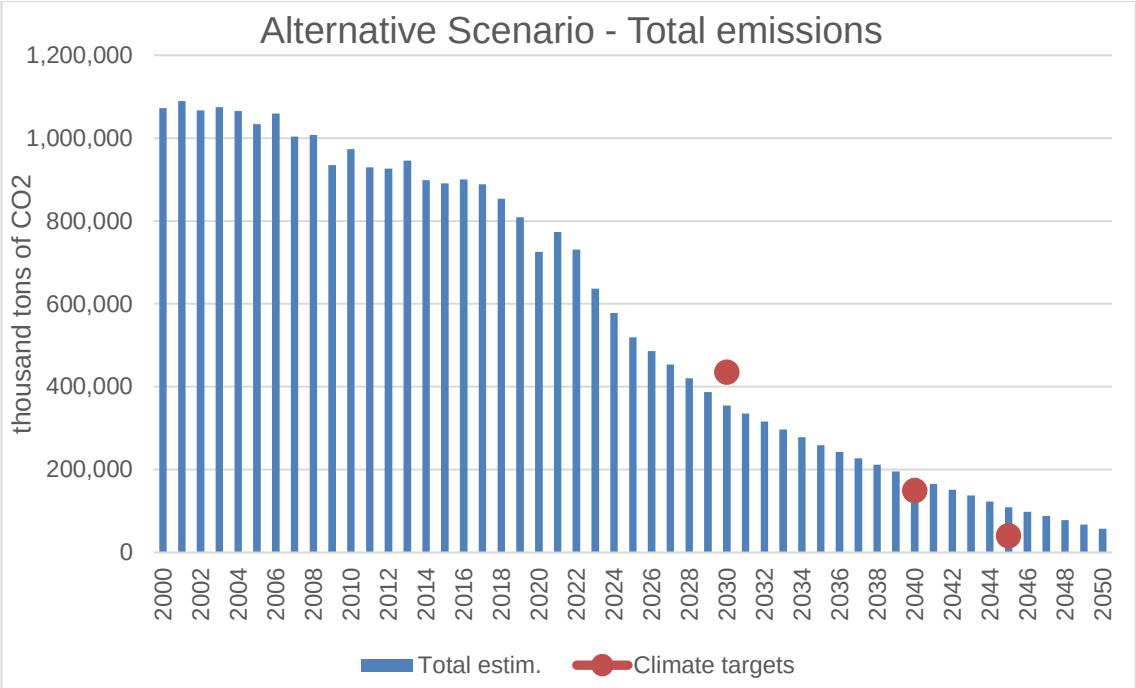

Figure 13. Emissions level in the alternative scenario.

In our scenario total emissions will reach 354,377.4 Mt CO2e in 2030 and 108,882.5 Mt CO2e in 2045 correspondingly. This is about 20% below the emission target 2030, but more than two times higher than emission level in climate target in 2045. This means that Germany possibly will not reach its sustainability targets by 2045 without accelerated growth of renewables and continuous use of natural gas.

4 Conclusion

Being an industrial giant that is highly reliant on natural gas as its primary energy source, Germany received a lot of attention after February 2022 when it announced about termination of cooperation with its biggest natural gas supplier – Russia. There were rising concerns whether Germany’s economy will survive in these complex circumstances. At the same time Germany's energy transition policy and its commitment to sustainability faced a critical test.

The analysis of the country's ambitious targets, as outlined in various policies and international agreements, reflects a profound dedication to mitigating

climate change and achieving a climate-neutral future. Germany’s approaches to phasing out coal and natural gas underline the complexities of balancing energy security, environmental impact, and climate goals.

However, the incorporation of LNG into the energy crisis strategy prompts concerns regarding its alignment with Germany's sustainability objectives. While driven by the urgent requirement for energy security, the decision to invest in ambitious LNG terminal projects necessitates careful evaluation. Despite addressing immediate energy needs, the substantial investments in LNG terminals and long-term contracts could potentially hinder the progress of renewable energy projects, receiving less funding than initially intended. This has the potential to hamper the pace of renewable energy development, deviating from the overarching goals of Energiewende and Germany's global climate commitments.

In navigating these challenges, Germany stands at a crossroads where economic considerations overlap with environmental responsibilities. The decisions made in response to the natural gas supply crisis will not only shape Germany's energy landscape but also determine its position as a leader in sustainable practices. The envisioned shift towards LNG underscores the complexity of balancing immediate energy needs with the imperative of fostering a resilient, low-carbon future.

This thesis develops a model for analyzing potential impacts of Germany’s deviation from its sustainability path due to possible favoring of NG in the country’s PEC over the 2023-2050 period on forecast total emission levels. The model sensitivity analysis results suggest that even if the overall forecast PEC target levels will be followed according to the government plans, variation in future renewable production levels have the most critical impact on achieving Germany sustainability goals.

The model was applied for testing scenario in which Germany reduces investments in RES to allow for longer use of LNG in the PEC to repay a higher

share of investments made in LNG terminals during the energy crisis. It was assumed that RES development would continue but it would not exceed the growth levels seen during the last 20 years.

The results suggest that in such a scenario, Germany most likely will not reach its proclaimed sustainability targets 2045 although intermediate targets 2030 and 2040 may not be completely unreachable. There is a risk that in case of lower RES development, the 2045 emission levels will be near their times higher than the targeted 40 000 MtCO2e and only by 2050 Germany will approach closer to its 2045 targets with total emission levels of 57 300 MtCO2. This may suggest that if such scenario is realized, Germany would see about a 5-year delay in implementation of its sustainability targets.

The envisioned LNG terminals, while addressing immediate concerns, must be critically evaluated to ensure they complement, rather than hinder, the long-term transition to renewable energy sources. It is crucial for Germany to remain steadfast in its commitment to sustainability, considering the potential risks and benefits associated with its evolving energy strategy. The thesis has explored the intricacies of Germany's energy landscape, and the conclusion draws attention to the need for a delicate balance between energy security and sustainable practices.

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Appendices

Appendix 1: Porter 5 Forces analysis

PORTER 5 Forces analysis was used in this paper to analyse NG industry on domestic level and describes existing challenges and opportunities on the NG market for its suppliers and consumers. Porter's Five Forces is a tool for analysing a certain industry through so-called five forces perspective. Those forces are: threat of new entrants, bargaining power of suppliers, bargaining power of buyers, threat of substitutes and industry rivalry. The tool analyses what effect on competition and performance as well as it recognizes weaknesses and strengths of a company withing a certain industry (Investopedia 2023).

Threat of New Entrants:

There is intense competition in the industry between key NG importers and operators. The natural gas industry in Germany has significant barriers to entry as the field is highly regulated by the Federal Network Agency (Bundesnetzagentur) (BNetzA) and the federal-state regulatory authorities. This is due to NG serves as the dominant energy source in the country, and basically all sectors and industrial fields are highly dependent on it. For the new entrants this means the need for specialized knowledge and expertise as well as high initial investment to entry NG market in Germany. In addition, due to energy transition policy Enregiewende, new entrants will have to comply with safety and environmental regulations. This strictly obliged companies to follow all controlling acts and lows and to be able to report their compliance.

Conclusion: Threat of new entrants is low due to the state of competition, environmental regulations compliance, and capital requirement. The environmental regulations and Energiewende might influence the industry's operational practices and investments in emission-reduction technologies

Bargaining Power of Suppliers:

As it was mentioned already, Germany is highly dependent on NG gas supplies. In NG field countries that owes this energy source are suppliers for those that needs it. Germany major supplier countries were Russia, Norway, and the Netherlands. In other words, Germany's NG importing and operating companies are highly dependent on their supplier – a country that owes NG reserves. NG suppliers' power is in ability to control prices or restrict the availability of natural gas. In 2022 due to political tension and sanctions against Russia, Germany is experiencing sharp shut downs of NG supplies. This significantly effected on energy prices increase. However, if Germany finds another reliable NG supplier that would fulfil the need in this source of energy, the situation can stabilize.

Conclusion: The suppliers have high power over its consumers (Germany's NG operators) and can control NG availability and prices. NG operators must establish strong relationships with their suppliers, develop back up plans for emergency situations such as supply shut downs and look for alternative suppliers and options.

Bargaining Power of Buyers:

The main buyers or consumers of NG in Germany are industrial and residential sectors. The large industrial consumers, such as chemical and manufacturing companies, have relatively higher buying power due to their NG consumption - 31,2% of total country's NG consumption (DE Statistics 2022a). In 2018 the noticeable decrease in NG consumption was observed due to reduction of NG demand in chemical industry. This proves that chemical industry demand in NG has significant influence on Germany's overall NG demand.

However, residential and small commercial customers have limited options and are more dependent on the existing infrastructure, that limits their buying power. Especially the households that were equipped with gas powered heating

systems have the lowest buying power. In 2019 41.2% of households used NG as a main energy source especially for heating purposes. (DE Statistics 2022b)

Conclusion: Bargaining power of buyers depends on type of consumer. The manufacturing giants have influence and power over consumption compared to household owners that are more dependent on energy supply operators.

Threat of Substitutes:

Germany aims to reduce its dependence on fossil fuels, including natural gas as a part of its energy transition policy – Energiewende. According to Energiewende, the country aims to fulfil all its electricity needs with energy supplies from renewable sources by 2035. It is expected that the share of wind or solar power should reach 80% by 2030 (International Trade Organization 2022).

In addition, development of green gases, such as hydrogen or biomethane, might change the landscape of the natural gas industry (IEA 2023).

Despite NG is likely to be substituted by greener options due to Germany's sustainability initiatives, there are dirtier alternatives to NG that are also used. Thus, for instance, Germanys' chemistry market giant Evonik attempted to substitute natural gas with LPG (liquified petroleum gas) and coal (Evonik 2022).

Conclusion: The threat of substitutes is quite high due to Germany's activities in renewable energy sources transition, such as wind and solar power on the one hand. On the other hand, there are also attempts of temporarily NG substitution with coal and LPG.

Appendix 1

Industry Rivalry:

The natural gas industry in Germany faces competitive rivalry among several gas importers and facility operators such as Uniper, RWE and EnBW/VNG. Competition is driven by the presence of established utilities, regional gas companies, and independent gas traders. However, the NG market in Germany is liberalized. This means that none of the companies, which pursue generation activities, can influence electricity prices on the wholesale market by using their market power (Next Kraftwereke 2023). This allows fare competition and market-driven pricing for consumers. However, the level of competition might vary across regions, with more competition in densely populated areas and less in remote regions.

Conclusion: NG industry rivalry in Germany is under marked liberalization that allows fare competition among all market players. correct.