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Nuclear Energy Reconsidered: Germany's Post-Crisis Dilemma

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ABSTRACT

The Russia-Ukraine war has triggered widespread disruptions and long-term consequences in international trade, accompanied by significant political and legal ramifications. Energy has emerged as a primary concern. Russia's substantial share of the European Union's natural gas imports, coupled with its utilization of energy as a geopolitical weapon, has precipitated a severe energy security crisis for European nations, particularly Germany. This study investigates the responses and policy decisions undertaken by the German government since the onset of the war, with a focus on enhancing energy security and self-sufficiency. Within this context, the long-term objective of utilizing renewable energy as the primary source for total energy consumption, a cornerstone of German energy policy for many years, has been critically examined in terms of its effectiveness in ensuring energy security. Furthermore, the study explores alternative pathways to address the precarious energy security environment created by the heavy reliance on imported fossil fuels. In this regard, nuclear energy, which was phased out of German energy policy in the 1980s, has been re-evaluated as a potential solution to Germany's current energy predicament. The study concludes that nuclear energy, like natural gas in the past, could serve as a bridge towards transitioning from fossil fuels to renewable energy sources, thereby bolstering Germany's energy security. Additionally, the study finds that Germany's prioritization of environmental concerns over security in its energy policies has contributed to national energy supply security challenges, as exemplified by the Ukraine crisis.

1. Introduction

Energy is a fundamental input that increases economic development, welfare and national security. Providing energy resources from domestic sources or diversifying import countries significantly enhances energy supply security and thus national security. As an industrialized country, Germany is a country that needs energy, especially in sectors such as industry and transportation. Recognized as a global role model in renewable energy utilization, Germany has pursued a low-carbon future since the 1970s. In the 1990s, Germany's energy supply faced significant disruptions, primarily due to the privatization of coal mines in the former East Germany, the closure of inefficient electricity companies, and a decline in employment within the energy sector (Boehmer-

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Christiansen1992). Throughout the 2000s, energy supply remained relatively stable. Until 2010, fossil fuels—especially coal and lignite—accounted for approximately half of electricity generation in Germany's energy mix, while nuclear energy constituted a significant portion of the remainder. However, starting in the early 2010s, the share of renewable energy sources increased rapidly in line with Germany's *Energiewende* (energy transition) [1] targets, while nuclear energy's role declined accordingly. According to BMWK data (BMWK, 2021), between 1990 and 2020, Germany's energy mix shifted from a coal-dominated structure to a more diversified model, with the share of renewables rising from less than 5% to approximately 45%.

This shift began in the late 1990s, supported by legal frameworks that accelerated the integration of renewables. This legal framework and subsequent decisions enabled Germany to make rapid progress in renewable energy. During this period, German policymakers developed exemplary tools that fostered both national renewable energy consumption and provided a model for other countries seeking to increase their renewable energy share. When Germany's energy landscape is analyzed over the last four decades, it is observed that it has shifted from coal and oil dependency to a more diversified energy mix. This rapid diversification began with the Energiewende initiative presented in the early 1980s (Gailing & Moss, 2016). Energiewende provides a roadmap for how political decision-making and public institution dynamics should be reshaped, particularly in the transition from fossil fuels to clean energy and the reduction of coal and nuclear power. The main reason for this strong focus on renewables in the energy transition is the desire to gradually remove nuclear energy from the energy mix. Public attitude towards nuclear energy has undergone significant transformations in the history of German energy policy.

Since the 1980s, compared to many other European countries, the German public has been significantly more cautious about nuclear energy. While nuclear energy enjoyed strong public and political support in the 1950s and early 1960s, concerns about its safety and environmental impact began to emerge in the late 1960s and early 1970s. However, the situation changed in the 1980s, and a group of people with serious concerns about nuclear energy began to emerge. Although the Chernobyl nuclear power plant disaster in 1986 did not significantly reduce the use of nuclear energy in Germany, it did cause a significant decrease in political and social support for nuclear energy. Indeed, after the Fukushima disaster in 2011, the public debate on nuclear energy shifted significantly, with a marked decline in political and social support for its continued use. Thus, the foundations of Germany's path from an industrial power dependent on coal, oil and nuclear energy to becoming a pioneer country in turning renewable resources into primary consumption were laid in the second half of the 1980s. In fact, the Fukushima disaster had a major impact on the acceleration and direction of Germany's Energiewende plan (BMU & BMWi, 2011).

Germany has elevated its energy transformation goal by announcing a long-term carbon neutrality target for 2050. In this context, low-carbon and environmentally friendly energy policies were quickly put into effect. Additionally, Germany, as a party to the Paris Agreement, has committed to reducing carbon emissions by 40% by 2030. With the advances made in energy over time, Germany has increased this rate by implementing stricter climate policy regulations in 2021 and has announced that it aims to reduce carbon dioxide emissions by 65% compared to 1990 and reach zero carbon emissions by 2045 (FMER, 2022). In addition, Germany aims to increase the share of renewable energy sources in the total energy mix to 80% by 2050. In Germany, fossil fuels are projected to account for 57.6% of total electricity consumption in 2023, while renewable energy sources are expected to account for 42.4%. In terms of local energy resources, renewable energy sources are projected to hold the largest share, reaching 57.7% (Energy Institute, 2023). Germany has long positioned itself as a leader in environmental policy (Jänicke, 2010).

Russia's attempt to militarily seize Ukraine, which began in February 2022, and the subsequent use of energy resources as leverage against European countries, have

[1] The "Energiewende" (energy transition) refers to Germany's long-term plan to shift away from fossil fuels and nuclear power towards renewable energy sources.

been a turning point for German energy policies. In the initial stages of the crisis, many German politicians believed that Russia's decision to cut off natural gas supply would serve as a catalyst for accelerating Germany's transition to clean energy.

However, achieving a fully renewable energy system in the short term remains challenging due to social, economic, and infrastructural constraints, including supply chain disruptions, regional disparities in grid infrastructure, and local opposition to large-scale renewable energy installations. The situation becomes even more complicated when considering Germany's policy of using imported Russian gas as a bridge fuel in the transition from fossil fuels to clean energy, despite its environmental impact. Notably, current data indicate that despite Germany's irreplaceable position in combating climate change and environmental pollution, it falls short of its target of reducing carbon emissions by at least 65% below 1990 levels by 2030 (Adedoyin, Erum, Taşkin, & Chebab, 2023). Countries affected by the crisis, particularly EU member states, face a critical policy dilemma: prioritizing national energy security or accelerating the clean energy transition. This dilemma presents significant consequences for Germany, where the choice between focusing on renewable energy investments and the energy transition versus supporting nuclear and coal-fired electricity generation carries significant implications. At this point, the Energiewende is therefore fundamentally framed as a conflict between the potential risks of nuclear energy use, the negative climate impact of fossil-based energy, and the installation costs and instability of renewable energy. For Germany, this conflict was previously resolved with the energy transition policy, which aimed to gradually replace fossil fuels and nuclear energy with renewable energy. As part of this policy, Germany is continuing to gradually close its nuclear power plants. This is part of the policy of elevating renewables to the level of primary energy source in the energy mix (Beveridge & Kern, 2013). However, various analyses over time have shown that Germany's goal of reducing carbon emissions by 95% by 2050 is difficult and costly in a scenario where the use of nuclear and coal-based fuels is completely phased out (Bohdanowicz, Łopaciuk-Gonczaryk, Gajda, & Rajewski, 2023). Therefore, there are increasing calls for Germany to reconsider its policy of phasing out its existing nuclear power plants and phasing them out completely in the future (Financial Times, 2021).

After the Ukrainian crisis, European countries, especially Germany, have faced challenges such as energy becoming a national security issue, ensuring energy security and re-evaluating fossil fuels considering carbon neutrality policies. The sudden disruption of natural gas supply and the inadequacy of installed renewable electricity capacity to meet energy demand have brought nuclear energy back into the spotlight. Nuclear energy currently meets approximately a quarter of Europe's electricity needs. Increasing this share will require strong political and public support, as well as a comprehensive regulatory and legal framework and significant financial support. Nuclear energy offers a clean and stable energy source that can meet a significant portion of total electricity demand once it is operational. For Germany in particular, restarting nuclear energy could serve as an important, albeit short-term, option to both decarbonize the energy sector and enhance energy security during the transition (Bohdanowicz et al., 2023). Therefore, all these factors should be evaluated with importance by all institutions.

This study examines how the Ukraine crisis has reshaped Germany's energy policy priorities, particularly the reconsideration of nuclear energy as a transitional solution.

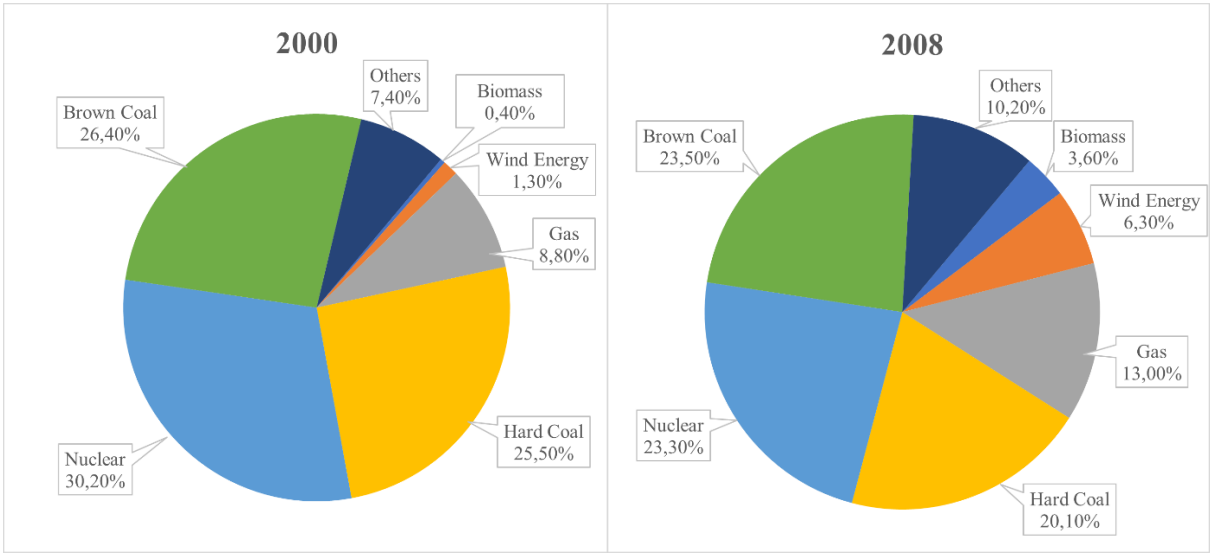
2. Germany Energy Outlook Before Ukraine Crisis

Germany has played a leading role in clean energy investments globally and was one of the first countries to address the concept of energy security at a national level. Germany's renewable energy policies began to take shape in the 1950s. In the following years, support for the energy issue was provided at a national level through studies and R&D investments. In terms of financial support, the government invested 10 million German marks (DM) in renewable energy within the scope of R&D projects initiated by the Ministry of Research and Technology in 1974. Later, in 1977, the German government developed an incentive system providing 25% investment support covering solar panels and geothermal heat pumps. By 1982, a total of

approximately 150 million DM had been invested in renewable energy projects (Gasser, Pezzutto, Sparber, & Wilczynski, 2022; Mez, 2005). Public pressure in the 1970s and 1980s prompted the government to invest heavily in renewables, leading to Germany's early leadership in this fiel

Despite these early successes, many politicians and industrialists remained skeptical about the potential of renewable energy to become a major source of electricity in the future (Hake, Fischer, Venghaus, & Weckenbrock, 2015). While a small portion of electricity generation came from green sources in the early 2000s (Bechberger & Reiche, 2004), Germany maintained its position as Europe's largest market for solar and wind energy throughout the 2000s (Barroso & Iniesta, 2014). Despite this strong progress in renewables, the share of coal and nuclear energy remained significant in Germany's energy mix in the early 2000s. Notably, discussions surrounding the role of nuclear energy continued within the Angela Merkel government from 2005 onwards, albeit with a more cautious approach. In 2010, the Merkel government announced the "Energiekonzept," a strategic plan to raise the renewable share to 20% by 2020 and reduce emissions by 40% from 1990 levels. As seen in Figure 1, the percentage of wind energy in total energy consumption increased from 1.30% in 2000 to 6.30% in 2008. Similarly, photovoltaic (PV) capacities experienced rapid growth; annual installations nearly tripled between 2004 and 2009, and in 2008, Germany accounted for 42% of the global PV market (REN21, 2009). In this sense, the chart reflects Germany's determination in the transition to renewable energy and its rapid growth in this area. Conversely, during these years, public concerns over nuclear safety and political pressure for a nuclear phase-out led to a decrease in the share of nuclear energy in electricity generation, falling from 30.20% in 2000 to 23.30% in 2008. These dynamics highlight the fundamental tensions and strategic orientations that shaped Germany's energy landscape prior to the Ukraine crisis.

Figure 1: *Gross electricity production in Germany in 2000 and 2008*



Source: *Frondel, et all. (2010).*

Germany launched the Energiewende with the aim of reducing CO_2 emissions and global temperature increase, and subsequently strengthened its commitment to these targets by signing the Paris Agreement in 2015 (UNFCCC, 2015). Germany's significant progress in increasing the share of green electricity in its energy mix has led to its recognition as an important role model for other European countries. This recognition stems from the fact that Germany has exceeded its initial 2010 renewable energy targets (Frondel et al., 2008). In fact, when looking at the data for this period, the share of renewable electricity in total electricity consumption in EU countries increased from 14.3% in 2004 to 25.4% in 2013, while in

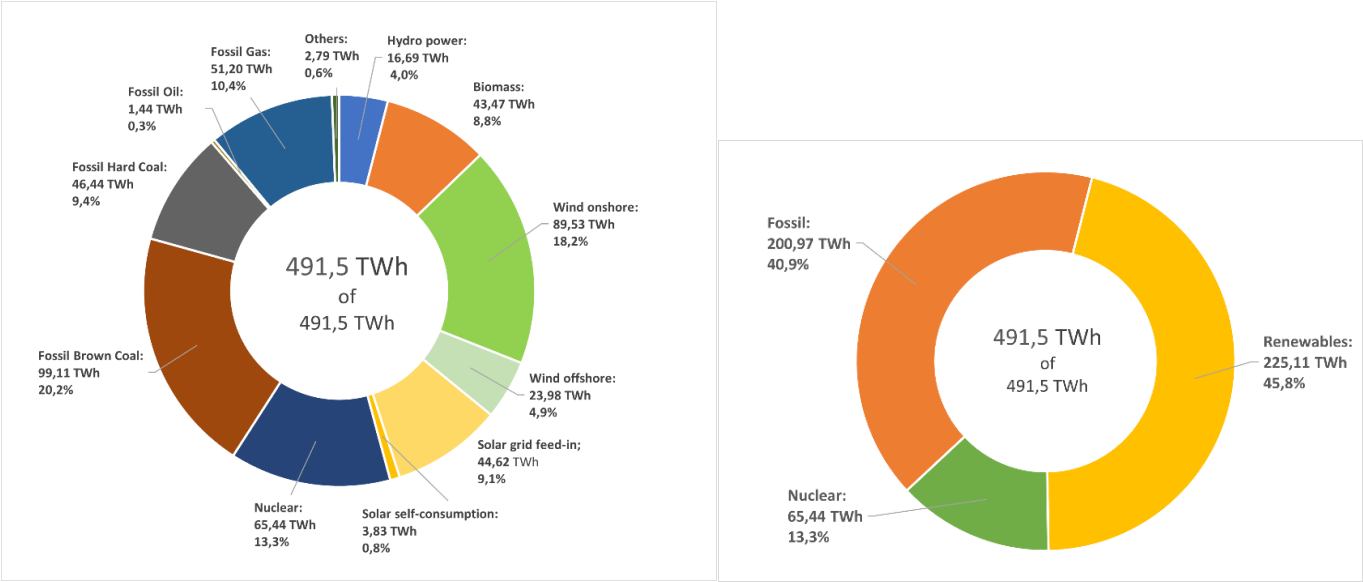
Germany it increased from 9.3% to 25.4% in the same period (Strunz et al., 2016).

Similar developments took place internationally, for example, at the Bonn Climate Conference in 2017, the 'Better Power than Coal Alliance' (PPCA) was established, which promised to put an end to the continued use of coal for power generation in OECD countries by 2030 at the latest (PPCA, 2017). Subsequently, the German government established a stakeholder commission on 'growth, structural change and employment' (later named 'Coal Commission') in 2019, which stated that coal should be phased out by 2035-2038 (BMWİ, 2019). In addition to these targets, Germany aims to significantly reduce carbon emissions by 2030 in line with the Paris Agreement's goal of limiting global warming to well below 2°C above pre-industrial levels, with efforts to pursue the 1.5°C target. In the following years, Germany has made it a policy priority to import natural gas as an alternative to coal. In 2020, natural gas accounted for 26.4% of Germany's total energy mix, while oil consumption remained the highest at 34.3%. Renewable energy sources contributed 10.4% to the energy mix (Halser & Paraschiv, 2022). Germany, which had a 55% import share in its natural gas supply in 2020 (BP, 2021), developed a significant dependence on Russian natural gas, with imports reaching 46 billion cubic meters (bcm) by 2021 (BMWK, 2021).

Furthermore, natural gas is considered a less carbon-intensive fossil fuel compared to coal, emitting approximately 45% less CO_2. Therefore, while natural gas is considered a transition fuel, investments in this area may not be fully aligned with the EU's long-term zero-carbon targets (Directorate-General for Financial Stability & Financial Services and Capital Markets Union, 2022). Natural gas, which had an industrial consumption share of 37.2% in Germany in 2021, is applied in diverse industrial processes, mainly for process heat. At the household level, a heavy dependence on natural gas has emerged over time. The biggest challenges in alleviating the gas supply crisis in Germany include heavy dependence on imports, rising energy prices, and the limited availability of alternative energy sources to quickly replace natural gas.

Notably, Germany's financial burden from natural gas imports nearly doubled between 2020 and 2021, surging from 18.3 billion euros to approximately 35.4 billion euros. The significant percentage of natural gas in Germany's energy consumption and its import dependency are relatively high compared to neighboring countries. For example, in France, the share of natural gas in total consumption is only 16%. The main reason for France's lower reliance on natural gas is its significant reliance on nuclear power, which accounts for more than half of its total electricity generation (Eurostat, 2022). Unlike France, Germany has long adopted an energy policy of phasing out nuclear energy and has increased its dependence on natural gas over time.

Figure 2: *Net public electricity generation in Germany in 2021.*



Source: *Fraunhofer, 2022.*

As shown in Figure 2, Germany's net public electricity generation in 2021 provides key insights into its energy situation right before the main impact of the Ukraine crisis. While renewables continued to grow strongly, coal and natural gas still made up a significant portion of the electricity mix. This highlights the ongoing challenge Germany faces in balancing its ambitious decarbonization goals with the need for energy supply security, especially given the geopolitical risks tied to its heavy reliance on natural gas, particularly from Russia.

In compliance with the programming of AG Energiebilanzen, the annual proportion of total gross electricity output, together with power plants operating in the mining and quarrying industry is about 41.8%. Regarding nuclear energy, accounted for 65.44 TWh in 2021, corresponding to 13.3% of total public electricity production. This production level for nuclear power was around 7% higher than the earlier year (60.9 TWh). The low production in 2020 was a result of power interruptions at the Gundremmingen C power plant. Additionally, the fuel arrangements at the Brokdorf and Gundremmingen C nuclear power plants, which were scheduled to cease operations on December 31, 2021, were not altered in 2021, effectively extending their operational lifespan (Fraunhofer, 2022, p. 202).

3. Changes in German Energy Policy After the Ukraine Crisis

The radical changes in Germany's energy policies following the Ukraine crisis have raised the question of whether renewable energy alone will be sufficient to achieve the country's long-term energy security and sustainability goals.

3.1. *Crisis Impacts on Energy Security and Economy*

The war in Ukraine has significantly impacted the reliance of European countries on Russian energy. This challenge has also brought a major economic burden on countries dependent on Russian gas. Moreover, the migration of more than 3 million Ukrainians to the region (with over 1 million seeking asylum in Germany) may have contributed to an increase in energy demand, potentially adding to the current economic burden. Between February 2021 and 2022, the price of natural gas rose significantly, reaching levels between €20 and €80/MWh. These price increases have also driven up electricity prices, with some reaching as high as €180/MWh (Heather, 2022).

Germany imports approximately 60% of the energy it consumes. Notably, Germany is significantly dependent on Russian energy. Specifically, approximately 50% of Germany's gas and coal imports and approximately one-third of its oil imports are imported from Russia. The aggregate value of goods imported by Germany from Russia in 2021, inclusive of diverse product categories, reached 33 billion euros. While this represents a significant volume of trade, Russia's contribution to Germany's total trade activity remains relatively limited, constituting merely 2.3% (Bachmann et al., 2022). The current crisis has raised concerns about potential economic consequences including potential industrial shutdowns and a significant increase in energy poverty. Soaring energy costs are posing a severe challenge for many households (Politico, 2022).

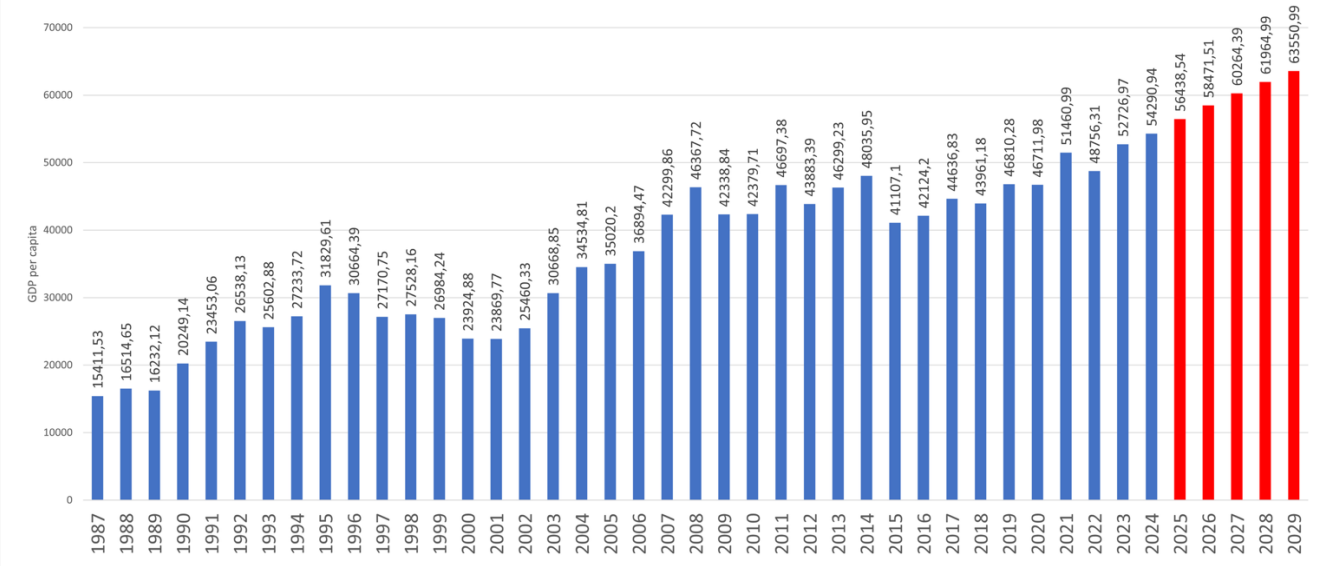
In a speech to parliament, German Deputy Chancellor and Minister of Economic Affairs and Climate Protection Robert Habeck highlighted the main consequences of Russia's 2022 war against Ukraine on German energy discussion and policies.

> *"In the past, we were blind to the fact that energy and energy policy are not just economic issues, but also geopolitics and, in this case, power politics" (Wiertz,2023).*

This statement underscored a significant shift from Germany's historical approach, where energy politics primarily viewed energy as an environmental and economic issue. Public opinion primarily focused on the environmental aspects of energy policy, which influenced many of the government's decisions, particularly concerning nuclear energy. Europe's geopolitical position has exacerbated the impact of this crisis, with the consequences manifesting rapidly and clearly. Consequently, European countries have taken rapid measures and political actions to eliminate problems caused by energy supply security and to ensure stability of the current political and economic climate.

The sudden disruption of Russian gas imports has underscored the high level of uncertainty surrounding Germany's economic outlook (Krebs, 2022).

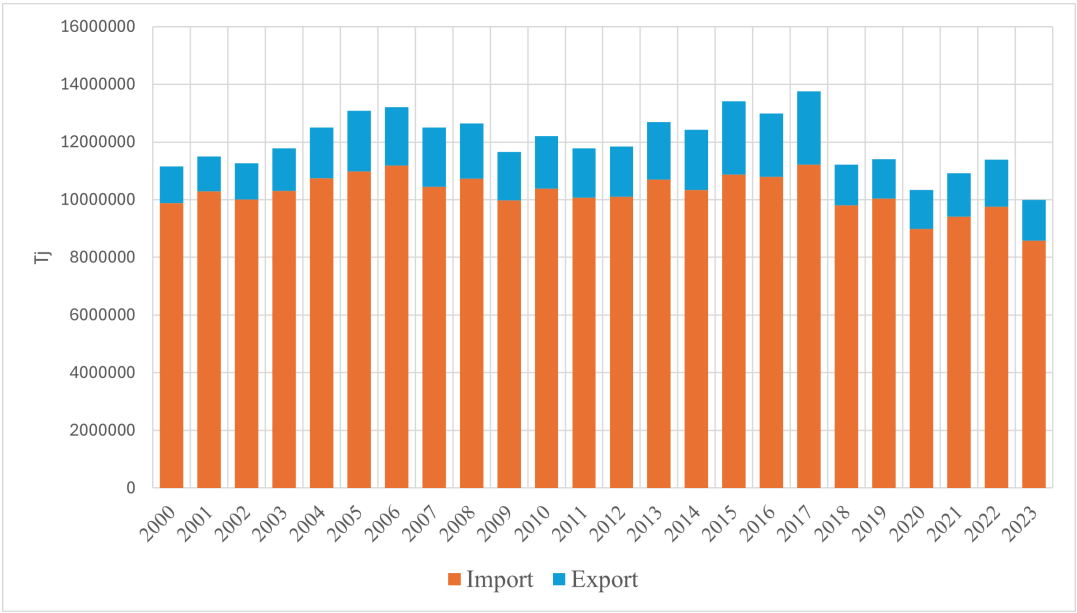
Figure 3: *Germany: Gross domestic product (GDP) per capita in current prices from 1987 to 2029 (in U.S dollars).*



Source: *Statista, (2025b)*

Figure 3 illustrates that the Ukraine crisis, which began in February 2022, resulted in a significant decline in Germany's GDP, with real GDP per capita falling from $51,460.99 in 2021 to $48,756.31 in 2022, representing a 5.25% decrease. This sharp decline highlights the significant impact of energy instability on various sectors of the German economy, including trade, industry, and household incomes.

Figure 4: *Germany Energy Trade (2000-2023)*



Source: *IEA (2024)*

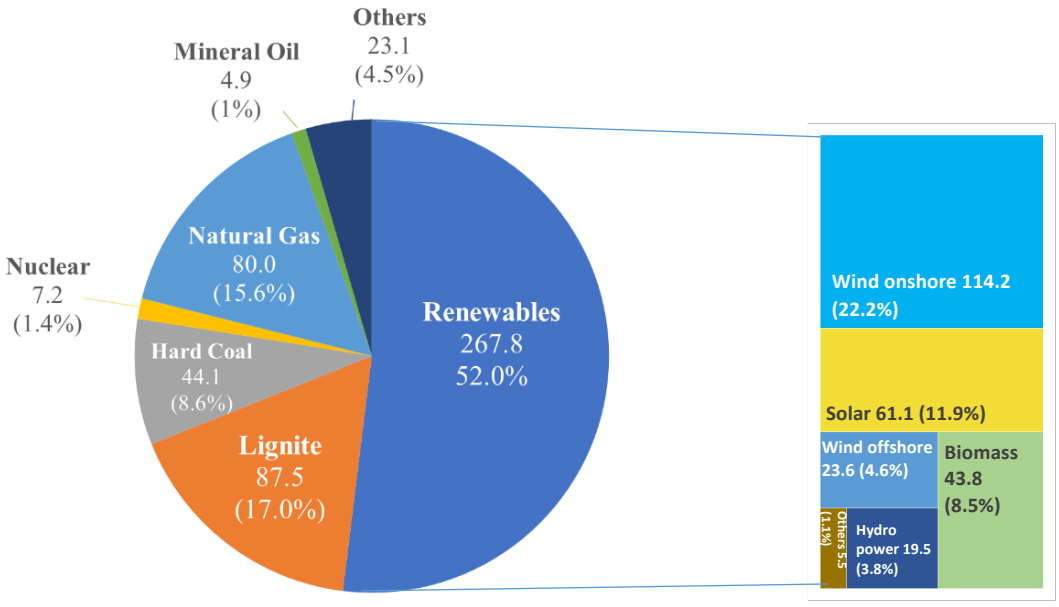
3.2. Germany's Strategic Responses; LNG strategy and renewable targets

Europe needs to diversify its energy supply, which may include new natural gas infrastructure such as LNG terminals, storage facilities, and pipelines, while simultaneously accelerating the transition to renewable energy sources (Ibadoghlu, 2022).

The EU's REPowerEU initiative has committed €10 billion to various energy projects, including joint gas projects, but the total cost of implementing the entire REPowerEU plan across Europe remains uncertain. Germany has pledged €3 billion to build floating LNG terminals (Bordoff & O'Sullivan, 2022). The German government, through the allocation of €177 billion to the Climate and Transformation Fund and €200 billion to the Transition Fund, explicitly acknowledges the indispensable role of state investment and the imperative of ensuring a just and equitable distribution of the financial costs and societal benefits of the domestic energy transition (Ashurst, 2022). Germany also aims to ensure energy supply security by diversifying its energy imports. Notably, during the crisis, Germany's overall energy imports increased by 3.72% compared to the previous year (Figure 4). Since these imports were sourced from countries with higher energy prices compared to Russian gas, the overall cost of energy imports significantly increased, placing a greater burden on the German economy. Specifically, the diversification away from Russian pipeline gas, primarily towards LNG from the United States and Qatar, meant shifting from relatively stable long-term contracts to a highly volatile spot market where prices often surged dramatically (McWilliams, Sgaravatti, Tagliapietra, & Zachmann, 2022).

The plans, approved at the cabinet meeting in April 2022, show that Germany will reach 115 GW of onshore wind (more than double the 2022 amount), 30 GW of offshore wind and 215 GW of solar photovoltaic (both four times the 2022 level) by 2030 (Pous, 2022). After the abolition of the tax on the electricity price for renewables in July, electricity suppliers will be obliged to reduce energy bills for consumers, a measure that also reflects the government's commitment to phasing out coal power generation by 2030. 2023 was the first year in which more than half of Germany's gross electricity consumption was covered by renewables. This upward trend continued in 2024, with the share of renewables rising well above 55% (BMWK, 2024). When examining the share of renewables in total energy consumption, this figure reached 52% in 2023 (Figure 5).

Figure 5: *Share of energy sources in gross German power production in 2023.*



Source: *Clean Energy Wire (2015)*

Despite these positive developments, the recent sharp rise in energy prices may discourage investments in renewable energy projects, as companies prioritize cost-effectiveness and seek to minimize immediate expenses (Sadath & Acharya, 2015). Furthermore, in addition to the energy it directly imports, Germany also imports a significant number of parts, equipment and raw materials for renewable energy technologies produced on its own soil. In fact, many of these critical raw materials are imported from China.

At this point, many EU countries have begun to consider solutions that restructure their energy policies, such as re-exploring local reserves and diversifying energy imports, to improve and sustain their energy security after the Ukraine crisis. Consequently, some member states have resorted to increased coal use as a short-term measure. As an illustration, Germany has temporarily increased coal-fired electricity production and expanded its capacity to address the immediate energy crisis (Storbeck & Sheppard, 2022). Austria, the Czech Republic, and the Netherlands have also begun to recognize coal as a crucial component of their energy security (Kuzemko, Blondeel, Dupont, & Brisbois, 2022). This may appear to directly oppose climate goals, but it's crucial to recognize these measures as temporary and exceptional responses to the energy crisis, with the long-term commitment to decarbonization remaining firmly in place (Mišík & Nosko, 2023). Thus, there has been a renewed focus on energy security and the role of traditional energy sources, including fossil fuels, in addressing the current crisis.

Fossil fuels continue to dominate energy consumption in Germany, particularly in sectors such as district heating (81.5%), industrial heating and cooling (92.3%), and transport (93.2%), with natural gas remaining a significant fuel source for industrial processes and district heating. These figures highlight the continued reliance on fossil fuels in key sectors, indicating that Germany's transition towards fossil fuel independence is not progressing as rapidly as some might expect, despite the widespread political backing and international acclaim for the Energiewende. In July 2022, the German government committed to investing €56.3 billion in energy efficiency improvements by 2026. Germany has not only set out a strategy to reduce dependency on natural gas and reduce emissions, but also aims to leverage the energy transition as a driver of economic modernization (Kurmayer, 2022). At this point, in Germany, both politically and socially, environmental protection is no longer the top priority in terms of energy transformation. Therefore, the Energiewende policy, which prioritizes the environment, is being reviewed by all social segments. Specifically, when looking at the political environment, even the Green Party, which defines green energy as a condition of freedom in Germany, has compromised on its strict stance on the temporary use of coal and nuclear energy in terms of ensuring energy supply security. When looking at the policies of the Green Party before the crisis, it has a political stance against fossil fuels. For example, LNG is an energy product that is considered harmful to the environment and opposed by the Green Party. However, in the energy crisis that emerged after the crisis, the Green Party abandoned this opposition and supported the decisions to increase the use and import of LNG. Robert Habeck, a member of the Green Party and Minister of Economic Affairs and Climate Action in Germany, went to Qatar in March 2022 to discuss Germany's LNG imports from Qatar. With this visit, Habeck held discussions on the supply of LNG imports and aimed to secure an agreement between the two countries. Therefore, at this point, even for the Green Party, security comes before environmental and climate protection policies. This diversification of LNG imports from countries like the USA and Qatar has therefore helped to alleviate Germany's immediate energy supply concerns.

The efforts to secure LNG supplies and the re-evaluation of domestic lignite and nuclear energy sources indicate a significant shift in the trajectory of Germany's Energy Transition. This reprioritization challenges previous commitments and agreements on phasing out coal and nuclear power, casting doubt on the feasibility of achieving the original goals of Energiewende. Thus, the once-envisioned roadmap for phasing out lignite and nuclear energy faces significant hurdles. This new geopolitical framing of energy policy repositions the transition from environmental and economic concerns to concerns about security, freedom, and sovereignty. This elevated status of energy security underscores the urgency of accelerating the development of renewable energy sources to ensure long-term energy independence and reduce reliance on fossil fuels (Wiertz, Kuhn, & Mattissek, 2023).

4. Nuclear Energy as a Solution

4.1. Public perception

Public perception regarding the carbon footprint and climate-friendliness of nuclear energy began to shift in the 1970s. The emergence of the environmental movement during this decade, focusing on potential risks such as nuclear accidents, radioactive

contamination, and long-term environmental consequences, significantly altered public views. These concerns were further intensified by issues like nuclear waste disposal and the potential for misuse, gaining widespread attention after incidents like the Three Mile Island accident and the Chernobyl and Fukushima disasters. In this environment of increasing concern, environmental organizations continue to voice their concerns about nuclear energy, believing that nuclear energy poses greater threats to people and the environment than other energy sources (Barca & Delicado, 2016). This persistent negative public perception of nuclear energy presents a significant obstacle for governments seeking to expand the use of nuclear power in achieving emissions reductions and enhancing energy security (Sonnberger et al., 2021). Notably, reports and future scenarios published by the IPCC suggest that nuclear energy will be a component of countries' decarbonized energy policies and total energy consumption in the future (IPCC, 2023).

Achieving energy security while completely excluding nuclear energy from the energy mix presents significant challenges. Indeed, no developed country has yet fully decarbonized its energy consumption based solely on renewable sources. According to some analyses, such as the BP Statistical Review of World Energy (BP, 2022) and a report by McKinsey & Company (Feldhaus, Fürstenwerth, Gohl, Schröter, & Vahlenkamp, 2010), achieving carbon neutrality targets may be challenging without including nuclear energy as part of the energy mix. Germany has historically implemented a series of policy measures aimed at rapidly developing renewable energy sources and phasing out nuclear power. In practice, achieving the ambitious goals of the Energiewende, including 100% renewable energy by 2050, has proven to be more challenging than initially anticipated.

4.2. Political history

In 1949, the newly established Federal Republic of Germany, lacking a defined energy policy, relied heavily on coal and lignite as the most readily available and secure energy sources. After the establishment of the European Coal and Steel Community (ECSC) in 1951, the government decided to establish atomic energy sources. Subsequently, in 1955 and 1956, the government established the Federal Ministry for Nuclear Affairs and the German Atomic Commission, respectively. In 1957, Germany joined EURATOM (European Atomic Energy Community) and started the first national nuclear program ("Eltviller Programme"). The crisis in the German coal industry that emerged during this period played an important role behind this important step. Politicians of the period suggested that nuclear energy should be encouraged in response to the instabilities experienced in coal and oil. Despite concerns about high installation costs and uncertain profitability, the government actively promoted nuclear energy as a technology of national importance for social and economic development. Until 1967, the federal government (West Germany) invested 5.3 billion DM in R&D to encourage the industrial use of nuclear energy. German manufacturers had achieved global standards in nuclear technology, and over 24,000 MW of nuclear power capacity was installed in Germany between 1968 and 1989. Consequently, nuclear energy began to be adopted as "modern technology" in energy markets. This importance increased further with the increasing dependence on imports in the 1970s. The German government initiated the second national nuclear program, the 'Spitzingsee Program,' in 1963, a four-year initiative.

In 1973-74, Arab countries imposed an oil embargo on Western European countries, which became known as the oil crisis. France responded differently to this oil crisis than many other countries. The 1973-74 oil crisis led France to develop the "Messmer Plan", aiming to increase nuclear energy capacity to 25% of France's energy demand by 1990 (Żuk & Żuk, 2022). This crisis also seemed to emphasize the importance of nuclear energy in terms of energy security for West Germany. However, the 1970s were one of the peak years of national anti-nuclear protests for Germany. Throughout the early 1980s, with the establishment of the German Green Party, the anti-nuclear movement gained significant momentum and support. One of the core tenets of the Green Party's platform was the immediate shutdown of all existing nuclear power plants. Crucially, the 1986 Chernobyl nuclear disaster had intensified public anger and led to various socio-political decisions during this period. Under then Chancellor

Helmut Kohl, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) was established. Public opinion in Germany was generally against nuclear energy. In fact, polls conducted during this period showed 86% of the population was in favor of phasing out nuclear energy, *with* 17% specifically favoring an immediate end to civilian use. The late 1980s and early 1990s witnessed a series of setbacks and cancellations for planned nuclear power projects in Germany.

In the national elections of 1998, the government changed, and the SPD-Greens coalition ("red-green coalition") was established. Since its founding, the Green Party has consistently advocated for a transition to a sustainable energy system based on renewable energy sources, the decarbonization of the energy sector, the complete phase-out of nuclear power, and the protection of the environment. In contrast to the Greens' position, the SPD has opposed the closure of nuclear power plants due to energy security concerns. The SPD argued that phasing out nuclear power would have negative economic consequences, including increased electricity costs and job losses in the nuclear power industry. Considering all these political discussions, the Red-Green coalition had to reach an agreement. The final decision of the coalition was the idea of gradual elimination of nuclear power, which partially met the views of both parties. According to this agreement, the new government's energy policy aimed to promote environmentally friendly and economically sustainable energy sources. This 1998 coalition between the SPD and the Green Party is a turning point in many aspects of German energy policy. With this agreement, the life of nuclear power plants currently in use was limited to 32 years. A reference amount of 160.99 TWh was set for annual energy production. Ultimately, despite the planned phase-out, German nuclear power plants continued to operate and generated a total of 2.6 million GWh of electricity after 2000. The subsequent "Act on the Orderly Phase-Out of Nuclear Power for Commercial Electricity Generation" came into force in April 2002, cementing the agreement between policymakers and energy companies. This legislation banned the building of new nuclear power plants within Germany and, from July 2005, the reprocessing of German nuclear fuel abroad. At the same time, the German Renewable Energy Act (EEG) was passed by the joint Social Democratic-Green government in 2000. The primary goal of this major policy initiative was to hasten the transition from fossil fuels to renewable energy sources. The EEG was specifically designed to be consistent with Germany's emission reduction targets as stipulated by the 1997 Kyoto Protocol. The government's energy strategy included a provision for a temporary extension of nuclear power plant operation, which was later misinterpreted by some as a decision to abandon the phase-out plan. The plan proposed a temporary extension of the operational lifespan of nuclear power plants by an average of 12 years to facilitate the transition to a sustainable energy future. The government considered nuclear energy to be an essential bridge for achieving energy security and economic efficiency during this period of transition. This extension was formalized through an amendment to the Atomic Energy Law in October 2010, allowing nuclear power plants to operate until approximately 2036.

The Fukushima nuclear meltdown on March 11, 2011, fundamentally changed the views of both the government and the public in Germany regarding nuclear energy. Specifically, public reports following the disaster, such as the Ipsos 2011 survey, indicate that support for nuclear energy in Germany plummeted to approximately 20%, one of the lowest levels globally (Ipsos, 2011). Compared to other EU countries, like France and the United Kingdom, the German public has developed a much more negative attitude towards nuclear energy. Responding to intense public pressure, the German government took immediate action. On March 15, 2011, Chancellor Merkel announced a "nuclear moratorium," citing a precautionary safety provision in the Atomic Energy Act. This led to the immediate and temporary shutdown of the seven oldest German nuclear reactors. In addition, the government suspended plans to extend the life of existing nuclear power plants for an initial three-month period (Haunss & Hollway, 2023).

In the aftermath of the Fukushima disaster, the German government established the “Ethics Commission for a Safe Energy Supply” in March 2011 (Ethics Commission for a Safe Energy Supply, 2011). The Commission's recommendations ultimately

lent legitimacy to the subsequent phase-out of nuclear power. The decisions made in spring and summer 2011 effectively ended the planned extension of nuclear power plant lifespans, accelerating Germany's transition towards a sustainable, environmentally sound energy future. The phase-out of nuclear power subsequently became an integral component of Germany's Energiewende (Kunz & Weigt, 2014).

Following the Fukushima disaster, driven by heightened public concern about nuclear safety and a growing demand for stronger climate action, all major political parties in Germany recognized the need for a fundamental transformation of the country's energy system. In response, Chancellor Angela Merkel announced the phase-out of nuclear power by 2022, accompanied by measures to enhance energy efficiency and accelerate the transition to renewable energy sources (Paul, 2018). Following these policy decisions, the transition to renewable energy became a widely accepted goal in German politics, although challenges and debates regarding the pace and implementation of the Energiewende continued. Internationally, Germany's Energiewende was seen as a role model for energy transition and climate leadership. However, while significant progress has been made, the transition is not yet complete. Renewables accounted for just 15.7% of Germany's total primary energy consumption in 2021. The majority of progress was observed in the electricity sector, with the share of renewables rising from 20.4% to 41% between 2011 and 2021, largely attributable to the phase-out of nuclear power (Wiertz et al., 2023).

4.3. Technical feasibility

The significant energy price hikes of 2021, further exacerbated by the global energy crisis triggered by the Russian invasion of Ukraine in 2022, have intensified the urgency of achieving energy self-sufficiency and reducing dependence on fossil fuels. In exploring potential solutions, it is crucial to reassess nuclear energy and understand the factors that influence public perception. Nuclear energy currently constitutes a significant portion of the EU's energy supply. Based on Eurostat's 2020 data, the EU's electricity generation is comprised of 25% nuclear power, 39% renewables, and 36% fossil fuels (Eurostat, 2020). Nevertheless, Germany has implemented a policy of phasing out all nuclear power plants as part of its Energiewende, with the last reactors being shut down in 2022. Meanwhile, the country plans to gradually phase out lignite and coal-fired power plants by 2038 (Bredberg et al., 2020).

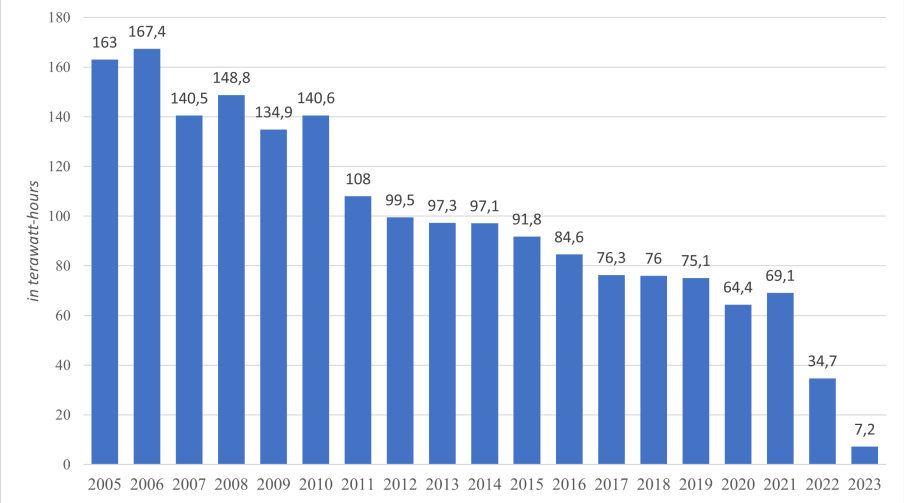
The share of fossil fuels in electricity generation decreased from 57% in 2010 to 51% in 2017. During this period, Germany experienced a significant decline in nuclear power generation, with its share being halved. As an illustration, the percentage of nuclear-sourced electricity in Germany fell by 45.73% from 2010 to 2017 and further decreased to 9.44% from 2017 to 2023 (Figure 6). Germany's post-Fukushima nuclear phase-out led to an increase in renewables to compensate for the reduction in nuclear power. Germany could significantly improve public health outcomes by preserving some of its nuclear power and prioritizing coal reduction. If Germany had maintained some nuclear power generation instead of adhering to the linear phase-out target between 2018 and 2035, it could have potentially avoided between 50,000 and 130,000 air pollution deaths and prevented the release of between 6800 and 7400 Mt CO_2 of cumulative emissions from coal combustion. By prioritizing the phase-out of nuclear power while continuing to rely heavily on coal, Germany may have missed an opportunity to more significantly reduce air pollution and CO_2 emissions in the short term. This choice has exacerbated the country's challenges in addressing climate change and air quality. A more strategic approach would involve prioritizing the reduction of fossil fuel-based electricity generation, thus benefiting both public health and environmental sustainability (Kharecha & Sato, 2019).

Despite the compelling arguments for nuclear power's environmental benefits, public opposition, as discussed in '4.1. Public perception', remains a significant factor; in Germany, less than 10% of individuals with the highest scores on the NEP scale expressed support for nuclear development. This public opposition to nuclear energy can be attributed in part to the strong anti-nuclear sentiment fostered by environmental movements in Germany (Bohdanowicz et al., 2023). Furthermore, studies show that public opinion within the EU is mostly negative towards nuclear energy, especially among

individuals with environmental concerns (Corner et al., 2011). Thus, the restart of nuclear energy in Germany depends entirely on political will. Despite public resistance, discussions around nuclear revival continue at the political and technical levels.

To reintroduce nuclear power into the German energy mix, the government would need to halt the decommissioning of existing reactors and amend the Atomic Energy Act to allow for the potential restart of nuclear power plants. There is significant support for reversing Germany's nuclear phaseout, with arguments for its economic viability and technical feasibility. Recently decommissioned reactors can be reactivated without major technical hurdles.

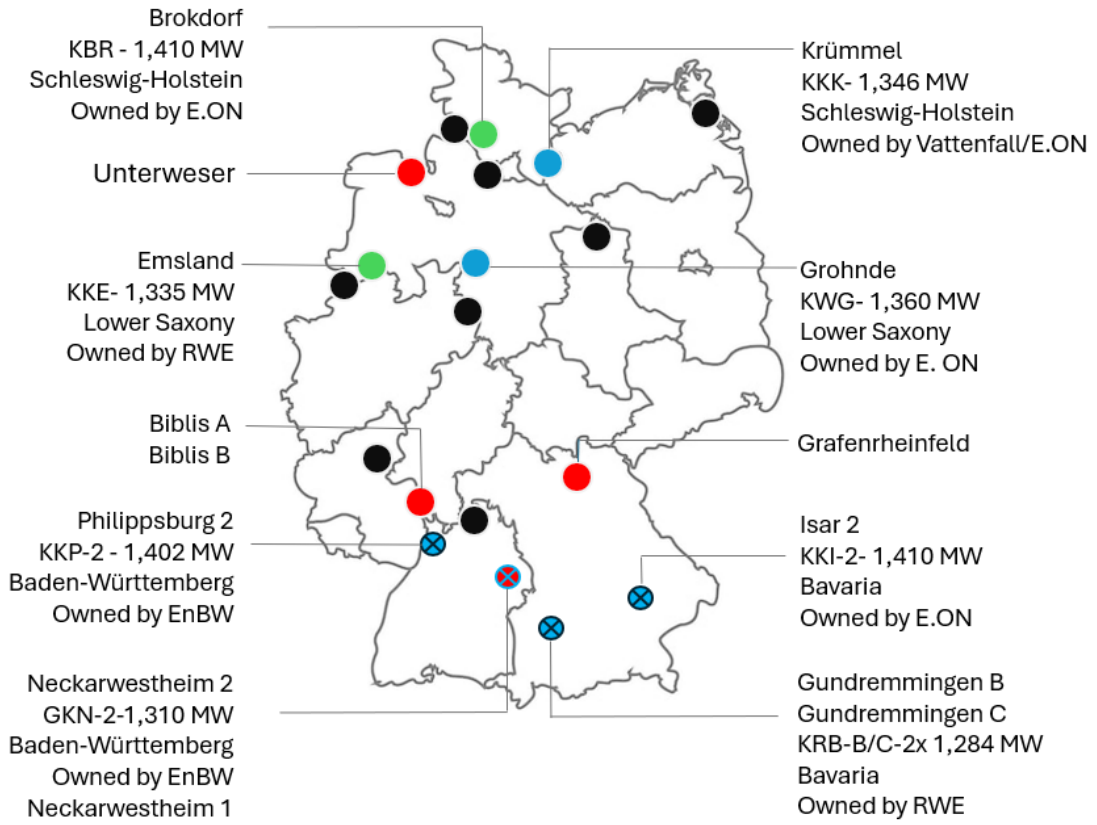
Figure 6: *Gross electricity generation from nuclear sources in Germany from 2005 to 2023*



Source: *Statista (2025a)*

Restarting the three previously planned-for-closure nuclear power plants (Brokdorf, Emsland, and Grohnde) by 2028 could potentially increase Germany's power generation capacity by approximately 4 GW. If the decision to decommission nuclear power is reversed, and the necessary legal and regulatory processes are expedited, the Brokdorf nuclear power plant could potentially continue operating until the end of 2025, and the Emsland and Grohnde plants until the end of 2028. Six additional nuclear reactors could potentially be brought back online by 2032, assuming necessary investments and regulatory approvals are obtained. The restart of nuclear power generation could potentially lead to a reduction in CO_2 emissions compared to increased reliance on fossil fuels, create employment opportunities in rural areas, and stimulate Germany's advanced nuclear technology sector (Pata, Kartal, Erdogan, & Sarkodie, 2023).

Figure 7: *Geographical overview of Germany's nuclear portfolio.*



Restart class	Cost to restart	Time to restart	Reactors	
Class 1	≤ 1 €bn/unit	1-3 years	2 units 2,745 MW	Brokdorf, Emsland
Class 2	≤ 3 €bn/unit	4-8 years	7 units 9,400 MW	Grohnde, Gundremmingen B & C, Isar 2, Krümmel, Neckarwestheim 2, Philippsburg 2
Class 3	Needs detailed assessment	Needs detailed assessment	5 units 5,812 MW	Biblis A & B, Grafenrheinfeld, Neckarwestheim 1, Unterweser
Class 4	Not applicable	Not applicable	17 units 9,838 MW	Brunsbüttel, Greifswald 1-5, Gundremmingen A, Isar 1, Lingen, Mülheim Kärlich, Obrigheim, Philippsburg 1, Stade, Stendal 1 & 2, Würgassen

Restart Class 1	The power plant has been shut down, but significant decommissioning work has not taken place. The plant requires maintenance, minor repairs or replacements, rehiring of staff, and nuclear fuel purchases.
Restart Class 2	Significant decommissioning work has begun, and parts of the turbine island and nuclear steam supply system have been dismantled. A significant number of major components, such as the reactor pressure vessel, steam generators, and fuel handling systems, remain intact and could be reused if the missing parts are replaced.
Restart Class 3	Most major components of the nuclear steam supply system, turbine, and generator have either been removed or are beyond repair. Restarting the plant would necessitate the installation of an entirely new nuclear steam supply system or at least various new, major nuclear steam supply system components. The integrity of the containment building remains intact or is within feasible repair.
Restart Class 4	The containment building is either irreparably damaged or has been partially or demolished. The site still has infrastructure that would support the construction of a new reactor. Some former nuclear sites have already been restored to greenfield status and are therefore outside the scope of this report.

Source: *Hippauf (2024); Radiant Energy Group (2024); WNN, n.d.*

Lignite, nuclear power, and LNG, while conflicting with the long-term goals of the Energiewende, are being considered as short-term measures to enhance energy security. Germany has been phasing out coal-fired power plants and has closed its nuclear reactors. To compensate for this, Germany has increased its reliance on natural gas imports, with imports increasing by around 25% in recent years. However, this increase in reliance on Russian gas imports occurred prior to the 2022 energy crisis (Cîrdei, 2021). Some EU countries are also reducing domestic gas production as part of their efforts to achieve carbon neutrality, while others are seeking to increase domestic gas production. However, declining domestic gas reserves, which account for approximately 25% of primary energy consumption, are a major factor contributing to the decline in domestic gas production (Rokicki & Perkowska, 2021). Although the EU aims to decarbonize energy by 2040, phasing out nuclear power as a domestic energy source could jeopardize energy security. Russia currently supplies a significant portion of the EU's energy needs, providing 40% of its coal, 30% of its crude oil, and a smaller but still significant portion of its uranium. To mitigate potential disruptions to energy imports from Russia, the EU needs to diversify its energy sources, including increasing domestic gas production where feasible, while simultaneously accelerating the transition to renewable energy sources (Liu, Fu, Wong, & Bashir, 2023).

World Nuclear Association Director General Sama Bilbao y Leon announced that interest in nuclear energy has increased amid energy security concerns following the Russia-Ukraine war. While some European countries are considering expanding their nuclear energy capacity, others remain committed to phasing out nuclear power.

"There is a huge turn towards nuclear energy, and this is not only in Europe, but also in many countries around the world, from South Korea to Japan, from India to North America. In Europe, except for Germany, there are different approaches to countries' nuclear phase-out plans. While everyone is talking about Germany's nuclear phase-out process, most countries in Europe plan to continue using nuclear energy and increase their capacity. Many countries, including the UK, France, Sweden, the Netherlands, the Czech Republic, Slovakia, Romania, Estonia, Slovenia and Croatia, have growth plans. The energy crisis has become a serious alarm for countries. The energy crisis and the rising energy bills have forced politicians to move forward with pragmatic, realistic and feasible decisions (NTV, 2023)*."*

Extensive studies have demonstrated that hybrid systems integrating nuclear energy with renewable sources or energy storage technologies can significantly contribute to decarbonizing energy consumption, mitigating environmental impacts, and enhancing grid stability. Therefore, nuclear energy is a vital component of efficient, low-carbon energy systems that are less reliant on fossil fuels (Bohdanowicz et al., 2023). Furthermore, comprehensive analyses of future energy system scenarios demonstrate that achieving decarbonized electricity generation may necessitate the utilization of nuclear energy to some extent (Buongiorno, Corradini, Parsons, & Petti, 2019).

Research in the field of nuclear energy development indicates that nuclear energy can play a crucial role in future energy systems, offering a reliable, low-carbon, and safe energy source. While concerns regarding the safety and environmental impact of nuclear energy are frequently expressed, risk assessments have consistently shown that these risks are relatively low in comparison to other energy sources. Burgherr and Hirschberg's analysis (Burgherr & Hirschberg, 2008), based on historical data, revealed that nuclear energy presents the minimal risk of accidents and that the estimated costs of potential nuclear accidents are less than the environmental and air pollution costs associated with fossil fuels.

5. Conclusion and Policy Recommendations

This study has shown that the Ukraine crisis marked a turning point in Germany's energy policy, exposing structural vulnerabilities stemming from the country's reliance on fossil fuel consumption and energy imports. While renewable energy remains the central objective of German energy policy, the current crisis has necessitated a reconsideration of nuclear energy as a transitional option. In

this context, the Russia–Ukraine conflict has served as a major trigger for renewed focus on energy security concerns to the forefront of both national and EU-level decision-making.

The ongoing Russia-Ukraine conflict has escalated geopolitical risks and global economic policy uncertainty, creating an increasingly tense international situation for European countries. European countries, especially Germany, have faced a security risk in terms of energy supply due to Russia's weaponization of natural gas supplies. Therefore, Germany may face significant challenges in achieving its ambitious zero-carbon objective, given the scale of the required expansion and the need to overcome existing infrastructure and grid limitations. Nevertheless, the German government's early responses to the potential energy shortage caused by the conflict in Ukraine and the increased focus on renewable energy may be a positive push that will contribute to national goals. Germany can intensify efforts to reduce its dependence on fossil fuels and lower energy consumption costs by increasing renewable energy investments and providing additional financial instruments, thereby enhancing the share of renewables in the overall energy mix and mitigating the insecurity caused by the crisis. Therefore, it would be important for Germany to perceive the ongoing energy crisis as a transitional juncture and utilize this period as an opportunity to expedite the energy transformation. As a result, the effective implementation of the Green Budget, along with other policy measures, will be instrumental in achieving the necessary capacity to achieve ambitious goals such as a carbon-neutral economy by 2045.

Despite increased attention to energy security following the Ukraine crisis, Germany's current energy policies remain insufficient to fully address the structural vulnerabilities and long-term challenges of its energy transition. The reasons for this choice and the negative attitude towards nuclear energy are diverse and multifaceted, as discussed in the study. However, what seems particularly problematic, especially in the context of climate change, is Germany's exclusive emphasis on domestic policy measures and its unwavering commitment to a single "technology family", renewable energy. Energy security must also be a key consideration for countries, alongside environmental and climate goals. Crucially, poor coordination of energy policy has the power to trigger not only social crises but also political and legitimacy crises. Initially, Germany turned to nuclear energy to address concerns about domestic energy security, particularly the reliance on imported coal and oil. However, years later, Germany is facing an energy supply security crisis due to its limited progress in establishing sufficient renewable energy capacity and its continued dependence on foreign sources of oil and natural gas. Therefore, as a solution to this crisis faced by Germany, it was suggested that nuclear energy be developed and used as a bridge again in the energy transition. Negative public opinion towards nuclear energy poses a major obstacle to its re-emergence in Germany, despite potential technical and political solutions. However, to accurately reflect public sentiment towards nuclear energy in Germany, it would be prudent to conduct a new survey after February 2022, when the Russian invasion of Ukraine has raised awareness of the risks associated with energy security and energy dependence. The intensification of the climate crisis is likely to engender a gradual increase in public acceptance of low-carbon energy sources, which may include nuclear power. Therefore, ongoing research is essential to track the evolution of these attitudes over time. The German Federal Government should consider the possibility of reactivating recently decommissioned nuclear power plants in the short term to reduce energy security risks until the renewable energy infrastructure reaches a sufficient level of maturity. Based on the findings of this study, the European Union is also advised to expand co-investment mechanisms that support grid modernization and enhance cross-border energy resilience. In addition, policymakers should invest in public awareness initiatives aimed at addressing widespread misconceptions about nuclear energy and fostering a more informed and balanced public discourse.

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