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Research Article

The German Energy System: Analysis of Past, Present, and Future Developments

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Abstract: The scientific and public debate centers on the specific policies that make up the energy transition policy, as well as issues surrounding how they interact and fit into the European context. The Federal Government of Germany came to a conclusion to change the existing structure of the country's energy supply system by ending nuclear energy conversion and strongly promoting the development of renewable energies. It is been seen that briefly after the Fukushima Daiichi nuclear disaster in Japan in 2011, it is seen the Federal Government of Germany came to a conclusion to change the existing structure of the country's energy supply system by ending nuclear energy conversion and strongly promoting the development of renewable energies. This paper aims at reviewing the past, present, and future of energy in Germany. It provides an overview of the historical trends of energy in Germany under energy use (kg of oil equivalent per capita), fossil fuel energy consumption (% of total), renewable energy development, and evolution of renewable energy patents. The requirements of such a system are not satisfied by policy approaches or recommendations that target short-term effects or that are perceptions of problems extrapolated from individual sectors. By collecting information from the literatures, it analyses current energy issues in Germany and the future of energy in Germany. This paper tends to bring to understanding the state of energy in Germany.

***Keywords*:** energy transition, renewable energy sources, sustainability, Germany

Abbreviations

EEG	Erneuerbare-Energien-Gesetz
EU	European Union
TSOs	Transmission System Operators
DSOs	Distribution System Operators
GDP	Gross Domestic Product
CDP	Carbon Disclosure Project
BDEW	The German Association of Energy and Water Industries
Kgoe	Kilogram(s) of oil equivalent

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1. Introduction

Since the social and economic well-being of the contemporary world depends on the availability of a sustainable supply of energy, energy is sometimes regarded as a crucial element that influences our lives and fosters civilization [1]. The German Federal Government allegedly agreed to stop converting nuclear energy not long after the Fukushima Daiichi nuclear tragedy in 2011. It is apparent that all nuclear reactors in the nation must be phased out by 2022 in compliance with the 13th Amendment to the German Atomic Energy Act. As a result, it is evident that 18% of the power presently provided by nuclear energy will need to be switched over to alternative sources in the near future [2]. Accordingly, it can be observed that the German Federal Government is trying to promote the growth of renewable energies, particularly wind, photovoltaic (solar), and hydroelectricity, which would eventually bring about fundamental changes to Germany's energy supply [3]. However, it is evident that other elements, such as the decrease of CO_2 (greenhouse gas) emissions and the dependency on oil mostly from oil-producing nations, as well as the nuclear phase-out action plan, also highlighted the necessity for a move in this direction [4]. This study examines the "history, present, and future of energy in Germany," gathering data from the literature and interpreting it in accordance with the subheadings provided in the article's components. The planned shift by Germany to a low-carbon, ecologically responsible, dependable, and economical energy supply is known as the *Energiewende*, which is German for "energy transition." Most current coal-fired power, if not all of it, has reportedly been decommissioned. Germany is thought to be aiming for a more affordable, sustainable, and secure energy source.

2. Literature review

2.1 *Related literature in Germany*

Germany has been viewed as a country that has led by example, which makes it clear how important it is for nations to have an all-encompassing vision for a sustainable energy system from the start and an all-encompassing strategy for achieving it that is in line with the EU objectives and implemented in coordination with the other member states [5] since early 2020, can compromise the world commitment to the 2030 Agenda for Sustainable Development. This study discusses critical aspects of the global pandemic for the achievement of the Sustainable Development Goals (SDGs). The green and sustainable future of Germany is still a long way off, though, as is evident. Despite significant growth in the usage of renewable energy sources in the production of power, the overall picture is still viewed as less than favorable, at least according to the records [6]. The Federal Republic of Germany is expected to fall short of its goal of reducing greenhouse gas emissions by 40% by 2020 because it has been noted that the country has primarily focused on the electricity sector and that very little has been done to create an energy transition in the transport and heating sectors [7]. As a result, fossil fuels continue to be the main source of energy in Germany. In particular, it has been noted that the switch to renewable energy has irrefutably shown the value of adequate grid capacity, cost-effective investments, the use of solar cells to give bioenergy the proper weight in the energy mix, the role of the general public, and cooperation with other EU member states [3]. German dependence on fossil fuels is considered a major concern today because of its conflicting nature [8]. Germany has been identified as a key producer of lignite as well as a major importer of coal; this dependency on coal and the lack of a timetable for a phase-out of coal is considered as having detrimental effects on both the nation and the rest of the EU [9]. Gas, on the other hand, is typically categorized as a transition fuel since it is thought to increase gas use while creating issues of energy security and politics, particularly if it would do so by increasing reliance on Russian gas [10]. Additionally, given Germany's key position as a vehicle manufacturer, it would appear that improvements in the transportation industry would have a variety of effects both domestically and in foreign nations [11]. Therefore, it is believed that the Federal Republic of Germany has the potential to significantly contribute to the EU's discussion on energy. In order for the EU to fulfill its goals in terms of enhanced energy security, increased energy efficiency, and the decarbonization of its economy, Germany is considered as having a crucial duty [12].

The Federal Republic of Germany was given a detailed and consistent information base that took into account the long-term implementation of renewable energies and, as a result, the potential future structure of the energy system in line with the political long-run targets [13]. Scenarios were explored that substantiated the consistency and attainability of the policy targets of Germany's energy concept if appropriate policy measures were to be put in place [14]. A thorough analysis of the political economy of Germany was conducted in order to determine the level of investments, the strength of the market dynamics, and the potentially substantial economic benefits that could come from this course of development in terms of reduced fuel importation and lower fuel costs [15]. Results from the scenarios were based on hypotheses and assumptions used to generate the paths. Future requirements for fossil fuel capacity and storage were expected to be dependent on the ability to import renewable energy on demand and, consequently, on the expansion of the grid. The efficiency goals that are set for each sector have also been demonstrated to strongly support the expansion of renewable energy technology. These scenarios' political economic assessments are considered as being very dependent on the presumptive pricing pathways and costs associated with technological advancement. The relevance of the strategy's components-increased efficiency and the utilization of renewable energy sources-was shown to differ significantly between the electrical, heating, and transportation sectors [1]. The usage of renewable energy clearly influenced the decrease in CO_2 emissions within the power supply sector, with a net reduction of 209 million t CO_2/yr. With just 51 million t CO_2 per year of contribution from efficiency measures in power use, total electricity output was projected to decline very marginally until the year 2050. On the other hand, it appears that the significant reduction in heat consumption is the primary means by which the CO_2 emissions associated with the provision of heat are reduced [16]. Therefore, the expansion of renewable energy would account for 47 million t CO_2/yr, while efficiency improvements would account for 196 million CO_2/yr. In a similar vein, a motor fuel weighing shows a decrease in t CO_2 of 96 million t/yr from efficiency improvements and 26 million t/yr from renewable energy use. The lower ultimate energy consumption in the transportation industry as a result of the advent of electromobility is, nonetheless, important to highlight since it is accounted for in efficiency [17]. In Scenarios A and B, and 42 million t CO_2/yr in Scenario C, electromobility utilizing renewable power was only seen to contribute to a decrease of roughly 23 million t CO_2/yr. It was determined that effective CO_2 emission reduction in each sector required a combination of significant structural changes, the application of a good set of energy-policy measures with targeted incentives for different individual actors, as well as the removal of a number of barriers and explicit interests. Additionally, it was seen that the interactions between the sectors were developing due to expanding balancing and storage procedures for both the supply of electricity and gas as well as the supply of electricity and heat.

Electricity is generated by conventional and renewable power plants, with generation costs varying according to energy source-specific charges, taxes, and subsidies. While only a few companies generate most of the electricity from fossil fuels, the renewables segment is much more fragmented. In addition, some electricity is generated independently: industrial self-producers usually operate gas power plants, while domestic self-producers typically operate solar panels. Some of the capacity of certain power plants is, however, permanently designated as reserve capacity or is temporarily used for dispatch services coordinated by the transmission system operators (TSOs) [1].

As the German transmission grid is connected to transmission grids of neighboring countries via so-called cross-border interconnectors, German power generators can export electricity to foreign customers, while electricity suppliers and some corporate end-users can also import electricity from non-German suppliers [18]. In principle, both power generation and power supply are subject to effective competition. By contrast, transmission system operators (TSOs) and distribution system operators (DSOs) are natural monopolists, and therefore are subject to regulation. Two of the four German TSOs (50 Hertz, Transnet BW, Amprion, and Tennet) and the hundreds of DSOs belong to a vertically integrated energy company also active in power production and supply.

2.2 *Related literature in other countries*

In Asian countries, there was a strong link between per capita GDP and energy consumption throughout the ten-year period between 1983 and 1992. The possibility of a trend change was considered from the perspective of the then-current Asian economic crisis. In this study, energy consumption in 8 nations and 2 areas from 2005 to 2010 was estimated using data from the United Nations population projections and the Japan Economic Research Center's CDP growth rate estimations. This information was seen to be followed by a sharp rise in the energy consumption of several nations, particularly China, which was anticipated to account for 15.9% of global energy consumption in 2010. From 1983 to 2020, the United States energy consumption was projected to rise by 40% as a result of the country's growing population. The effects of these changes were shown to be somewhat bigger in developing nations and to be less pronounced in industrialized countries, despite the fact that energy consumption would continue to rise as a result of both population growth and changes in the energy consumption structure. Despite this, it was claimed that Africa's energy consumption would be relatively low compared to the rest of the globe given its growing population. Both population growth and changes in the structure of energy use were found to be contributing contributors to rising energy demand. It was made clear that changes to the energy consumption structure were mostly to blame for the rise in energy use [19].

2.3 *General information about germany*

Germany's average over that time was 3,856.98 kilograms of oil equivalent, ranging from 1,952.59 kilograms of oil equivalent in 1960 to 4,685.3 kilograms of oil equivalent in 1979. 3,817.55 kilos of oil equivalent are the most recent figure from 2015. In contrast, the global average in 2015, based on 35 nations, was 4,155.99 kg of oil equivalent. Germany uses a variety of energy sources, both domestically produced and imported. The energy is measured in kilos of oil equivalent for convenience in comparison.

In 2015, Germany's fossil fuel energy usage (as a percentage of all energy) was 78.86. Over the previous 55 years, it fluctuated between 99.40, its greatest value, and 78.86, its lowest value. Due to favorable weather, renewable energy made up 49% of German power consumption in the first half of 2022, an increase of 6% percentage points over the same period in the previous year, according to industry organizations on Tuesday. According to a joint statement from utility industry organization BDEW and the Centre for Solar Energy and Hydrogen Research (ZSW), the trend was caused by both increasing solar intensity and wind speeds. Preliminary estimates were generated in accordance with EU regulations that base the market share of individual power sources on consumption rather than output; Berlin also used this methodology when defining its climate goal criteria, they said. In the first half of 2020, renewable energy accounted for 50.2% of German electricity consumption. In the first half of 2022, the total amount of electricity consumed in Germany decreased by 0.8% to 281 billion kilowatt-hours (kWh). 7 Germany's role as a net exporter of power increased as domestic energy output increased by 1.7% to 298 billion kWh, according to the statistics. Renewable energy sources, which include geothermal, solar, hydro, biomass, and waste energy in addition to the wind, provided 139 billion kWh to the total, up 13.5% from a year earlier. Onshore wind contributed 59 billion kWh, up 23.0%; solar, 33 billion; biomass, 24 billion; up 3.7%; and offshore wind, 12 billion, up 5%. In the last six months, 159 billion kWh of electricity were produced conventionally using coal, gas, and nuclear fuel, 6.7% less than in the same time frame in 2021. Germany's carbon dioxide (CO_2) emissions were down 39% last year compared to 1990, but it wants to cut them by 65% by 2030, which would require expanding its use of renewable energy sources with no carbon footprint.

2.4 *Historical trends in energy in germany*

2.4.1 *Energy use (kg of oil equivalent per capita)*

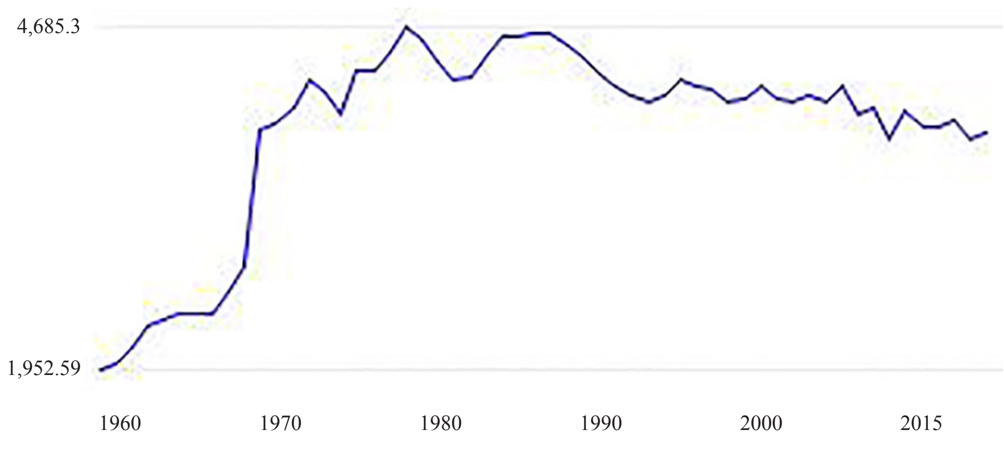

Figure 1. Energy use (kg of oil equivalent per capita in Germany)

Source: https://datacommons.org/place/country/DEU?utm_medium=explore&mprop=amount&popt=Consumption&cpv=consumedThing%2CEnergy&hl=en

Energy usage is the term used to describe the consumption of primary energy before it is converted into other end-use fuels. It is equal to domestic production plus imports and stock adjustments, minus export and fuel provided to ships and aircraft used in international travel. Germany's primary energy consumption per person is estimated to have decreased from 4,421 kgoe in 1990 to 3,877 kgoe in 2012. Below is a representation of the data for Germany's energy consumption (kg. oe per person) (Figure 1) [20].

2.4.2 *Fossil fuel energy consumption (% of total)*

The principal use of fossil fuels is thought to be in the production of energy. Germany is a producer as well as an importer of coal, making it the country's primary energy source. The percentage of total consumption in Germany is seen to have decreased from a higher value in 1990 to a lower value in 2016, indicating a need for the energy provided by fossil fuels. Below is a representation of the data for fossil fuel energy use as a percentage of all energy (Figure 2) [21].

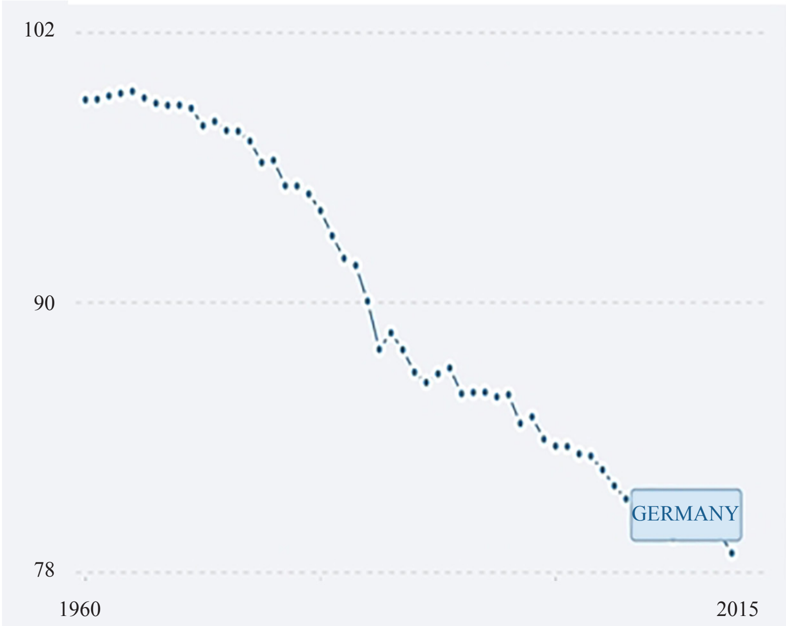

Figure 2. Fossil fuels energy consumption (% of total) in Germany
Source: https://datacommons.org/place/country/DEU?utm_medium=explore&mprop=amount&popt=Consumption&cpv=consumedThing%2CEnergy&hl=en

2.4.3 *Renewable energy development*

Germany has historically been a global leader in renewable-energy research, thanks to its sustainable-energy agenda and high levels of public funding. The result has been a wealth of opportunities for scientists working in the private and public sectors. The renewable-energy field employs nearly 340,000 people in Germany, and according to the Federal Ministry for Education and Research (BMBF), there are now more than 180 universities and 120 research institutes involved in the country's energy-transition program. *Energiewende*. However, over the past decade, Germany's renewables industry has been challenged by strong competition from elsewhere in the world. Its once-dominant solar-panel-manufacturing industry, for example, has largely been gutted by cheaper competitors in Asia [22]. Developments are already being seen in renewable energy with costs of renewable energy continuously declining and having been responsible for a higher percentage of power generation in Germany in 2019. The data for this is represented in Figure 3 below [23] viable, and generally a sustainable energy resource due to abundant supply of cheap feedstocks and availability of a wide range of biogas applications in heating, power generation, fuel, and raw materials for further processing and production of sustainable chemicals including hydrogen, and carbon dioxide and biofuels. The capacity of biogas based power has been growing rapidly for the past decade with global biogas based electricity generation capacity increasing from 65 GW in 2010 to 120 GW in 2019 representing a 90% growth. This study presents the pathways for use of biogas in the energy transition by application in power generation and production of fuels. Diesel engines, petrol or gasoline engines, turbines, microturbines, and Stirling engines offer feasible options for biogas to electricity production as prme movers. Biogas fuel can be used in both spark ignition (petrol).

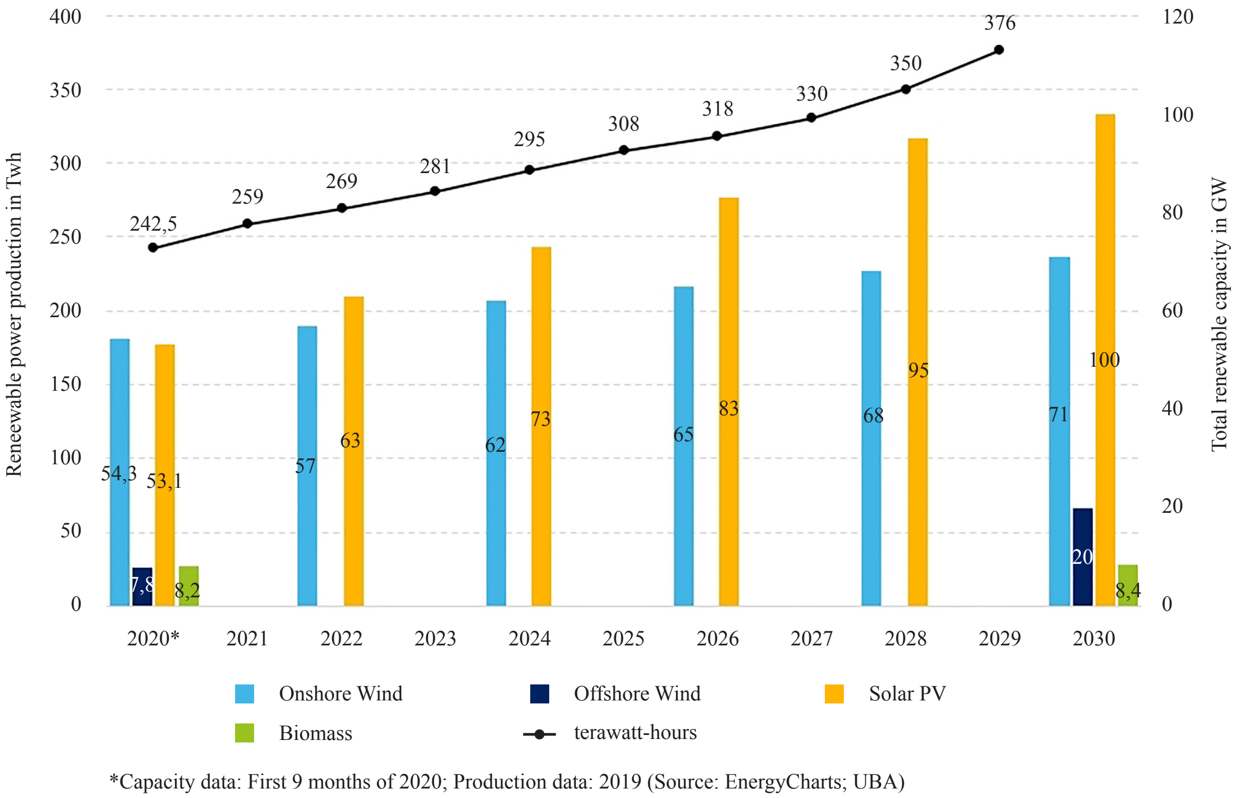

Figure 3. Renewable energy development in Germany

2.4.4 *Evolution of renewable energy patents*

"Funding levels are continually climbing," says Niklas Martin, head of the German Renewable Energy Research Association in Berlin. "You can count on funding when it comes to planning a career." The *Energiewende's* most ambitious goal-generating 80% of the country's power from renewables by 2050-was set in 2010. After the release of radioactive material at Japan's Fukushima Daiichi nuclear power plant following a tsunami in 2011, the shift took on a new urgency: German Chancellor Angela Merkel declared a complete nuclear pull-out, meaning Germany couldn't rely on nuclear power as part of its emissions-reduction plans. With nuclear energy off the table, policymakers and academics realized that achieving the emissions-reduction targets required major investments in energy research [24]. The funding fueled a boom in manufacturing capacity and innovation-between 2000 and 2013, Germany ranked third in the world in patent filings for renewable-energy technologies, behind China and the United States. This data is represented in Figure 4 below, Change in the number of renewable energy patents:

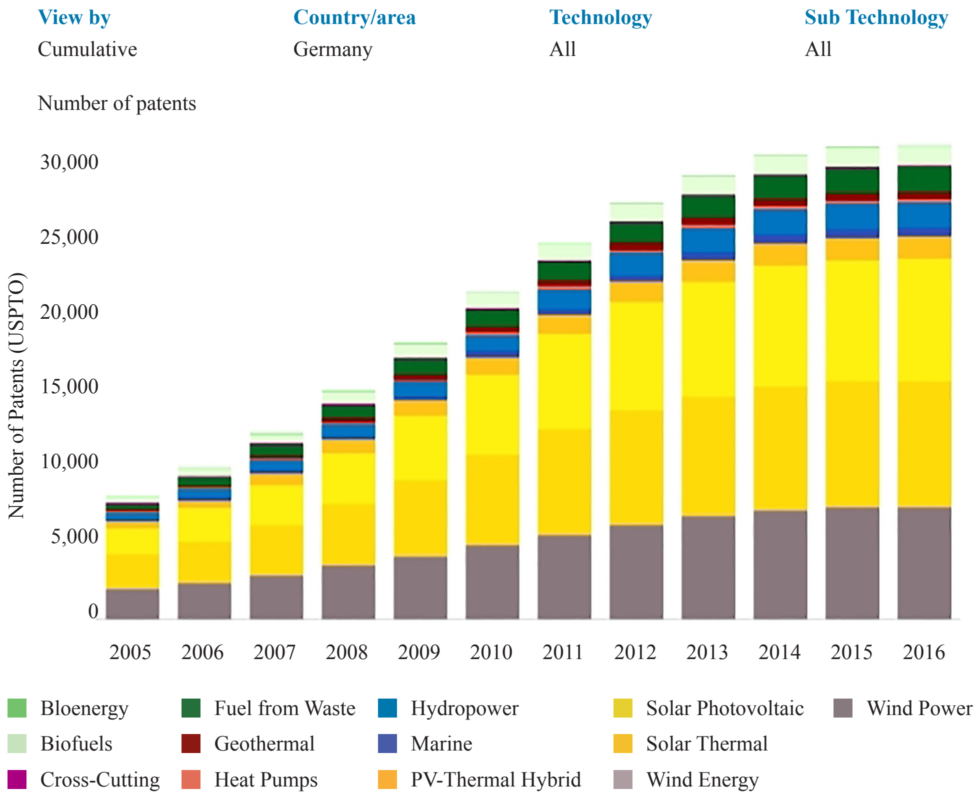

Figure 4. Evolution of renewable energy patents in Germany

Source: https://datacommons.org/place/country/DEU?utm_medium=explore&mprop=amount&popt=Consumption&cpv=consumedThing%2CEnergy&hl=en

2.5 *Current energy issues in europe*

The following advancements in energy storage, the internet of things, and artificial intelligence were viewed as three of the most important and concerning uncertainties in Europe about the technological cluster. These were seen to be followed with attention, but it appears that politicians, consumers, and businesses in various European nations still have concerns about how to implement them. Germany is now viewed as one of the European nations that have made success in the areas of digitalization and artificial intelligence, having transitioned from being a key area of uncertainty to a top priority for action. In Europe, the debate over the climate framework for the power sector has also been identified as a major source of uncertainty. In Germany, where it is believed to fall under the *Energiewende*, other sectors, such as transportation, have made less progress in this area and as a result, the future of these industries is still unclear. Despite the progress being made in the European Parliament's deliberations on new laws for the European Union's energy market, market design is still recognized as a top priority. Despite market players' knowledge of it as a single notion, the general public appears to have a lack of comprehension of the concept of market design. Furthermore, it appears that neighboring nations' readiness to collaborate on energy issues varies greatly. The German *Energiewende* and the various market designs inside the European Union must be understood from the perspective of market design. In terms of geopolitics, it can be seen that while there has been a significant decline in the uncertainty surrounding Russia since 2018, the potential impact on EU cohesion has gained significance in light of the ongoing Brexit negotiations and the upcoming elections for the European Parliament. With the support of rising energy and carbon prices in the EU and new regulatory frameworks created as part of the new EU energy package, energy efficiency and the use of renewable energy sources have been seen to be current in Europe and Germany for a number of years as a key action priority and have been seen to become even stronger investment priorities (Figure 5). Parallel to this, the price of energy and electricity has increased throughout 2018, giving EU market participants more financial confidence but causing political problems in several European nations [25].

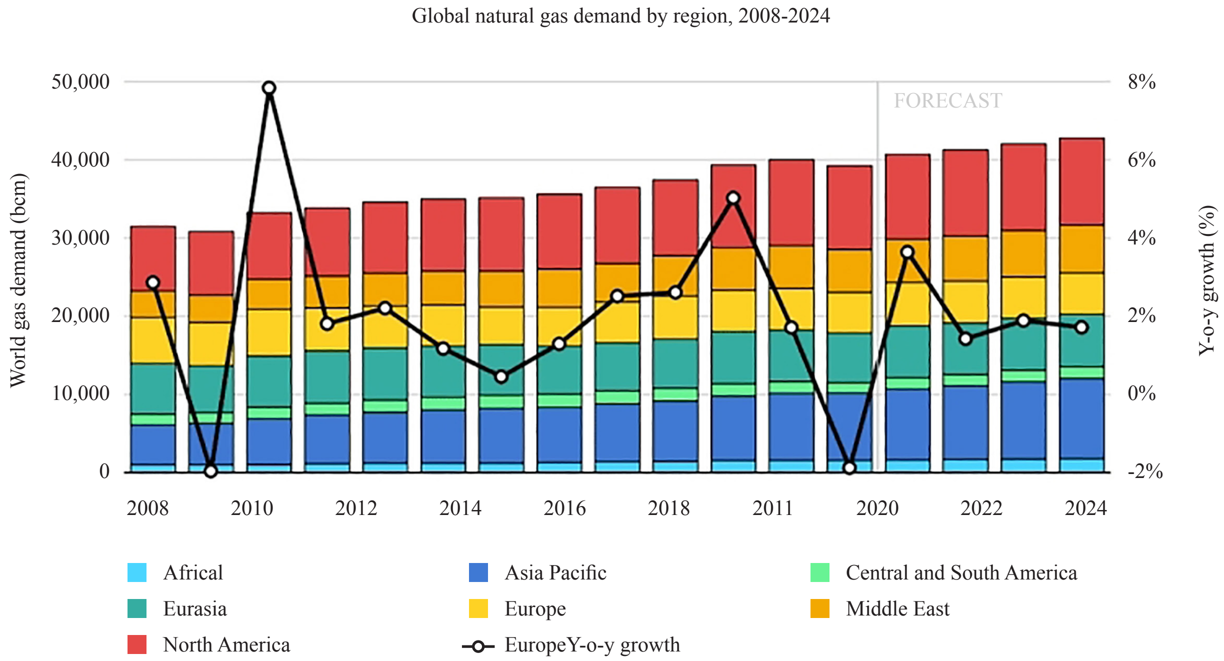

Figure 5. Current energy issues in Europe

2.6 *Future of energy in germany*

The Federal Republic of Germany has been to have taken a step to move its economy to a greener one with its *Energiewende*, energy transition. The Federal Republic of Germany's move for greener energy has been seen to be propelled by its call to cut out and replace nuclear energy by 2022. The Federal Republic of Germany's targets is seen to include:

a) Increasing the share of renewables in (gross final) energy consumption to 60% by 2050.

b) Increasing the share of renewables in (gross) power consumption to a minimum of 80% by 2050.

c) Cutting greenhouse gas emissions (GHG) by 40% by 2020 and up to 95% in 2050, compared to 1990 levels.

It is believed that in order to meet the aim, a decrease in CO_2 emissions connected to the energy of at least 85% is needed. It has been observed that the Federal Republic of Germany and the other 27 European Union members have reached a consensus on the goal of achieving more secure, affordable, and sustainable energy in Europe, together with proactive climate action. It appears that they concurred to establish an energy union based on the following five objectives:

• Decarbonizing the economy,
• Increasing energy efficiency,
• Energy security, while emphasizing the importance of solidarity and trust,
• Promoting research, innovation, and competitiveness, and
• Completing the internal energy market.

The objectives for 2020 and 2030 are regarded as a crucial component of the EU's framework for climate and energy policy (Table 1). In accordance with the international framework for climate action, the EU and its member states are urged to do their part in keeping the increase in the global temperature to 2 °C, ideally below 1.5 °C, over pre-industrial levels. According to reports, the EU has already created a number of tools to support the development of more secure, affordable, and sustainable energy sources. The European Commission has most recently added a "Clean Energy for All Europeans" package to the list of initiatives it has put up to turn the EU's energy and climate goals into laws and policies. This was done on November 30, 2016. This package is thought to include legislative proposals on energy efficiency (including one to raise the 2030 target to 30%), renewable energy, a new electricity market design, the security of the electricity supply, governance rules, as well as several initiatives to speed up innovation and encourage investment [2]. In order to achieve a carbon-neutral European economy by 2050, the European Commission is said to have just presented a comprehensive climate policy.

Table 1. EU's climate and energy targets.

Energy Targets	20/20/20 targets for 2020	2030 climate and energy framework
GHG emission reduction (compared to 1990 levels)	20%	40%
Share of renewables in energy consumption	20%	27%
Increasing energy efficiency	20%	27%

In 2018, it was predicted that Germany's entire power output will have come from renewable sources to the tune of 40%, with the potential for the instantaneous generation to increase even more. In 2050, renewable energy would account for 86% of total energy production, up from 25% currently. Variable renewable energy sources like the sun and wind would make up around 60% of the world's total generation in 2050. The cheapest electricity supply choices now available are thought to be those utilizing renewable power technology. From 20% currently to roughly 50% by 2050, it is predicted that electricity will become a larger portion of total energy production. Also expected to rise is the proportion of power used in buildings and industries. By 2050, there will be a need for it to rise from just 1% in transportation now to over 40%. It is anticipated that energy-related emissions must peak in 2020 and then begin to drop. Energy-related emissions are expected to need to decrease by 70% by 2050 compared to current levels. Over time, it is anticipated that traditional applications of bioenergy, mostly for cooking, would be phased out and replaced with energy technologies including electric cooking, sophisticated cookstoves, and liquefied petroleum gas (LPG). In the future decades, it is anticipated that a circular economy would become more and more significant, helping to reduce energy usage, enhance resource use efficiency, and boost industrial material efficiency as a result of advances. It is anticipated that improved connection and advanced digital and communication technologies would make it feasible to move large items, ultimately lowering the amount of energy used by freight as a whole. All new structures in cold and mild temperature zones should be constructed to zero energy standards starting in the following ten years, and efficiency improvements in buildings should be accelerated greatly.

The subsidies to promote the deployment of renewable energy and energy efficiency technology necessary to decarbonize the manufacturing and transportation sectors are predicted to increase over time while subsidies for power production technologies drop and are eventually withdrawn by 2050. The Sustainable Development Goals (SDGs) of the United Nations are also believed to have been intimately associated with the energy transition, and it is recognized as necessary to approach these issues within the context of broader economic growth and sustainability [26].

3. Conclusion

Around the world, the German energy transformation is being closely observed. Its success in organizing the overall sustainability of the energy supply in a highly industrialized nation within a reasonable amount of time and in maintaining profitability, supply security, environmental compatibility, and social acceptability in equal measure will determine how successful it is. Germany, which historically derived a larger portion of its energy from fossil fuels and nuclear power, has been credited with being the leading proponent of the switch to greener energy sources, such as renewables, and with providing a supportive environment through its domestic energy policies for this transition to take place. Although there has been some success with this shift, it still has its problems, just like any other significant undertaking. So it is feasible to create a greener Germany. By referencing earlier works, this study uses an illustration of the energy transition happening in Germany.

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Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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