International Journal of Economic Studies and Management (IJESM)
ISSN 2789-049X
Int. J. Econ. Stud. Manag. 3, No.6 (DECEMBER-2023)

Exiting and Re-entering Nuclear and Fossil-Fuel Energy in Germany

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Abstract: The German economy currently faces increasing energy expenses, which have partly resulted from its ongoing policy of energy transition. This paper seeks to identify the latest potential anomalies and the favorable or unfavorable choices in Germany's green energy transition process, whose origins may be traced back to the 1970s. It points out that the country's still existing dependency on fuel imports from Russia as well as the complete phasing out of nuclear power plants have made a negative impact on the green transition, and may harm economic activities in Germany. Following the shutdown of nuclear power plants, the growing use of fossil fuel fired power plants led to a rapid increase in greenhouse gas emissions. Meanwhile, the power consumption has been shrinking over the past few years. The war in Ukraine led to a sudden price shock in fossil fuels. Consequently, German administration was forced to decide about ramping up electricity production from solid fossils in order to maintain grid stability. This article seeks for answers for the questions whether the German government acted too hastily when it decided to shut down the nuclear power plants; whether this step was beneficial, i.e., power generation from renewable sources could reduce or eliminate that from fossil fuels; and whether nuclear energy has a role in the transition process. It further reveals that different calculation methods lead to failure of transparency in expenses of power generation and different sources interpret the same or similar data also in different ways. This case study suggests that under such conditions, the authorities should have either postponed the closure of nuclear power plants and simultaneously incentivize researchers to develop safer next-generation nuclear plants, or they could have accelerated the generation of alternative renewable energy.

Keywords: green energy transition, renewables, power generation, electricity trade, nuclear reactor phase-out.

Digital Object Identifier (DOI): https://doi.org/10.5281/zenodo.10382371

1. Introduction

The increasing climate change and its causes induced the authorities in Germany to implement regulations aimed at reducing the country's dependency on fossil energy sources for electricity generation and explore alternative sustainable ways of energy generation. Due to the electrification of transport, the demand for electricity has undergone a gradual increase. At the same time, climate scientists emphasized the necessity of phasing out fossil energy sources in order to prevent or at least alleviate extreme swings in weather, and to cap temperature increase at 1.5 degree in accordance with the Paris Agreement. During the last decades, companies and scientists have sought to find alternative ways either to reduce or offset greenhouse gas emissions. The method of carbon offsetting was introduced in different industrial sectors to reduce, remove, or avoid greenhouse gas emissions, measured in tones of CO2 (International Emissions Trading Association (IETA), 2019) . To reduce greenhouse gas emissions, the most damaging solid fossil fuel-fired reactors are to be taken off the grid and replaced by sustainable and possibly renewable sources (abbreviated as RES). The process of transition needs to be accelerated to make an immediate impact on the immense and still rising demand. To be able to maintain the major goals against global warming, many of the top industrialized countries subsidize research for the expansion of sustainable and renewable energy sources. The European Union added nuclear power and gas to the list of environmentally sustainable sources to assist the transition process. The inclusion of both shall be time-limited and dependent on specific conditions (Haahr, 2022).

Due to its responsibility for World War II, Germany was not allowed to operate any military nuclear program, but it managed to build its first electricity-generating nuclear power plant as early as 1960. Still, German public attitudes toward nuclear power have been considerably hostile, i.e., markedly different from the situation in, say, France (Selje, 2022). The German authorities' decision to phase out nuclear power plants without replacement was significantly influenced by the long-term environmental impact of major nuclear power plant accidents and the global growth of nuclear waste. The federal government signed agreements with the operators to shut down all nuclear reactors in the early 2020s (Mez & Piening, 2002).

The chronological implementation of regulations reveals the various retractions of the elected governments. In 2002, the German Federal Parliament passed the "Act on the Orderly Termination of the Use of Nuclear Energy for the Commercial Generation of Electricity" (Bundeszentrale für politische Bildung, 2023; Mez & Piening, 2002). The subsequent closure of the 37 nuclear reactors happened gradually. In 2009, the administration decided to postpone the complete closure of nuclear reactors to the date of 2040. However, two years later, in 2011, the same government decided that the nuclear phase-out must be accomplished by 2022. In 2022, the phase-out was again postponed in the wake of the Russian invasion of Ukraine. The final shutdown of the remaining three reactors occurred on April 15, 2023 (Bundeszentrale für politische Bildung, 2023). Although the majority of the German population has been against the use of nuclear energy, the rapidly growing cost of electricity necessitated a revision of these considerations. Most recently, leading politicians and the representatives of electricity-dependent industries expressed opposition to this "premature" shutdown, and proposed to extend the operation of the last three reactors until the end of their expected lifetime (Berbner, 2023; Tagesschau, 2023a). Accordingly, the newest trend in public attitudes indicates increasing acceptance of the utilization of nuclear power plants (Zeit Online, 2023). This reconsideration has received an additional impetus from the spreading auspicious news about the safety of next-generation nuclear power plants.

2. Methodology

Critical attitudes toward the deployment and development of nuclear power plants are fairly widespread in the German academic literature. Politicians and other opponents of nuclear power have made a

profound impact on German society, which is inclined to disapprove both the modernization of old nuclear power plants and the construction of new, more advanced power reactors. The research objective of this paper is to summarize, discover, and analyze the latest situation of Germany's green energy transition, with a focus on the gross electricity generation available for consumption. This empirical case study seeks answers to the following questions:

- The annual reduction of greenhouse gas emissions is vital for alleviating the threats posed by climate change. Were the target values neglected by the German government? Was the decision to take off all the nuclear power reactors off the grid sufficient justified, or was it too hasty?
- Could Germany benefit from the early phase-out? Are there alternative energy sources to meet the demand that is currently met by conventional fossil fuel fired power plants instead of nuclear power plants?
- Can nuclear power make a contribution to the energy transition process? Has the acceptance of nuclear power plants changed since the outbreak of the Russian-Ukrainian war?

Many of the relevant scientific publications and newspaper articles seem to argue on the basis of different data sources and different calculation methods. A few authors also emphasize that nuclear energy is a potential source for nuclear weapons, and it may become a target for terrorist attacks (Bundestages, 2022; Energiewende Und Megatrends, 2020; OECD, 2006; Rosenkranz et al., n.d.; Selje, 2022). In this article, nuclear energy will be taken into account only as a source of power generation.

3. Results

3.1. Ambitious Goals Without Clear Progress

The German authorities hoped that their country's strategies to overcome the challenges posed by the energy transition process would become a model for the entire world. Germany had to cope with the kind of issues that pioneers in the industrial world are prone to encounter. Some companies that used to be pioneers have already disappeared from the scene. While an entire country is more resilient than individual firms, Germany faces numerous problems which may be solved only through a further increase of financial expenditures. Sometimes the goals seem to have become too far-fetched and idealistic. This section depicts two major current issues, i.e., the increase of greenhouse gas emissions and the rising costs incurred by the Russian-Ukrainian war (which has forced the EU to reduce its dependency on imports of natural gas, oil, and nuclear fuel from Russia).

3.2. Increasing greenhouse gas emissions and the use of renewables

The indicator "direct CO_2 emissions per kWh of electricity" is also referred to specific emissions to compare the environmental compatibility of sources for electricity generation. Therefore, the greenhouse emissions described here refer to specific CO_2 emissions, while other emissions will be excluded from the analysis. Germany's energy transition process was intended to become a model for other industrial nations to follow. The authorities' objective was to demonstrate that greenhouse gas emissions could be reduced within the timeframe specified by the Paris Climate Agreement. Still, the events of last year showed a different picture.

If we take into account the electricity generation by nuclear power plants, different arguments can be found pro and contra. For instance, a German report (Wallner et al., 2011) stresses that the greenhouse emission of nuclear power plants is much higher than that of photovoltaic establishments, while a report published by the World Nuclear Association (World Nuclear Association, 2012) explains why the results of various studies may markedly differ, and presents a range for greenhouse emissions which is nearly half of the level presented by Wallner et al. (2011). Another German source, cited by Deutsche

Welle, shows nuclear-related emission values similar to the data published in the WNA report (Weber, 2021). Table 1 depicts the values of all the three estimates below. The units are provided as CO_2 emissions in gram per kWh.

Table 1: GHG emission range and mean values provided by three reports (Wallner et al., 2011; Weber, 2021; World Nuclear Association, 2012)

Technology	**Mean value of Lifecycle GHG Emission by WNA (2011)**	**Mean value by Weber, Deutsche Welle (UBA, WISE) (2021)**	**Values delivered by Wallner et al. (2022)**
Brown coal - lignite	1,054	1,034	n. a.
Coal	888	864	600-1200
Natural gas	499	442	n. a.
Nuclear power	29	117	82-210
Solar photovoltaic	85	33	19-59
Wind power onshore	26	9	2.8-7.4
Wind power offshore	n. a.	7	2.8-7.4
Hydro power	26	4	17-22

A comparison of the latter two sources (Weber, 2021; World Nuclear Association, 2012) also reveals that there has been no significant development of nuclear power reactors yet, while the emission values of renewable energy sources, especially in the case of solar photovoltaic and wind energy, may have decreased. While there was an attempt to use renewables to replace the electricity generated by nuclear power plants, so far this has remained insufficient to fill the gap, because the installation of wind-powered plants has been progressing slower than expected (Münchenberg, 2023; Staude, 2023). Staude (2023) noted that in 2022 and 2023, the installation of the new wind-powered units lagged behind nearly by 80 percent (900 Megawatt compared to the planned 4.000 Megawatt) and 60 percent (4.000 Megawatt compared to the planned 10.000 Megawatt), respectively. Bureaucratic obstacles (such as the absence of clear guidelines from the federal authorities at a time when the new regulations have brought about various changes) considerably hindered the installation process.

Furthermore, the gradual phase-out of nuclear power plants has resulted in an increase, rather than decrease, of greenhouse gas emissions. An Agora analysis (Agora Energiewende, 2023) shows that 2.9 percent, i.e., 8 million tones, more CO_2 was emitted through producing electricity, and that the emission levels of German power plants have increased during the last two years. The reason of these unfavorable developments is that due to the nuclear shutdown process and the high price of natural gas, more lignite and coal-fired power plants were in operation in 2021-2022 than before. In the recent years, the intense heat waves have also contributed to the higher electricity demand, which in turn led to the growing use of fossil fuels for electricity generation. By 2030, 80 percent of electricity consumption should come from renewable sources, but since the number of installations fell short of the targets set by the

government, a widening gap appeared between the climate targets and the actual expansion rate. To boost the expansion rate, tender volumes were increased, but as a result the number of successful biddings dropped. In the case of photovoltaics, tenders were fully signed. In the case of wind energy, 16 of the 20 onshore wind tenders have been signed since 2019. In 2022 alone, achievements fell short of the targets by 1.3 gigawatts. The cumulative gap between targets and achievements totaled at 5.3 gigawatts, which accounted for 32 percent fewer turbines than the tender volumes would have allowed. Offshore wind energy expansion has been sluggish, and contributed only a capacity of 0.3 gigawatts in 2022. These problems may be attributed to the fact that the grid network has remained insufficient to transmit the energy to Southern Germany, where the country's major industrial clusters are located. The target is to reach 30 gigawatts of offshore wind energy capacities by 2030. This means that installation should proceed at a pace ten times faster than in 2022. Thus, Germany's actual progress will obviously fall short of the climate targets unless subsidies and incentives are increased within a short time.

Mier (2022) foresees a higher price of natural gas in his report on 'Natural gas and electricity prices, profits, lifetime extensions and the climate,' and expects that its proportion in the total energy mix would fall from 41 percent in 2021 to around 7.6 percent in 2023, while the utilization of lignite and coal will continue till 2035 and 2045, respectively. In this scenario, CO_2 emissions are expected to be largely identical with the situation in which nuclear reactors would have had lifetime extensions. Mier (2022) explains how natural gas' share in the energy generation mix will decline, while admitting that the share of solid fossil fuels will grow, and they are to play a fundamental role in the future. In view of the increasing share of RES, particularly wind power and solar photovoltaic, Mier (2022) ultimately reaches an optimistic conclusion. In contrast, a Deutschlandfunk article (Deutschlandfunk, 2023) suggests that nuclear reactors could be operated to facilitate the proper provisioning of electricity generation while maintaining or even decreasing the level of greenhouse gas emissions instead of fossil fuel fired reactors. In any case, Mier (2022) fails to take into consideration that RES are not always available, nor is the storage technology and infrastructure sufficiently developed to ensure that the electricity produced could be stored for the future when production will be either low or unavailable.

A recent news report (Thelen, 2023) clearly underpinned the assumption that Germany actually would be unable to maintain the reduction targets of greenhouse gas emissions. This report was published before the remaining three nuclear reactors were switched off the grid. It reveals that Germany struggles with the problem of persistently high levels of greenhouse gases, although power consumption has fallen to the lowest level since Germany's reunification. The report concludes that Germany will probably keep falling behind the climate targets until 2030.

3.3. The increasing cost of producing electricity

It is not impossible but hardly easy to compare the price of sources used for producing electricity. Bruninx et al. (2012) used simulations to show that the complete shutdown of nuclear reactors would lead to increasing reliance on coal- and lignite-based energy generations, whereas generation by RES would remain at a low or medium level. Still, their research ignored the development of electromobility and the resulting rapid increase of demand for electricity. The simulation based on the ELMOD model developed by Leuthold et al. (2012) revealed that the complete phase-out results in a drop to 20 percent of previous average levels in export, while electricity imports increased by 200 percent as of 2012. Ten years later, the observable data revealed that Germany was a net exporter of electricity in 2022. In view of the data published in 2023 by the Federal Network Agency (Bundesnetzagentur), the share of RES for consumed electricity increased to 48.3 percent (Bundesnetzagentur, 2023a). Hence, the German plans of 2010 to increase the share of renewables to 40 percent of electricity production within twelve years were actually overfulfilled.

There are different methods to define the price and the manufacturing cost of electricity. A prevalent approach is to apply the levelized costs of electricity (abbreviated as LCOE), but the methods of calculating LCOE may vary. Furthermore, costs may vary from power plant to power plant and from region to region. Greenpeace Energy implies external costs, such as estimated environmental damage and government subsidies. Table 2 presents the price of electricity as total societal cost of electricity generation (Schrems, 2021; Wissenschaftlichen Dienste des Deutschen Bundestages, 2022). It also includes expected LCOE data based on prices in 2021 (Energy Information Administration, 2022). The costs of newly established power plants seem to exclude the development of small modular nuclear reactors and new nuclear reactor types, which promise sinking costs, higher utilization levels of fuel rods, and consequently less toxic waste.

Table 2: Total societal cost of electricity generation in 2021 in comparison (Bundesnetzagentur, 2023a; Energy Information Administration, 2022). 1 EUR is equal to 1.07 USD based on the currency conversion on September 11, 2023.

Technology	euro cents/kWh provided by government	euro cents/kWh for new power plants	euro cents/kWh for new power plants entering in 2027 without tax credits (LCOE) U.S. data
Nuclear power	37.8	46.4	(advanced) 7.7-9.2
Brown coal - lignite	25.5	33.1	-
Coal	23.3	33.3	(ultra-supercritical) 6.9-9.5
Solar photovoltaic	22.8	7.1	2.8-4.5
Wind power offshore	18.5	9.7	10.3-15.9
Wind power onshore	8.8	6.1	2.8-6.1

Wallner et al. (2011) predict that the decrease of uranium ore content will raise the price of uranium, which in turn will lead to higher cost of nuclear fuel. In contrast, a deeper analysis performed by the authors of an OECD study reveals that nuclear electricity generation is not impacted by price fluctuations as significantly as the electricity generation from fossil fuels. It also demonstrates that for nuclear power, the major external costs have already been internalized, while the analogous costs of solar power farms and fossil fuel-fired power plants have not been included in the calculations. The study concludes that the main risk lies in the long planning period of establishing a nuclear power plant (OECD, 2006). This risk may be considerably reduced by the use of the recently developed small modular reactors, which not only shorten the development time and lessen the costs, but also provide high scalability and flexibility. In the case of a conventional nuclear reactor, the initial investment accounts for about half of the entire expense of electricity production, while operation, maintenance, and the fuel cycle account for about 20 percent each. The OECD study on Projected Costs of Generating Electricity compares the average costs of generating electricity through different fuel types. Depending on country-specific factors, the building of a new nuclear reactor with its entire lifecycle would be the cheapest one with an annual discount rate of 5 percent in five of the examined twelve countries.

Another method to define the cost of electricity is that the price is set by the power plant which generates electricity at the highest price (Wissenschaftlichen Dienste des Deutschen Bundestages, 2022; Forst,

2022; Heymann, 2023). Accordingly, the natural gas-fired power plants became the price-setting electricity generator in 2022. Consequently, the average day-ahead wholesale price of electricity skyrocketed from 96.85 EUR/MWh in 2021 to 235.45 EUR/MWh in 2022, denoting a 143 percent rise (Bundesnetzagentur, 2023a). Just a few days after the outbreak of the Russian-Ukrainian war, the price soared to 487.57 EUR/MWh, and later rose as high as 699.44 EUR/MWh. Mier (2022) states that the gas price stood at 200 EUR/MWh in August 2022, i.e., ten times higher than during the COVID pandemic. He predicts that the price will go down to approximately 40 EUR/MWh, from which currently we are still far, as the price stands at 89 EUR/MWh for new contracts and 127 EUR/MWh for old contracts, respectively (CHECK24 Vergleichsportal GmbH, 2023). The price drop may continue, since EU demand for natural gas is falling due to the broadening use of heat pumps. The above-mentioned natural gas price shock led to additional operation of the existing coal- and lignite-fired power plants. To achieve the required reduction in greenhouse gas emissions and maintain the price of electricity generation, the utilization of the fossil fuel-fired power plants must be kept temporary, for otherwise Germany's energy transition might turn out a complete fiasco.

Renewable energy sources have made a significant contribution to the generation of cheap electricity, yet they are not always efficient. Due to fluctuations in sunshine and wind intensity, they may not generate sufficient electricity to meet the demand at peak times. Their greatest disadvantage is that they cannot be simply switched off or scaled down. Consequently, electricity prices may go negative. For instance, in the summer of 2023 the price stood at around -500 EUR per MWh due to the excess utilization of both wind and solar power (Krapp, 2023). This means that someone using 1 MWh per hour electricity could also have gotten paid for the consumption. Meanwhile, fossil fuel-fired reactors provided 11 gigawatts, which was necessary to maintain the stability of networks, but increased both greenhouse gas emissions and the price of electricity.

German society has traditionally favored the use of renewable energy. The majority of the population, 57 percent of the respondents of a survey, seem to believe that the expansion of renewable energies should be the best option to reduce dependency on energy imports from Russia. That is, the share of respondents preferring RES is nearly two times higher than that of those in favor of oil and gas imports (31 percent) or the increased use of nuclear reactors (28 percent) (Agora Energiewende, 2023). Nevertheless, the cost of RES is also bound to increase, which in turn will raise the overall costs of the transition process (Witsch, 2022). The cost of establishing the vital infrastructure and creating short- and long-term storages is staggering, and must be borne by the taxpayers. In 2021, the Federal Court stated that the energy transition "threatens to overcharge private households and companies financially," and the costs of the grid conversion "will propel the electricity price even further" (Holly, 2023). As the entire economy has started to cool down, the price of fossils dropped, whereupon OPEC and Russia curbed oil and gas production. Nevertheless, experts regard the latest decrease in energy prices as temporary, and expect a later price increase, which will in turn further increase the burden on households both in the EU in general and in Germany in particular (Moll, 2023). Greater dependency on renewables may also reduce the level of supply reliability, which in turn may cause power shortages. To assess the likelihood of a nationwide blackout, Germany's Federal Ministry for Economic Affairs and Climate Action initiated two stress tests. The first one was conducted soon after the outbreak of the Russian-Ukrainian war, and thus it could assess the impacts of the war only to a minimal extent. In contrast, the second stress test included all potential critical scenarios between July and September. While the ministry concluded that the probability of a nationwide blackout was minimal, a so-called brownout may happen. In such a scenario, power supply would be limited to those companies with which the ministry signed agreements in advance. Should this prove insufficient, even the aforesaid companies may be subjected to temporary and pre-planned shutdowns (Federal Government, 2023; Witsch & Winkelhahn, 2023).

The adverse attitude that German public opinion held toward nuclear energy was probably the most significant factor behind the all-out shutdown of nuclear reactors in the country. Actually, these reactors could have reduced the share of fossil-fired power plants. If one takes into consideration that nuclear reactors emit only a small fraction of the greenhouse gasses emitted by fossil-fired power plants, and assumes that science will develop advanced solutions for handling nuclear waste, the rapid phase-out of nuclear power plants may be regarded as a somewhat careless and hasty decision that was made largely in response to public opinion. Currently it is extensively discussed whether the closure could have been postponed until funding could have been provided for the establishment of small modular reactors. What is certain is that in the short and medium term, greenhouse gas emissions and electricity costs have increased and will remain high. It is to be seen whether they will undergo any significant decline on the long run.

3.4. Germany's Electricity Trade

Since Germany is among the pioneers for large-scale electricity generation from renewables, the country also faces some unexpected challenges related to alternative energy sources. The following section attempts to give an answer to the question of whether Germany could have found alternative sources for the electricity hitherto generated by nuclear power plants before the completion of the shutdown process and whether it could gain or maintain a competitive advantage through the increasing utilization of climate-friendly renewables.

The Federal Network Agency publishes the electricity market data on the website smard.de (an abbreviation of Strommarktdaten). The data show that Germany had remained a net exporter of electricity until 2022, when the level of electricity consumption fell to the level of 2020. Still, the rapidly increasing electromobility is expected to increase demand for electricity.

Figure 1: Changes in Germany's electricity exports, 2018-2023 (Bundesnetzagentur, 2023c)

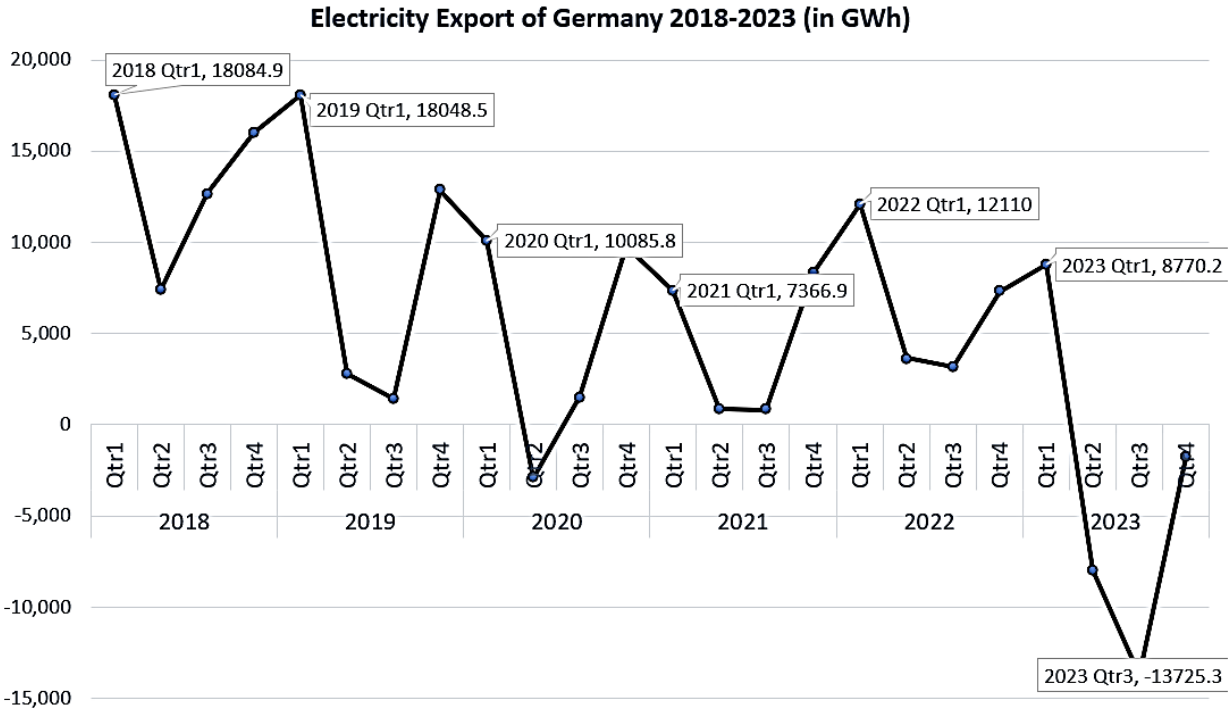

Figure 1 reveals substantial seasonal fluctuation in electricity exports. During the summer seasons, Germany usually imports electricity, whereas the excess production of its power sector is exported

during the cold seasons. At the same time, one can observe a long-term decrease in electricity exports. Net exports underwent an increase of 8.9 TWh from 2021 to 2022, only to be followed by a sharp drop during the year 2023. During the second quarter of 2023, an amount of 7.9 GWh (another source mentions 7.1 GWh) was imported, which roughly corresponds to the amount of electricity generated by nuclear reactors during the same quarter of 2022 (Bundesnetzagentur, 2023b; Tagesschau, 2023b). Thus, Germany has been transformed from a net exporter of electricity into a net importer, either because renewable sources were not sufficient yet to meet the demand for electricity, or because the price of imported electricity was lower than that of the electricity domestically generated from renewable sources. Krapp (2023) found out that neighboring countries, such as the Netherlands, Denmark and Norway, produced electricity at a lower cost than Germany by harnessing wind energy.

Meanwhile, changing weather conditions are expected to affect electricity production based on renewable sources, which in turn will lead to negative electricity prices, as it occurred in the first and second quarters of 2023 (Bundesnetzagentur, 2023c; Lincke, 2023). Periods of a negative price increased from 14 hours in the first quarter of 2022 to 23 hours in the first quarter of 2023.

4. Conclusion

This case study reveals a few challenges of the ongoing green energy transition in Germany. Following the complete phase-out of nuclear reactors, the data show a controversial picture: increased electricity production from natural gas, coal and lignite; negative electricity prices; and increasing energy dependency on Russian natural gas. At the same time, various European countries still rely on first- or second-generation nuclear reactors, which were switched off in Germany.

Having opted for a complete energy transition, Germany currently faces various challenges. The original targets of reducing greenhouse gas emissions may not be maintained, not only because the nuclear reactors were taken off the grid, but also because of several other important reasons. For instance, all photovoltaics tenders have been signed, while 16 of the 20 onshore wind tenders have been signed since 2019. In 2022 alone, achievements fell short of the targets by 1.3 gigawatts. The phase-out of nuclear reactors further increased the emission levels. Thus, this case study revealed that the phase-out might have been premature, and that the targets for reducing greenhouse gas emissions may have been too ambitious.

Electric power is an extremely perishable product that must be stored with great care. Unfortunately, consumers face considerable information asymmetry in that they are told that the use of renewable energy will lead to a decline of electricity prices. This may be partly true, especially if consumers also generate and store electricity. Renewables thus have the potential to reduce household expenses. Still, such storages are either unavailable at a price that ordinary consumers can afford, or they have not been developed yet. Accordingly, it is reported that prices are likely to undergo a new increase, and their recent decline may not continue (Moll, 2023). The use of renewables increases the instability of power supply. Judging from the results of the stress tests, a nationwide blackout is unlikely, but companies might be subjected to temporary power cuts (brownouts).

The price of power generation is not fixed. Its fluctuation is influenced by various factors, such as the season, the hours of the day, and the changing weather conditions. It is a commonly held view that the price of nuclear power generation is too high, but an OECD study argues that the major cost and risk lies in the planning period of establishing a nuclear power plant (OECD, 2006). As mentioned, this study was published before the recently developed small modular reactors and next generation reactors entered production. In Germany, in 2022 the price was set by the highest cost of electricity production that was consumed. This power was generated by natural gas fired reactors, and the price of natural gas was severely affected by the outbreak of the Russian-Ukrainian war in 2022. It is also known that such

extreme price fluctuations will not influence electricity prices if it is produced by nuclear power plants. In contrast, fossil fuel fired reactors are cheap to build but vulnerable to the volatile price of fossil sources. Due to the unpredictable fluctuation of oil and gas prices, Germany also needs to operate coal- and lignite-fired power plants to maintain grid stability. As far as prices are concerned, Germany was definitely harmed by the rapid phase-out of its conventional old nuclear reactors. Further inspections could have ascertained whether and how one or two of the last three nuclear reactors could have been operated for a few more years, thus facilitating the process of energy transition and possibly exerting a favorable influence on public attitudes toward nuclear energy, especially if the operation of small modular and next-generation reactors becomes safer than that of the conventional reactors.

Although German society has paid a high price for the energy transition process, German public opinion continues to favor renewables, but in the face of the rapid price hikes in 2022 and the intensified utilization of solid fossil fuels to produce electricity, many citizens expressed the opinion that the nuclear phase-out was probably a mistake (Zeit Online, 2023).

5. Acknowledgement

The present research has been conducted by the Research Grant of Kwangwoon University in 2023.

REFERENCES

[1] Agora Energiewende. (2023). *Die Energiewende in Deutschland: Stand der Dinge 2022* (Analysis 283/01-A-2023/DE). Agora Energiewende.

[2] Berbner, T. (2023, April 14). Wenn der Strom ausbleibt, friert alles ein. *Tagesschau*. https://www.tagesschau.de/wirtschaft/unternehmen/atomausstieg-folgen-wirtschaft-industrie-103.html

[3] Bruninx, K., Madzharov, D., Delarue, E., & D'haeseleer, W. (2012). Impact of the German nuclear phase-out on Europe's electricity generation. *2012 9th International Conference on the European Energy Market, European Energy Market (EEM), 2012 9th International Conference on The*, 1–10. IEEE Xplore Digital Library. https://doi.org/10.1109/EEM.2012.6254663

[4] Bundesnetzagentur. (2023a). *Bundesnetzagentur veröffentlicht Daten zum Strommarkt 2022* [Press release]. Bundesnetzagentur. https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2023/20230104_smard.html

[5] Bundesnetzagentur. (2023b, April 14). *Großhandelsstrompreis gesunken*. https://www.smard.de/page/home/topic-article/444/210326

[6] Bundesnetzagentur. (2023c). *Strommarktdaten*. https://www.smard.de

[7] Bundeszentrale für politische Bildung. (2023, April 14). *Atomausstieg – Deutschland verabschiedet sich endgültig von der Kernkraft*. https://www.bpb.de/kurz-knapp/hintergrund-aktuell/520059

[8] CHECK24 Vergleichsportal GmbH. (2023, September 22). *Gaspreisentwicklung: Das ändert sich für Gaspreise 2024*. https://1-gasvergleich.com/gaspreise/

[9] Deutschlandfunk. (2023, April 24). Die Auswirkung der Dunkelflaute auf die deutsche Energiewende. *Deutschlandfunk*. https://www.deutschlandfunk.de/dunkelflaute-erneuerbare-energien-kohleausstieg-100.html

[10] Energy Information Administration. (2022). *Levelized Costs of New Generation Resources in the Annual Energy Outlook 2022*. https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

[11] Engler, S., Janik, J., & Wolf, M. (Eds.). (2020). *Energiewende und Megatrends* (1st ed.). transcript Verlag; JSTOR. http://www.jstor.org/stable/j.ctv371bxt8

[12] Federal Government. (2023). *Stromausfall – eine Risikoanalyse*. https://www.bundesregierung.de/breg-de/schwerpunkte/klimaschutz/stromausfall-blackout-2129818

[13] Forst, K. (2022, October 8). *Warum neben Gas auch der Strom teurer wird*. https://www.sr.de/sr/home/nachrichten/politik_wirtschaft/warum_auch_der_strom_teurer_wird_100.html

[14] Haahr, T. (2022, July 6). *Taxonomy: MEPs do not object to inclusion of gas and nuclear activities*. https://www.europarl.europa.eu/news/en/press-room/20220701IPR34365

[15] Heymann, E. (2023). *Kosten der Stromerzeugung* (Deutschland-Monitor) [Research]. Deutsche Bank AG. https://www.dbresearch.de/PROD/RPS_DE-PROD/PROD0000000000528293/Kosten_der_Stromerzeugung%3A_Auf_die_Systemkosten_ko.PDF;REWEBJSESSIONID=4F64865231EE5D26889326CA53DDA1B9?undefined&realload=ANjzI0NG4L0SffIvYTBQDuGHPj6K~c8flp5NfPjOSP5~bk0wDtb55zteq~CxQ/ay

[16] Holly, L. (2023, June 20). *Unsozialer Ausstieg*. https://taz.de/Ende-der-Atomenergie/!5938892/

[17] International Emissions Trading Association (IETA). (2019). *Offsets: The Basics*. https://www.ieta.org/resources/Resources/101s/Offsets.pdf

[18] Krapp, C. (2023, July 6). *Wieso Verbraucher am Wochenende Geld verdienen konnten*. https://www.handelsblatt.com/unternehmen/energie/strompreise-wieso-verbraucher-am-wochenende-geld-verdienen-konnten/29236070.html

[19] Leuthold, F. U., Weigt, H., & von Hirschhausen, C. (2012). A Large-Scale Spatial Optimization Model of the European Electricity Market. *Networks and Spatial Economics*, *12*(1), 75–107. EconLit with Full Text. https://doi.org/10.1007/s11067-010-9148-1

[20] Lincke, F. (2023, July 4). *Negativer Strompreis: Wer kann davon profitieren?* https://www.br.de/nachrichten/wirtschaft/negativer-strompreis-so-koennen-verbraucher-von-schwankungen-an-den-energieboersen-profitieren,Tj1o0SV?UTM_Name=Web-Share&UTM_Medium=Link&UTM_Source=Link

[21] Mez, L., & Piening, A. (2002). Phasing-Out Nuclear Power Generation in Germany: Policies, Actors, Issues and Non-Issues. *Energy & Environment*, *13*(2), 161–181. https://doi.org/10.1260/0958305021501155

[22] Mier, M. (2022). Erdgas- und Strompreise, Gewinne, Laufzeitverlängerungen und das Klima. *Ifo Schnelldienst*, *75*(9), 20–26. Business Source Ultimate.

[23] Moll, M. (2023, January 30). Weshalb Strom- und Gaspreise immer weiter steigen werden. *Focus-online*. https://www.focus.de/earth/energie/energiepreise-von-morgen-warum-strom-und-gaspreise-immer-weiter-steigen-werden_id_184137308.html

[24] Münchenberg, J. (2023, July 18). *Zu langsamer Ausbau von Windkraftanlagen*. https://www.deutschlandfunk.de/windanlagenbauer-melden-ausbau-von-windkraft-dlf-f498100e-100.html

[25] OECD. (2006). *Kernenergie heute*. Éditions OCDE / OECD Publishing; OECD iLibrary. https://doi.org/10.1787/9789264026544-de

[26] Rosenkranz, G., Froggatt, A., Kreusch, J., Neumann, W., Appel, D., Diehl, P., Nassauer, O., Thomas, S., & Matthes, F. Chr. (n.d.). *Mythos Atomkraft. Ein Wegweiser* (Matthes, Felix, Ed.). Retrieved August 30, 2023, from https://www.boell.de/sites/default/files/assets/boell.de/images/download_de/oekologie/Mythos_Weg_Inh_Buch.pdf

[27] Schrems, I. (2021). *Gesellschaftliche Kosten von Kohlestrom heute bis zu dreimal so teuer wie Kosten von Strom aus erneuerbaren Energien*. https://foes.de/publikationen/2021/2021-09_FOES_Factsheet_Kostenvergleich_Kohle_EE.pdf

[28] Selje, T. (2022). Comparing the German exit of nuclear and coal: Assessing historical pathways and energy phase-out dimensions. *Energy Research & Social Science*, *94*, 102883. https://doi.org/10.1016/j.erss.2022.102883

[29] Staude, J. (2023, May 23). *Wind-Ausbau um fast zwei Drittel zu langsam*. https://www.klimareporter.de/strom/wind-ausbau-um-fast-zwei-drittel-zu-langsam

[30] Tagesschau. (2023a, April 14). Mehrheit ist gegen Atomausstieg. *Tagesschau*. https://www.tagesschau.de/inland/deutschlandtrend/deutschlandtrend-3357.html

[31] Tagesschau. (2023b, September 6). *Deutschland importiert deutlich mehr Strom*. https://www.tagesschau.de/wirtschaft/energie/stromimporte-erzeugung-energiemix-100.html

[32] Thelen, S. (2023, January 4). Verbrauch sinkt, Emission gleich: Kohle-Rückkehr lässt die Klimaziele platzen. *ZDFheute*. https://www.zdf.de/nachrichten/wirtschaft/energiewende-kohle-gas-solar-energie-ukraine-krieg-klima-100.html

[33] Wallner, A., Wenisch, A., Baumann, M., & Renner, S. (2011). *Energiebilanz der Nuklearindustrie* [Study]. https://wua-wien.at/images/stories/publikationen/studie-energiebilanz-nuklearindustrie-kurzfassung.pdf

[34] Weber, J. (2021, November 11). *Ist Atomenergie klimafreundlich?* https://www.dw.com/de/faktencheck-ist-atomenergie-klimafreundlich-was-kostet-strom-aus-kernkraft/a-59709250

[35] Wissenschaftlichen Dienste des Deutschen Bundestages (2022). *Gestehungskosten von Strom im Vergleich*. Zenodo. https://doi.org/10.5281/zenodo.6326972

[36] Witsch, K. (2022, January 28). Der Preisverfall der Erneuerbaren ist vorbei: Energiewende wird teurer. *Handelsblatt*. https://www.handelsblatt.com/28013512.html

[37] Witsch, K., & Winkelhahn, R. (2023, April 20). Wie wahrscheinlich ist ein totaler Blackout in Deutschland? *Handelsblatt*. https://www.handelsblatt.com/unternehmen/energie/stromausfall-wie-wahrscheinlich-ist-ein-totaler-blackout-in-deutschland/28822614.html

[38] World Nuclear Association. (2012). *Comparison of Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources* (WNA Report). World Nuclear Association. https://www.world-nuclear.org/uploadedfiles/org/wna/publications/working_group_reports/comparison_of_lifecycle.pdf

[39] Zeit Online. (2023, April 14). *Mehrheit der Deutschen gegen Atomausstieg*. Https://Www.Zeit.de/Wirtschaft/2023-04/Mehrheit-Deutschland-Gegen-Abschaltung-Kernkraftwerk-Atomkraft. https://www.zeit.de/wirtschaft/2023-04/mehrheit-deutschland-gegen-abschaltung-kernkraftwerk-atomkraft