How Can Germany Avoid the Next Energy Crisis? Impact of an Import Ban of Russian Energy Sources on Climate Protection Goals in Germany

by

Anas Abuzayed*, Niklas Hartmann, Anna Sandhaas, Cesar De Jesus Tabora, Hanhee Kim
Offenburg University of Applied Sciences
INES – Institute of Sustainable Energy Systems
Badstr. 24, 77652 Offenburg, Germany

* Corresponding author.
E-mail address: anas.abuzayed@hs-offenburg.de (A. Abuzayed).

Abstract

An import ban of Russian energy sources to Germany is currently being increasingly discussed. We want to support the discussion by showing a way how the electricity system in Germany can manage low energy imports in the short term and which measures are necessary to still meet the climate protection targets. In this paper, we examine the impact of a complete stop of Russian fossil fuel imports on the electricity sector in Germany, and how this will affect the climate coals of an earlier coal phase-out and climate neutrality by 2045.

Following a scenario-based analysis, the results gave a point of view on how much would be needed to completely rely on the scarce non-renewable energy resources in Germany. Huge amounts of investments would be needed in order to ensure a secure supply of electricity, in both generation energy sources (RES) and energy storage systems (ESS). The key findings are that a rapid expansion of renewables and storage technologies will significantly reduce the dependence of the German electricity system on energy imports. The huge integration of renewable energy does not entail any significant imports of the energy sources natural gas, hard coal, and mineral oil, even in the long term. The results showed that a ban on fossil fuel imports from Russia outlines huge opportunities to go beyond the German government's climate targets, where the 1.5-degree-target is achieved in the electricity system.

Keywords:

Climate change, Energy policy, Coal phase-out, Russian Ukrainian war

Highlights

- Ramping-up coal-fired power plants might secure a short-term energy supply, but most certainly can seriously violate the sustainable climate goals in Germany on the long-term.
- A system with 100 % renewable energy is possible, but highly demanding and challenging.
- The need for high flexibility measures significantly increases with the absence of conventional fired power plants.

Overview

Russia is the main supplier for Germany's fossil fuel needs, with more than 50% of its primary energy consumption (Figure 1). Recent events showed, however, that this addiction led to explosive energy prices, which will at one point, the least, lead to an energy crisis. A ban on the import of Russian energy sources to Germany is currently the subject of increasing discussion.

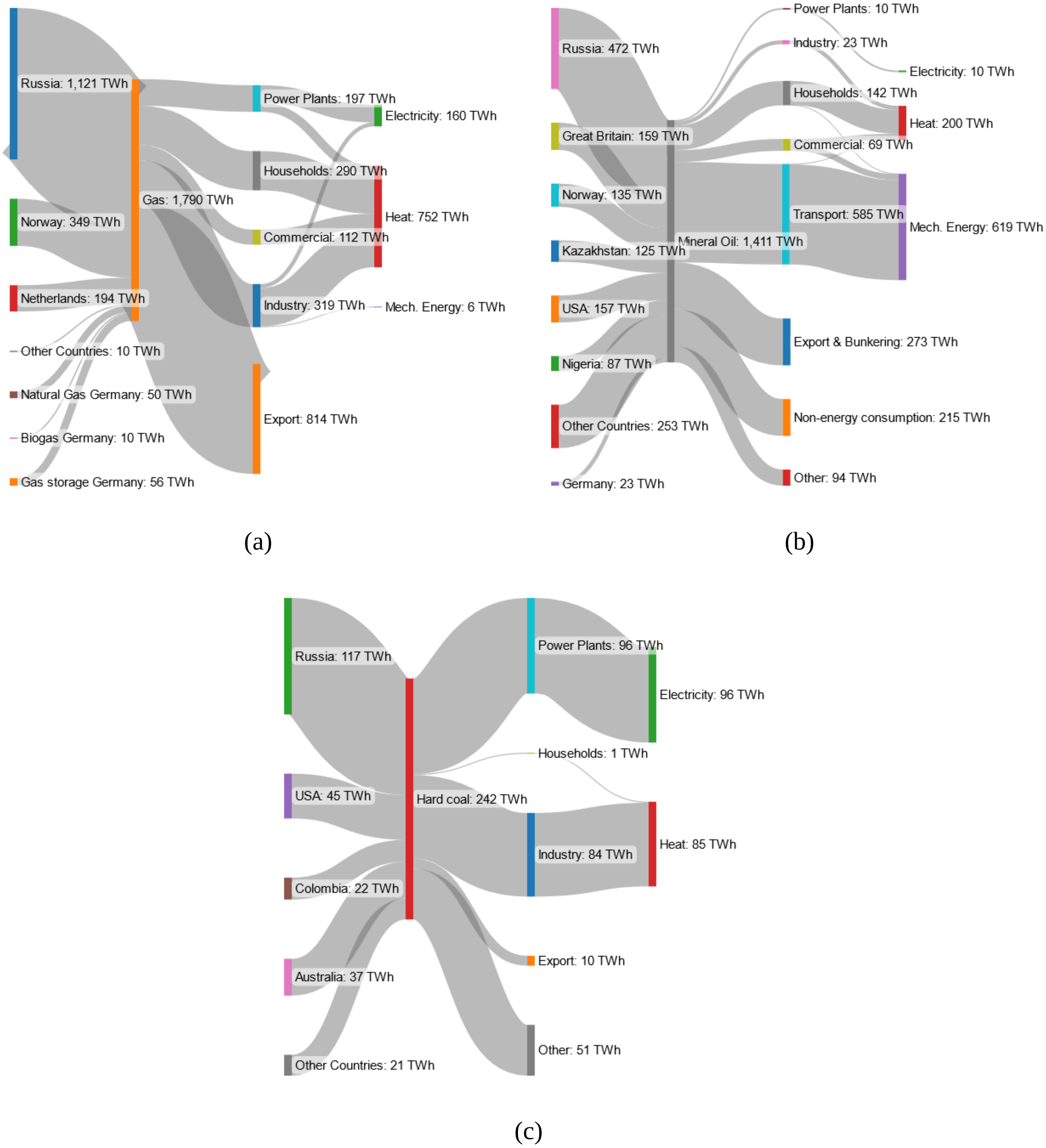


Figure 1: Imports and exports of the energy sources (a) natural gas, (b) mineral oil and (c) hard coal in 2020; the unit TWh indicates the energy content of the respective energy sources. [1-8]

In 2020, Germany imported 94 % of its natural gas (for simplicity, the term gas is often used below), half of which was further exported as shown in Figure 1 [1]. Within Germany, gas is used in four main consumption sectors for the provision of energy. The largest share is used in the household and commercial, trade and services (CTS) sectors for space heating and hot water, and in the industry to provide process heat [2] [3]. Mineral oil (the term oil is used in simplified form) in the chart includes crude oil (crude), crude gasoline, heating oil (light and heavy), liquid gas, refinery gas, gasoline, diesel and jet fuel. About 98 % of Germany's oil is imported (as of 2020), 19 % of which is re-exported [4]. One-third of oil imports comes from Russia. Oil is mainly used in the transport sector and for the provision of space heating, hot water and process heat [5]. Since 2018, Germany is importing all hard coal, the main customers being hard coal-fired power plants and the steel industry [6] [7] [8].

Scenario Development

Four scenarios are studied in this paper. Common to all scenarios is the assumption that fuel imports from Russia will be stopped at the end of 2022. Most recently, Russian supplies of natural gas through the MEGAL and Nord Stream 1 pipelines were decreased by around 70 % of their previous daily transmission capacities [9]. As the imports and exports of the energy sources in Figure 1 show, an import stop must reduce, above all, the demand for oil and the demand for gas in at least one of the demand sectors.

In this paper, we want to investigate how the electricity sector ("power sector") can compensate for a sudden abandonment of energy source imports from Russia as shown in Figure 2. With a priority given to heat supply, both oil and gas in 2023 will not be available for use in the electricity sector, and hard coal will only be available at 30% of the consumption volume in 2020. The available budget for the CO2 emissions in Germany for the electricity sector is calculated to be 2.14 and 1.34 Gt CO2 for the 1.75 and 1.5-degree-targets, respectively, assuming the electricity sector is responsible for 30 % of the total country’s emissions [10].

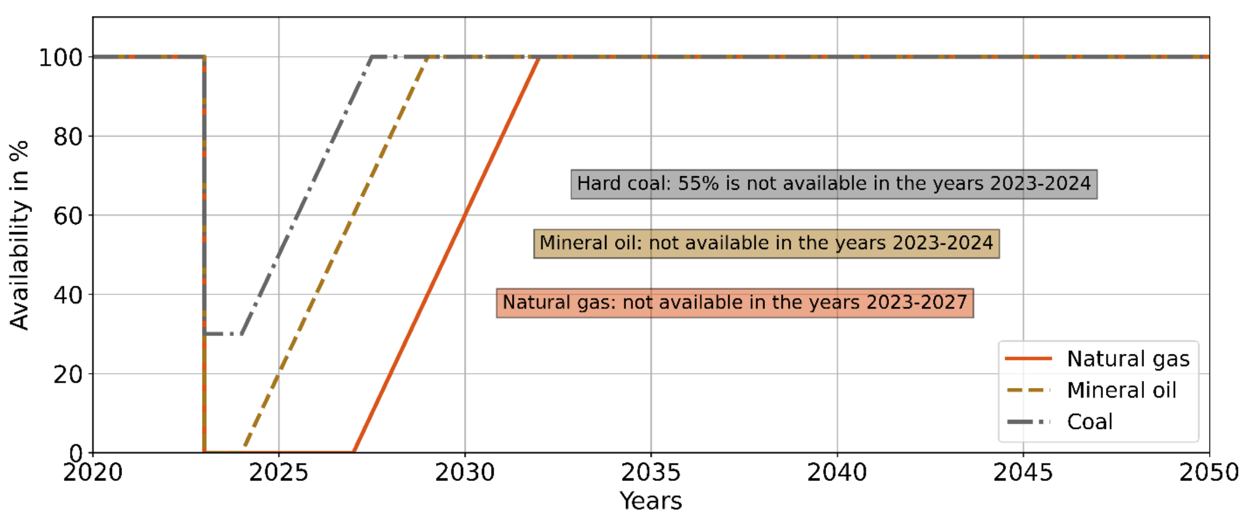
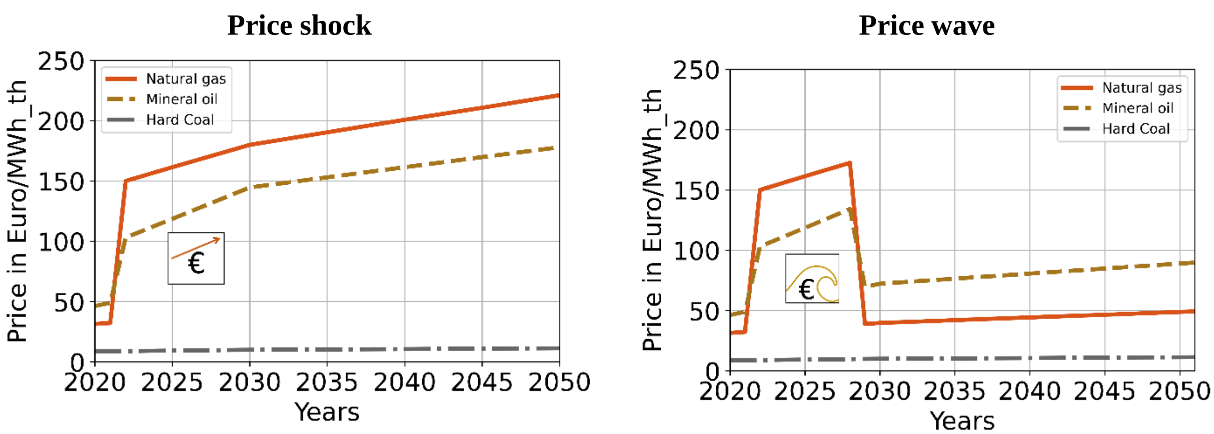


Figure 2: Scenarios availability of the energy sources hard coal, oil and gas in Germany's electricity system.

With the establishment of new relationships and contracts for energy imports from other countries, it is assumed that hard coal and oil will have limited availability for 2 years until their availability is raised again. For the import of natural gas, liquified natural gas (LNG) terminals have to be built. Here it is assumed that after 5 years the availability of natural gas also increases. All four scenarios show an annual total load of 543 TWh in 2020. The electrical demand is expected to increase rapidly in the coming years, either from the higher shares of electric mobility [11], or the potential of electrification in other consumption sectors, i.e. the industrial sector [12] [13], as well as the heating sector [14]. Therefore, an annual increase of 1 % is applied to the electrical demand so that partial electrification of other sectors are represented. A fixed cost of CO_2 allowance with a value of 25 Euros/t of CO_2 is assumed.

Scarcity of the energy supplies caused a historical rapid increase in the oil and gas prices in years. Currently, the prices spikes are more affecting in the short-term, but could also affect the long-term energy policies and sustainability goals [15]. The scenarios discussed in this study will differ in the prices for the energy sources gas and oil. Prices for hard coal remain unaffected from the price increase. Two different cost assumptions will be followed as shown in Figure 3. In the price shock scenario, fuel costs for natural gas and mineral oil rise sharply in 2022. Thereafter, fuel prices continue to rise moderately. Fuel costs in the price wave scenario will rise sharply in 2022, then fall again after 2028 and follow a normal price path of 2020 and 2021.



(a) (b)

Figure 3: Model costs assumptions for the two main scenarios (a) “Price shock” and (b) “Price wave)

With the continuous developments in Ukraine and the gas shortages in supply and storage facilities in Germany, many discussions are addressing the ability and robustness of the energy sector in Germany within the next winter, and which compensation measures will be implemented. The federal government announced at the end of 2021 a preponed phase-out date of coal and lignite fired power plants by 2030 [16]. However, recent warnings showed that the serious situation of gas supplies might lead to ramp up coal power plants again [17], especially in winter, as well as holding the ongoing phase-out by 2030 [18]. The feasibility of turning back to using coal fired power plants and prolonging their existence in the German electricity market will be studied throughout the scenarios, where the previous and new coal phase-out dates will be further analysed.

The general layout of the four scenarios is summarized in Table 1.

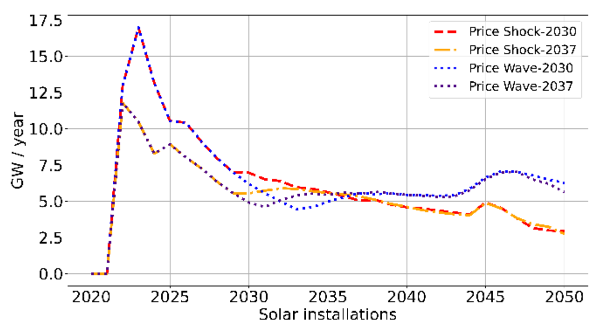
Table 1: Scenarios general settings.

Scenario	Coal Phase-out	Cost assumptions	Maximum RES expansion	Maximum ESS expansion
Price Shock 2030	2030	Figure 3 (a)	5 GW/region & 25 GW/year	16 GW/year
Price Shock 2037	2037	Figure 3 (a)		
Price Wave 2030	2030	Figure 3 (b)		
Price Wave 2037	2037	Figure 3 (b)		

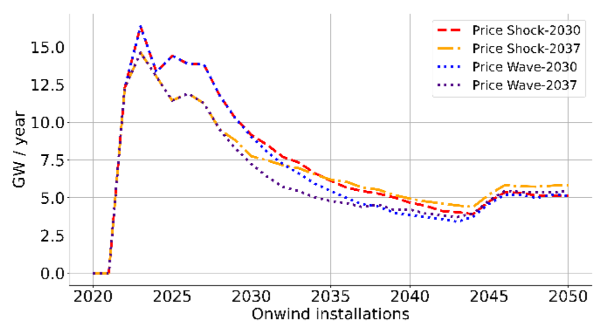
Results

The following results were calculated with the model MyPyPSA-Ger, an energy system model energy system model, which annually optimizes the expansion and and deployment of renewable and conventional power plants [19]. Using a myopic approach, the optimized years are combined to form a path to the year 2050 is developed. Thus, the transformation of the electricity system up to the year 2050 can be can be described. Last but not least, we would like to point out that energy system analysis always makes a large number of assumptions in the described scenarios. The assumptions underlying these scenarios are the same as those in the open source paper.

The studied scenarios showed some interesting aspects. Firstly, the earlier decommissioning of coal and lignite power plants by 2030 yielded higher investments in renewables, especially offwind technologies, along with short and long-term storage technologies. The complete shut down of power coming from gas power plants, along with the lack of adequate flexibility in the system, together incentivised the investments in renewables to nearly double the previous known installed rates in the country.



(a)



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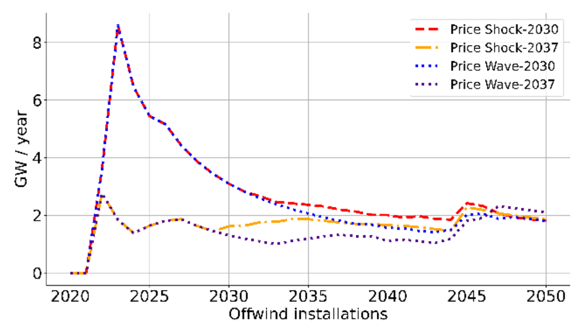


(c)

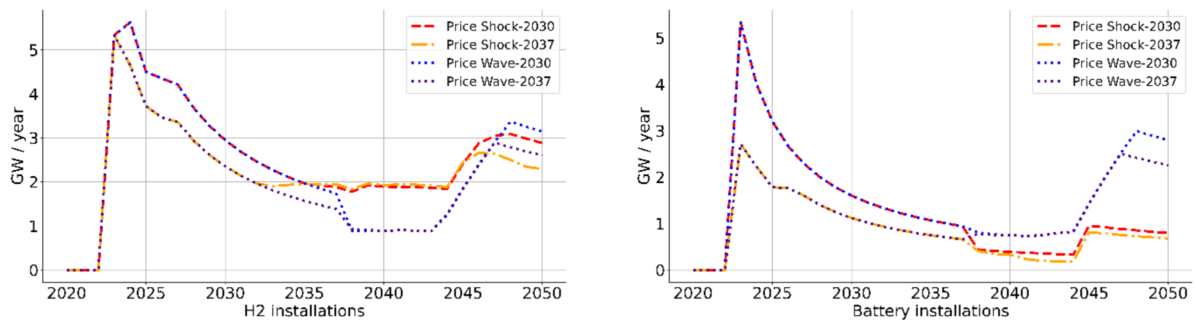
Figure 4: Yearly moving average installed power per renewable technology (a) solar, (b) onwind and (c) offwind

On the longer term, the price wave scenarios, where the fuel prices go down in the future, led to continuous high rates of yearly installed power, which means in total more additional installation in comparison with the wave shock scenarios, where less rates occurred due to the earlier investments. In other words, earlier and rapid investments in renewables will lead to lower system running costs, whereafter achieving climate neutrality by 2045, the system needs only to cover the additional demand in the network along with compensating for the decommissioned power plants. Table 2 summarizes the installed rates per scenario over the whole optimization period (2020-2050).

Table 2: Scenarios yearly average installed power

Scenario	Average solar installation in GW	Aearly average onshore wind installation in GW	Average offshore wind installation in GW
Price Shock 2030	3.0	5.1	1.8
Price Shock 2037	2.7	5.8	1.8
Price Wave 2030	6.2	5.1	1.8
Price Wave 2037	5.6	5.4	2.1

The nearly complete reduction in fossil fuel imports leads to huge investments in renewables in all scenarios, almost double the investments in previous years, in addition to huge investments in storage. With limited flexibility within the system, complete shortage of gas and oil, and limited usage of coal, the system faces high load shedding values by 2023 of nearly 40 GWh in the early phase-out scenario. This is mainly due to the ongoing phase-out by 2030 as well as the sudden absence of conventional flexibilities provided by gas power plants, as well as the inadequate storage capability of the system. In terms of storage investments as shown in Figure 5, higher needs of storage occur with the ban of Russian fuels in the system, especially in the early phase-out scenarios. However, on the long run, less investments were made, rather to compensate the outdated capacities which were earlier invested in.



(a) (b)

Figure 5: Yearly moving average of installed power per storage technology for (a) Hydrogen and (b) Batteries

After gas is reintroduced into the system, the system has already sufficient renewable generation capacity and enough flexible storage technologies, gas use in the energy mix experiences an almost complete decline and used to a small extent to provide flexibility and system security. The price wave scenarios came back to utilizing the gas fired power plants, especially with the earlier phase-out of coal, with a share of 8 % of the energy mix (56 TWh). However, in the price shock scenarios, the system had nearly only around 10 TWh (1.5 % of the energy mix) coming from gas fired power plants. Oil-fired power plants are not used due to their high prices and CO_2 emissions and the CO_2 allowances costs.

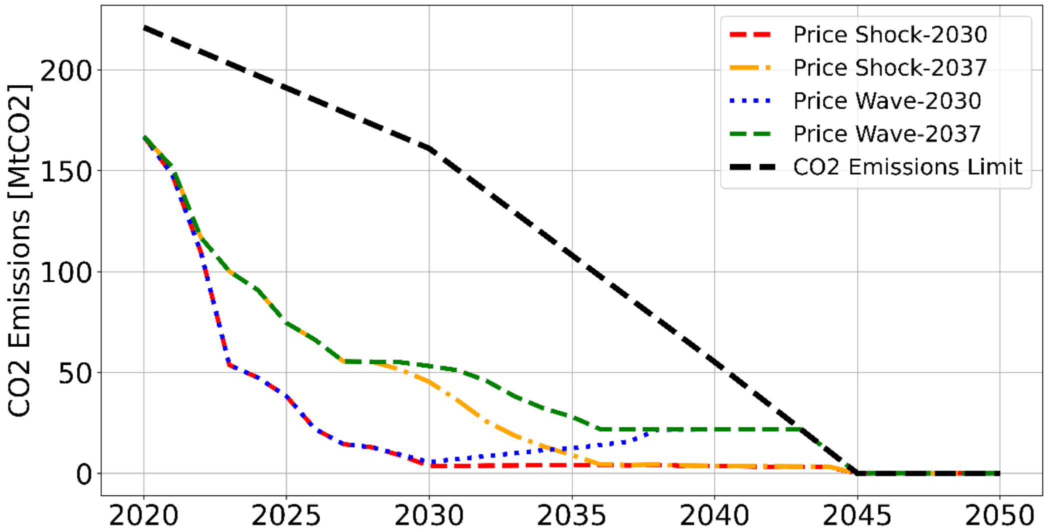


Figure 6: Scenarios emissions over the years.

Shortly around the complete phase-out of electricity generation from fossil fuels in 2045, another rapid increase in investment in renewable energies and storage technologies happens as well as a critical load shedding in the network, which reflects the enormous need for flexibility measures within the system. This is primarily because the final steps to achieve zero CO_2 emissions will require a great deal of effort. As this is a very difficult situation to accept in the German power system, higher investments in storage systems or industrial demand flexibility could prevent this load shedding.

The huge investments in renewables and storage technologies led not only to less dependence on fuel import, but to less utilization of conventional power. This was translated into the system emissions in Figure 6, where all scenarios except the price wave 2037 stayed in line with the 1.5 °C target of Germany. The scenarios main findings and results are compared in Table 3.

Table 3: Scenarios comparison

Scenario	Load Shedding at 2023 in GWh	Load Shedding at 2045 in TWh	Total System Emissions in Mt CO_2	Total System Cost in 10^9 Euros
Price Shock 2030	38	1.2	677	278
Price Shock 2037	0.1	0.98	1112	271
Price Wave 2030	38	5.76	849	277
Price Wave 2037	0.1	5.36	1366	299

The phase-out of coal and lignite by 2037 helped the system in terms of adequate flexibility from conventional sources, where in the 2030 scenarios these sources were compensated by using storage technologies. It can be seen from Figure 8 how the system reacted to the price increases and the fuel ban around 2022. Later after 2027, the wave scenarios had relatively lower total system costs due to the cheaper gas prices, while after that with the lower co2 limitations on the network, the total system costs increased again to compensate for the fuel-based power plants. The price shock scenario with a late phase-out was the cheapest system among all others. This is mainly due to the period where fuel imports from Russia were banned, as well as the relatively higher existence of coal-fired power plants, which helped the system to maintain a secure supply earlier on. Nonetheless, higher investments were made after the coal phase-out by 2037 and near the climate-neutral year by 2045. However, the scenarios with a later phase-out plan had extremely higher emissions compared to the other scenarios, where the best in terms of emissions was with the price shock, which incentivized a rapid transition, and an earlier coal phase-out from the system.

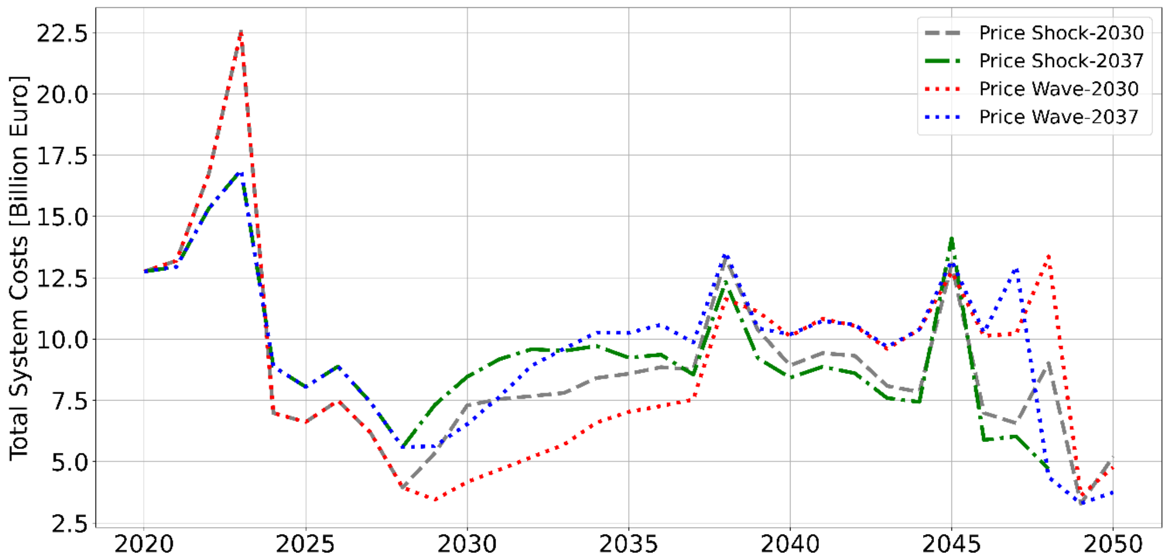
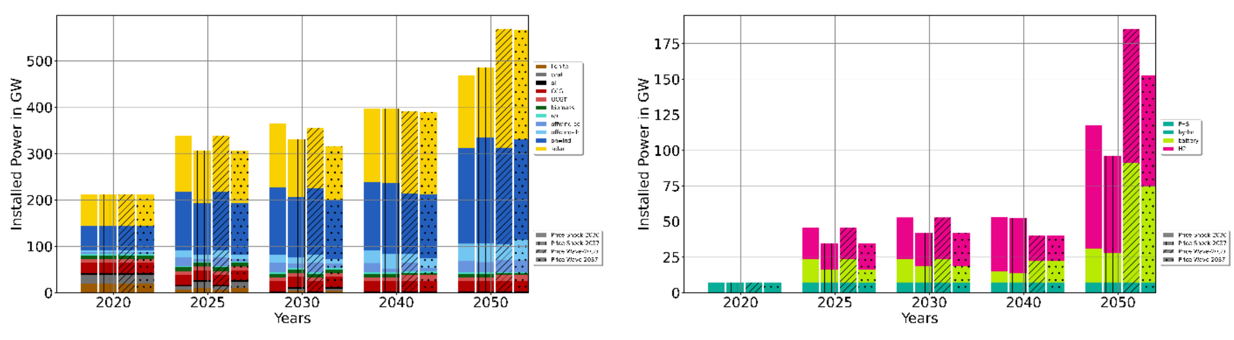


Figure 7: Total system costs over the years [excl. load shedding cost].

More to that, although the system faced earlier investments in the price shock scenarios due to many factors, mainly the fuel costs. However, both scenarios had way less total investments by 2050 as the system had already enough renewable generation and storage flexibility as show in Figure 8. In addition to that, more storage facilities were installed in the price wave scenarios, mainly due to the existing utilization of gas as a source of conventional flexibility in the network up to the climate neutrality year by 2045.



(a) (b)

Figure 8: Scenarios (a) power plants and (b) storage investments over the years.

Conclusions

It can be summarized that an early phase-out of conventional energy sources and an expansion of renewables pave the way to a low-carbon electricity system. The short-term reduction in fossil fuel imports leads to enormous investments in renewable energy in all scenarios, almost twice as high as the investments in the previous years, in addition to enormous investments in storage. However, many positive aspects can also be taken from the scenarios. For example, the early expansion of storage facilities means that not only in the short term, but also in the medium and long term, there is no need for significant quantities of natural gas in the electricity system. Moreover, the climate targets of the German government are met and, more importantly, the available CO_2 budget for the 1.5-degree target in the electricity system is undercut in all scenarios, except the Price Wave-2037 scenario. This will most certainly have a great advantage in the long-run and will allow for a rapid transition towards a carbon-neutral electrical system.

Although following the previous goals of phasing-out coal-fired power plants led to a more secure supply with absence of adequate conventional flexibilities. However, the total emissions in that scenario were nearly double the emissions with an earlier phase-out, and with normal gas prices, the total system emissions exceeded the 1.5 °C target. Other sources of flexibility within the system can be further analyzed and their potential along with the storage facilities should be adequate to run a secure system with 100 % renewables and not depend heavily on fuel imports.

The results showed that it would be possible after 2028 to run the electrical system without the gas-fired power plants, meaning that it is more important to focus on higher renewables and storage investments rather than building LNG gasification stations to replace gas pipelines. Stopping the gas, coal and oil imports can be very challenging, but not necessarily impossible. Great obstacles must be resolved in order to develop and achieve a 100 % self-sufficient energy strategy.

Acknowledgment

We gratefully acknowledge the German Federal Ministry of Economics and Technology (BMWi) for their fund. The work on the model in this paper was carried out as part of the project GaIN - Gewinnbringende Partizipation der mittelständischen Industrie am Energiemarkt der Zukunft; FKZ 0EI6019E, BMWi 2019 - 2022.

References

[1] AGEB, „Auswertungstabellen zur Energiebilanz Deutschland: Daten für die Jahre von 1990 bis 2020 [Evaluation tables for the energy balance for Germany: Data for the years from 1990 to 2020],“ AGEB, 2020.

[2] Equinor, „Anwendungsbereiche – Multitalent Erdgas [Areas of application - multi-talent natural gas],“ Equinor, 2022.

[3] Fraunhofer ISI, „Erstellung von Anwendungsbilanzen für die Jahre 2018 bis 2020: für die Sektoren Industrie und GHD [Preparation of application balances for the years 2018 to 2020: for the industry and CTS],“ Fraunhofer ISI, Karlsruhe, 2019.

[4] AGEB, „Auswertungstabellen zur Energiebilanz Deutschland: Daten für die Jahre von 1990 bis 2020 [Evaluation Tables for the Energy Balance Germany: Data for the Years from 1990 to 2020],“ AGEB, 2021.

[5] BAFA, „Amtliche Mineralöldaten für die Bundesrepublik Deutschland [Official mineral oil data for the Federal Republic of Germany],“ BAFA, 2020.

[6] Destatis, „Einfuhr von Steinkohle für die Jahre 2017 bis 2021 [Imports of hard coal for the years 2017 to 2021],“ Destatis, 2022.

[7] BMWK, „Conventional Energy Sources: Coal,“ BMWK, Berlin, 2022.

[8] German Institute for Economic Research, Wuppertal Institute, Ecologic Institute (eds.) , „Phasing out coal in the German energy sector : interdependencies, challenges and potential solutions," German Institute for Economic Research (DIW Berlin), Berlin, 2019.

[9] NDR, „First gas supplier calls for the state," 2022. [Online]. Available: https://www.tagesschau.de/wirtschaft/unternehmen/gas-krise-uniper-staatshilfe-101.html. [Zugriff am 30 06 2022].

[10] SRU, „Using the CO2 budget to meet the Paris climate targets - ENVIRONMENTAL REPORT 2020," The German Advisory Council on the Environment (SRU), Berlin, 2020.

[11] GTAI, „Future Mobility in Germany," Germany Trade and Invest, Berlin, 2021.

[12] S. Göss, „Germany's electrification ambitions: TSOs scenario for 91% Renewables by 2045.," Energy Post, 2022.

[13] T. Fleiter, M. Rehfeldt, M. Neuwirth und A. Herbst, „Deep decarbonisation of the German industry via electricity or gas? A scenariobased comparison of pathways," Fraunhofer ISI, Karlsruhe, 2020 .

[14] Fraunhofer IWES/IBP, „Heat transition 2030. Key technologies for reaching the intermediate and long-term climate targets in the building sector. Study commissioned by Agora Energiewende," Fraunhofer IWES/IBP, Berlin, 2017.

[15] J. Tollefson, „What the war in Ukraine means for energy, climate and food," *Nature,* Bd. 604, pp. 232-233, 2022.

[16] S. Amelang und B. Wehrmann, „Next German government aims for coal exit in 2030 in bid to get on 1.5 degree path," CLEW, 2021.

[17] E. Meza, „RWE halts early retirements as Germany ramps up coal use to replace Russian gas," CLEW, 2022.

[18] B. Jennen und J. Shankleman, „War Forces Germany to Put G-7 Coal Phaseout Push on Hold," Bloomberg, 2022.

[19] A. Abuzayed und . N. Hartmann, „MyPyPSA-Ger: Introducing CO2 taxes on a multi-regional myopic roadmap of the German energy system towards achieving the 1.5 °C target by 2050," *Applied Energy,* 2022.