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MARKET REPORT

2024

Increasing transmission capacity as a key
for the European energy transition

The Amprion annual market report analyses the developments of the European electricity market and the effects on the underlying transmission grid. This year's report addresses the developments on the electricity market and the European transmission grid from 2023. Based on these developments, it shows that grid expansion and increasing transmission capacity are key for the European energy transition.

For further information on the previous market reports and additional material on the Flow-Based Market Coupling concept, please visit the Amprion website: amprion.net/market/market-report

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EXECUTIVE SUMMARY

We have seen new records in the expansion and generation of renewable energies in Germany during 2023. However, for the first time in 21 years, Germany has become a net importer of electricity.

In 2023, more than 14 GW of photovoltaic and 3 GW of wind power were installed in Germany. During the same period, renewable electricity generation increased from around 242 TWh in 2022 to around 260 TWh. Then again, the last three nuclear power plants in Germany were decommissioned in April, while the overall electricity consumption decreased, and electricity imports increased substantially. These three factors have resulted in lower domestic electricity production in Germany. Consequently, the relative share of renewable energies in this lower level of domestic electricity production in Germany increased overproportionately from 47% in 2022 to 58% in 2023. This change to the electricity supply structure also has an impact on the electricity grid operation.

The completion of major grid expansion projects has relieved one of the biggest congestions in the German electricity transmission grid. In addition, the significant drop in prices for electricity has reduced the congestion management costs of transmission system operators.

Besides the structural changes in electricity generation, wholesale prices for electricity, hard coal and natural gas decreased in 2023. The average 2023 day-ahead electricity price in Germany was around 102 €/MWh, compared to 236 €/MWh in 2022. This helped in reducing congestion management costs across Germany from around 4 billion € in 2022 to 3.3 billion € in 2023. It is also worth emphasising

last year's completion of the major grid development project "EnLAG2" (Energy Line Expansion Act Project 2). Since the commissioning of this new transmission line connecting the control areas of Amprion and TenneT Germany, network congestions and the associated costs have dropped considerably.

The current Network Development Plan examines a transmission grid for a carbon-neutral energy sector of Germany for the first time. Amprion is contributing substantial grid investments both onshore and offshore to accelerate grid expansion.

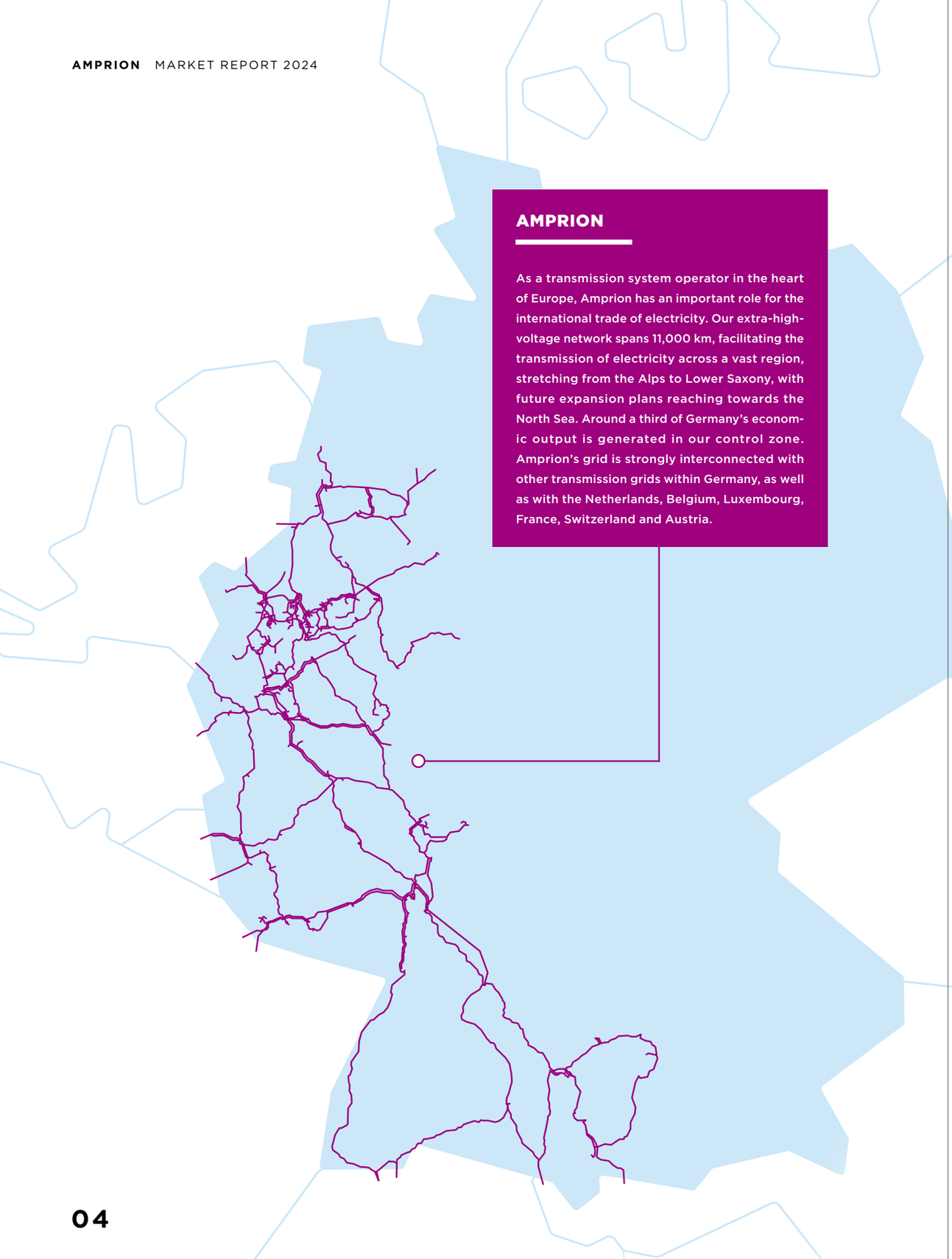
For a carbon-neutral electricity system, the installed renewable electricity generation capacity needs to expand up to 700 GW by 2045, corresponding to a fourfold increase compared to today. Storage technologies would have to support the integration of renewable energies with more than 100 GW of installed capacity. These are values from the underlying scenario of the new German Network Development Plan. Looking at these figures, the German coal phaseout in 2030 is just another step on the road to a carbon-neutral energy system. In order to accomplish the full transition, a further 7,400 km of grid reinforcements and expansion measures are required compared to the previous Network Development Plan from 2021.

No transition without transmission. Amprion and the European transmission system operators are ready for accelerating the pace of grid development in Europe if the right regulatory framework is in place.

As interconnected and stable electricity grids are the backbone of a well-functioning energy market, Amprion is developing holistic solutions for accelerated grid development. This needs to be accompanied by long-term network planning and the European market integration to fully exploit the potential of the electricity grids. Therefore, these processes are key for the European energy transition.

AMPRION

As a transmission system operator in the heart of Europe, Amprion has an important role for the international trade of electricity. Our extra-high-voltage network spans 11,000 km, facilitating the transmission of electricity across a vast region, stretching from the Alps to Lower Saxony, with future expansion plans reaching towards the North Sea. Around a third of Germany's economic output is generated in our control zone. Amprion's grid is strongly interconnected with other transmission grids within Germany, as well as with the Netherlands, Belgium, Luxembourg, France, Switzerland and Austria.



INTRODUCTION

The European Green Deal of 2019 has set the course of the European energy transition. Its major goal is achieving climate neutrality by 2050. To meet this goal, greenhouse gas emissions are to be reduced by 55% by 2030 compared to 1990. In 2023, member states and the European Parliament agreed with the third Renewable Energy Directive on a binding targeted share of renewable energies in the EU energy mix of at least 42.5% but are aiming for 45% by 2030. As the transmission grid is the key enabler for the further integration of renewable energies and the interconnection of markets, transmission system operators (TSOs) play an important role in the entire energy transition. On a national level, the German energy system is undergoing an unprecedented transformation. Electricity production from nuclear energy has just been phased out in middle of April 2023 and coal power generation is intended to be phased out by 2030. At the same time, an increasing share of renewable energies of up to 80% is envisaged. Ensuring a stable electricity system where generation and consumption is in balance at all times will become much more demanding in an increasingly dynamic and changing environment. Efficient cooperation between European TSOs and all other involved institutions is a key prerequisite for achieving this target.

Amprion is – and has been for decades – an integral part of such cooperations. We have been engaged in various regional and European system operation, grid planning and market integration initiatives. Our involvement in these initiatives has always been based on a close, trustful and constructive collaboration with the European TSOs, National Regulatory Authorities (NRAs), the EU's Agency for the Cooperation of Energy Regulators (ACER), power exchanges, a vast number of market parties and our association, the European Network of Transmission System Operators for Electricity (ENTSO-E).

AMPRION CONNECTS ELECTRICITY MARKETS ACROSS BORDERS

MARKET ANALYSIS 2023

RENEWABLE ELECTRICITY GENERATION IN GERMANY

The year 2023 shows some significant changes in the German electricity generation mix (cf. Table 1). The largest increase can be seen in the onshore-wind electricity production. Apart from grid expansion, favourable weather conditions contributed to this.

- A new record for feed-in from onshore wind was set for 2023 with a total of 119.2 TWh[1] or 26% of the overall electricity production. This is the largest increase among all types of electricity production technologies. Both the grid expansion facilitating more injections and favourable weather conditions contributed to this.
- Although installed capacity for solar has been increasing, with a record expansion in 2023 of more than 14 GW in installed capacity[2], unfavourable weather conditions led to fewer full-load hours (FLH)[3] compared to 2022[4]. The decrease from around 850 FLH in 2022 to just around 700 FLH on average in 2023 has even led to a decline in total electricity generation from PV in Germany. However, due to the overall decrease in domestic electricity generation, its relative share in electricity generation increased slightly from 11% to 12% in 2023.
- The share of renewable energies in overall electricity generation reached a new peak of around 58% in 2023. Newly installed capacity of renewable energies increased by 19 GW in 2023 compared to 11 GW in 2022, thereby surpassing the previous year.[5]
- Due to this significant increase in installed renewable electricity generation capacity, as well as further power plant decommissioning, coal-fired electricity production decreased by 7 percentage points in 2023 compared to 2022.
- At the same time, nuclear generation dropped further down to 2% following the nuclear phaseout in April 2023.

Other sources of electricity production (e.g. offshore wind) remained at constant levels or changed only moderately (e.g. hydro generation) compared to 2022.

New records in the expansion of renewable energies as well as in renewable electricity generation.

1 Source: smard.de/page/home/topic-article/209944/212762

2 Source: energy-charts.info/charts/installed_power/chart.htm?l=de&c=DE&expansion=installation_decommission&year=2023

3 Full-load hours for technical plants are calculated by dividing the annual generated electricity by its nominal capacity. It therefore shows how many hours a technical plant would need to produce a certain amount of electricity when operating at full capacity.

4 Source: energy-charts.info/downloads/Stromerzeugung_2023.pdf

5 Source: energy-charts.info/charts/installed_power

	Solar	Wind onshore	Wind offshore	Hydro	Bio-mass	Natural gas	Coal	Nuclear	Others
2021	9%	18%	5%	5%	8%	10%	30%	13%	3%
2022	11%	20%	5%	5%	8%	11%	33%	6%	2%
2023	12%	26%	5%	6%	8%	11%	26%	2%	3%

TABLE 1 Overview of electricity generation in Germany in 2021–2023 by source[6]

Another important aspect associated with this shift in electricity generation was the significant drop in coal and gas prices as well as CO_2 prices during 2023, which also resulted in a significantly lower electricity price. The average DA price in Germany was around 102 €/MWh, compared to 236 €/MWh in 2022. This is similar to the level reached in 2021 with DA prices averaging 97 €/MWh.

Despite low solar radiation in 2023, photovoltaics increased its share in electricity generation.

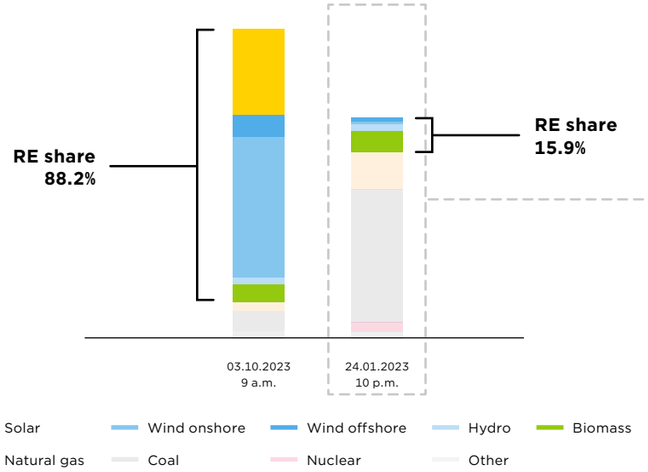


FIGURE 1 Highest and lowest share or renewable (RE) electricity generation in Germany in 2023[7]

6 Source: transparency.entsoe.eu

7 Source: transparency.entsoe.eu

The significantly large share of onshore-wind generation can also be seen in the point in time with the highest hourly renewable electricity production on 3 October 2023 at 9 a.m. with 46% of total electricity production (cf. Figure 1). With a share of 88% (27% solar, 53% wind, 8% other renewables) of total electricity production this marks a new record for renewable electricity production in Germany, compared to 82% on 21 May 2022 at 11 a.m.

In contrast, renewable electricity production reached its lowest level on 24 January 2023 at 9 p.m., with only 16% (0% solar, 2% wind, 14% other renewables) of total electricity production, followed by a period of relatively low renewable electricity production, until 29 January 2023 (cf. Figure 2).

Overall, the year 2023 displays further records of renewable electricity production. At the same time, the need for more flexible and controllable generation capacities remains. It continues to challenge the design of a future electricity system in which flexibilities must be available during times of low renewable electricity infeed to ensure the balance of generation and load. Furthermore, it was mainly large power plants with their constantly rotating masses that provided ancillary services in the past to keep the grid robust. In the future, renewable energy plants and consumers will increasingly have to supply these instruments. In the next five years, another 200 GW of wind and solar are to be connected to the grid. To ensure the stability of the grid, holistic solutions addressing an accelerated grid expansion are needed (cf. “Future developments” chapter).

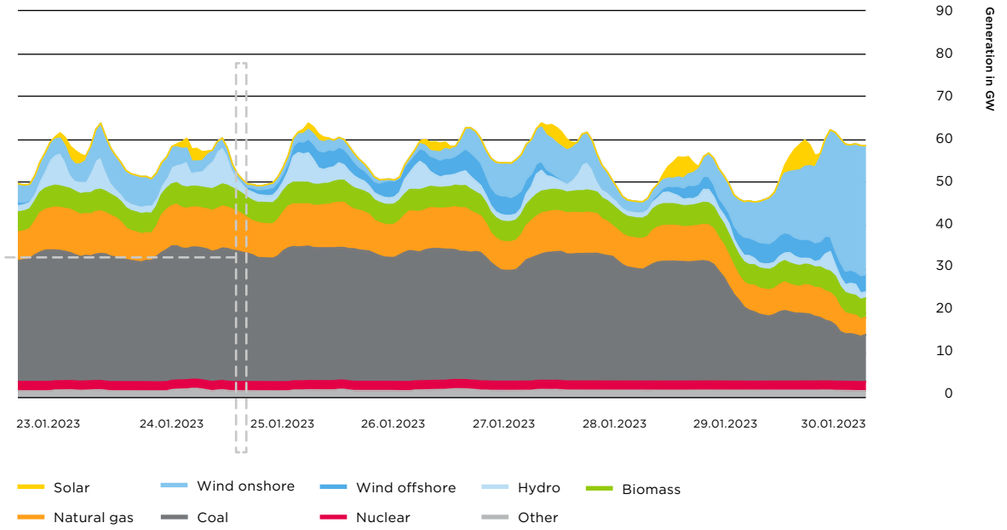


FIGURE 2 Electricity generation in Germany from 23 to 30 January 2023 by source[8]

8 Source: transparency.entsoe.eu

EXPORTS AND IMPORTS

Electricity exports and imports to and from bidding zones are represented by their net positions. As the net positions reflect the difference between exports and imports, a positive net position indicates a (net) exporting bidding zone, while a negative net position shows a (net) importing bidding zone.

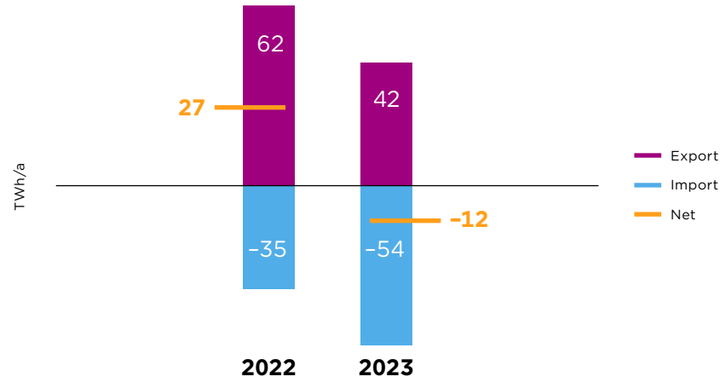


FIGURE 3 Yearly day-ahead exports and imports of Germany for 2022 and 2023[9]

For the first time in 21 years, Germany has become a net importer.

German day-ahead exports decreased by 20 TWh to 42 TWh in 2023 while German day-ahead imports increased by 19 TWh to 54 TWh in 2023 (cf. Figure 3). The net position of Germany therefore jumped from net exports of 27 TWh in 2022 to net imports of 12 TWh in 2023.

One example of this change can be seen on the German-French border: While Germany exported around 15 TWh to France in 2022, in 2023 0.4 TWh were imported from France to Germany. It should be noted that 2022 was an exceptional year with particularly high exports from Germany to France, as explained in the Amprion Market Report 2022/23[10]. Nevertheless, Figure 4 shows that Germany imported from several countries in 2023. Most imports, both in 2022 and in 2023, originated from Denmark with 10.7 TWh last year, followed by Norway with 4.6 TWh and Sweden with 2.9 TWh. Price differences are the primary reason for imports and exports. The argument that Germany is importing more since the nuclear phaseout should thus be interpreted with regards to the price level in its neighbouring countries. Meaning that importing electricity has been cheaper than local generation.

9 Source: transparency.entsoe.eu
10 Source: amprion.net/Dokumente/Strommarkt/Marktbericht/2023/Amprion_Market-Report_2022-23.pdf

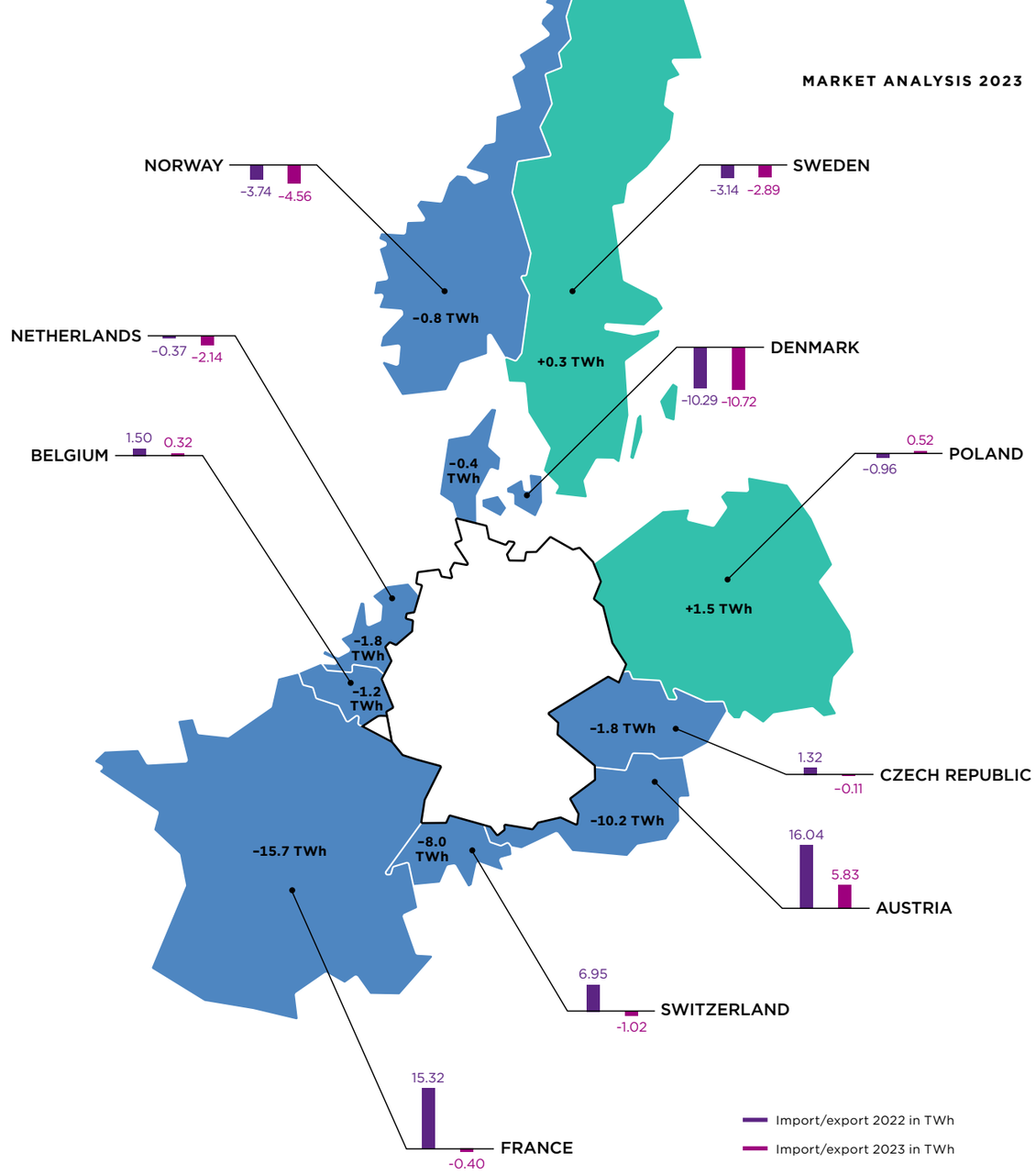


FIGURE 4 Yearly day-ahead exports (positive +) and imports (negative –) of Germany with its neighbouring countries in 2023[11]

11 Source: transparency.entsoe.eu
Positive values (TWh) display exports from Germany (blue), while negative values display imports to Germany (green).

PRICE CONVERGENCE AND MARKET-LIMITING GRID CONSTRAINTS

The reduction of price differences and increasing price convergence[12] within a region is one of the main targets of market coupling. Sufficient cross-zonal transmission capacities are a crucial prerequisite for achieving this target.

In the case of sufficient cross-zonal exchange capacities, prices between bidding zones converge. In the opposite case, if commercial exchanges are limited by transmission constraints, prices between the bidding zones diverge. The price convergence rate is therefore one indicator for the level of market integration in the Core region. However, since bidding zones are delineated by structural congestions, some level of price divergence is inherent to the zonal market by design. Besides the price convergence, which means that all trading requests of neighbouring bidding zones can be realised to allow the most economic dispatch of generation units to serve the demand of these bidding zones, the price spread is another important indicator of market coupling. In the case of price divergence, the remaining price spread reveals the need for further exchange capacities and the respective grid investments.

In general, full price convergence indicates that there are no transmission grid limitations of cross-zonal trade. On the other hand, situations in which there is still a price spread between two bidding zones indicate limitations of transmission capacity. Figure 5 provides some insights into the average price spreads in 2023. On all borders, we can observe a reduction in average price spreads compared to 2022, a year which was characterised by remarkably high electricity prices as a result of the gas supply shortage in Europe. The highest average price spreads in the Core region are observed on the German-Polish and the Polish-Czech borders. A border which faces above-average price divergence without any external constraints is the German-French border. In both the German and the French domestic electricity markets large volumes are traded, which naturally means a high demand for cross-zonal trade capacities. Figure 6 shows that within the Amprion control area the most active critical network element constraining cross-border trade in 2023 is located close to the French-German border.

An overall decrease in electricity prices also led to a decline in price spreads within borders of the Core Capacity Calculation Region[13].

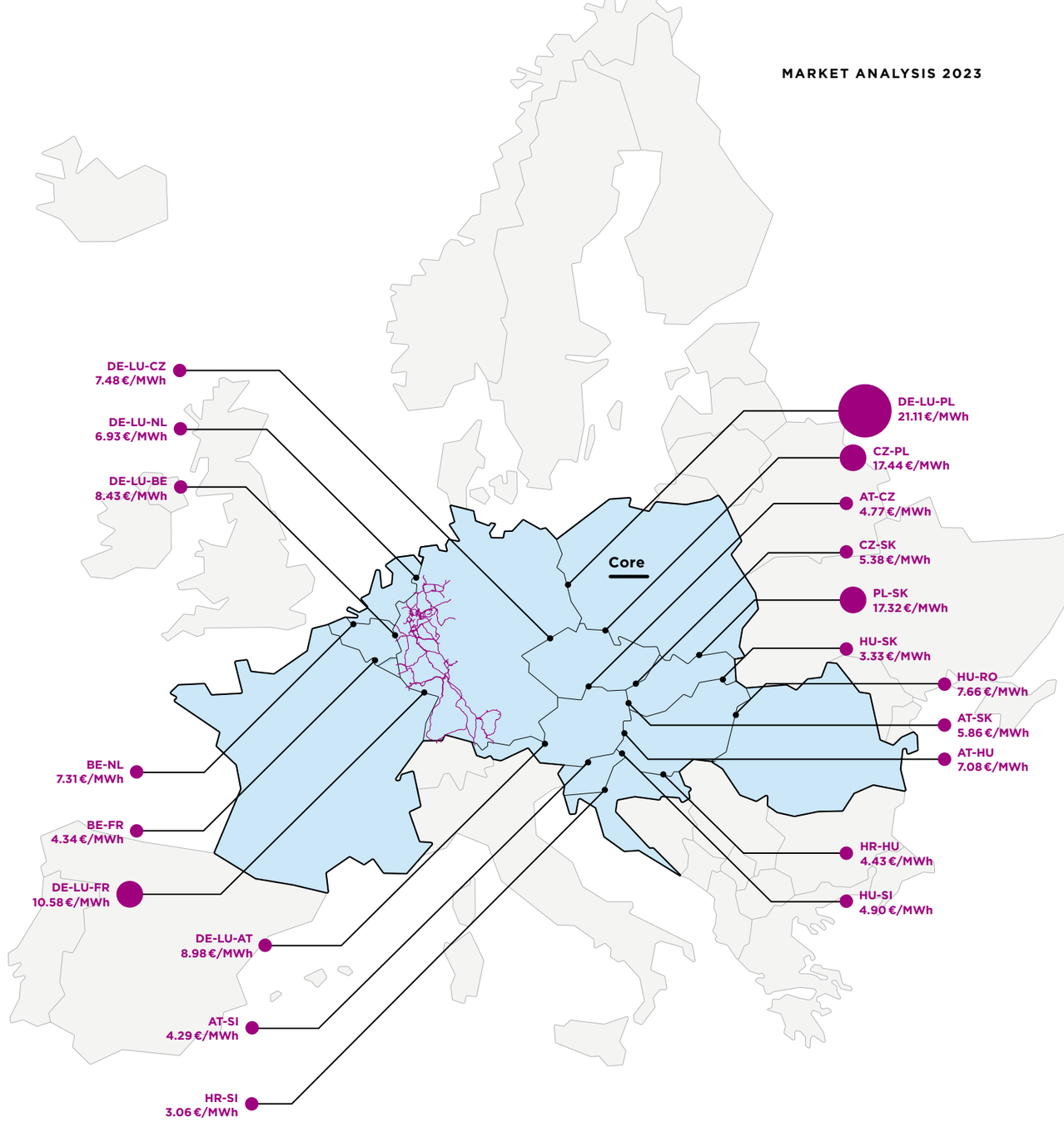


FIGURE 5 Average price spread in Core in 2023 by border[14]

12 Full price convergence is reached if prices are equal across all bidding zones of a region.

13 A Capacity Calculation Region is a region where transmission capacities for cross-zonal electricity exchange are jointly calculated. The Core region is the Central European Region where this calculation takes place. Figure 6 displays this region.

14 Source: transparency.entsoe.eu

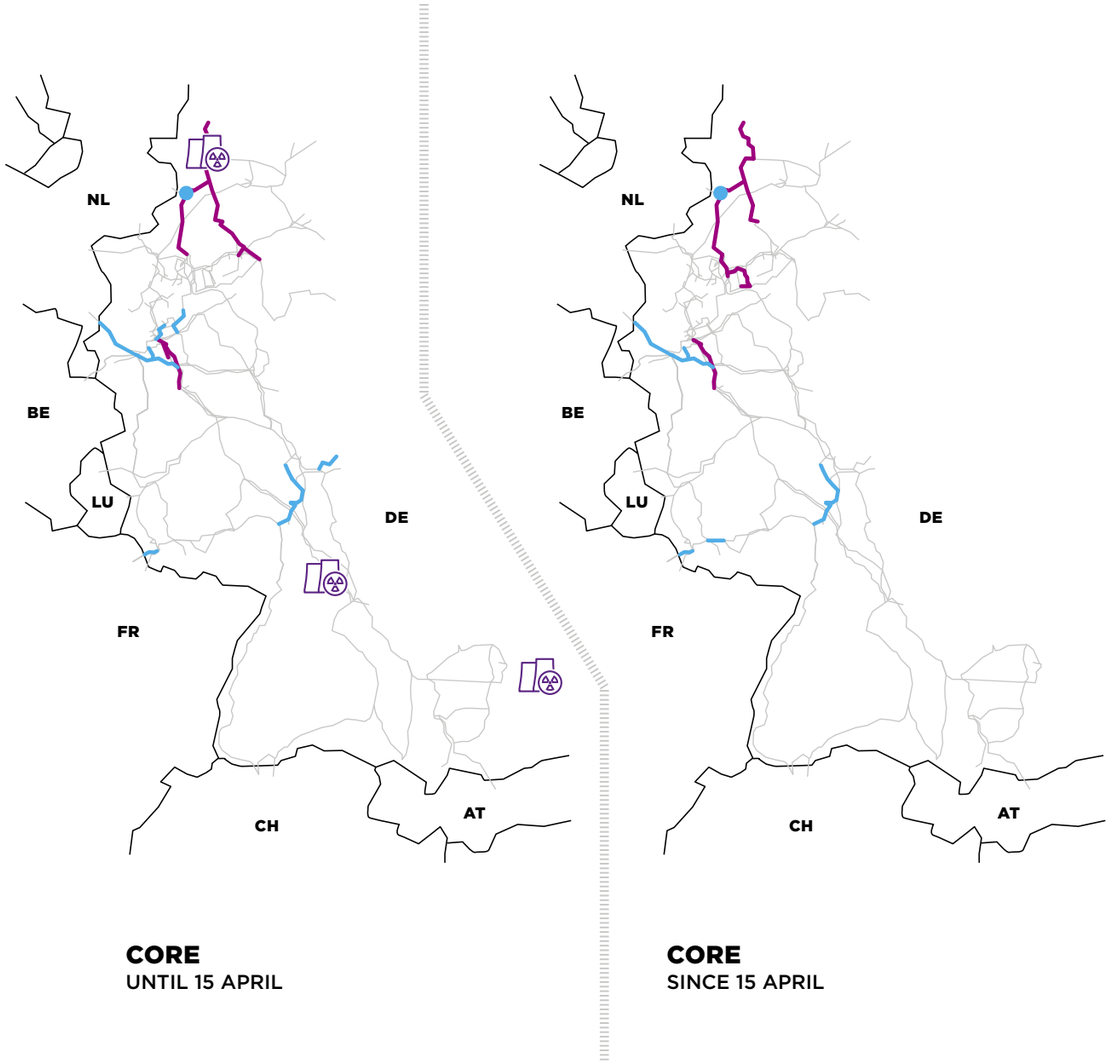


FIGURE 6 Location of major (top 10) active critical branches in Flow-Based Market Coupling of Amprion as well as the ones with the lowest offered trading margin before and after April 2023[15]

15 The general information about the critical branches can also be downloaded via the Utility tool available via JAO, see utilitytool.jao.eu

GEOGRAPHICAL LOCATION OF LIMITING AMPRION ELEMENTS

Looking at the most relevant critical network elements in Flow-Based Market Coupling in the Amprion grid, the geographical location of congestions has not changed fundamentally compared to 2022. It is noteworthy, though, that the most frequent limitation has occurred on elements close to the French border (Vigy lines). In 2022, the most frequent limitations could be seen in the north of Amprion's control area (Emsland lines). A possible explanation is the phaseout of nuclear power generation in Germany and a subsequent shift in trade flows. Imports from France to Germany have increased after 15 April 2023, the exit date of German nuclear power generation. Over the full course of the year 2023, the most active critical branch – a transmission line close to the French border – was limiting trade in about 20% of hours. By comparing the period before and after the nuclear exit we observe a striking difference: While in the period from 1 January until 14 April that same transmission line was limiting trade in approximately 4% of hours, it was limiting trade in 26% of hours in the period from 15 April until 31 December. Trade limitations become particularly evident when electricity is imported from France to Germany. Amprion continues to enhance the transmission grid and to improve cross-zonal trading capacities, to reap the full benefit of the integrated European electricity market.

Need-oriented grid expansion still remains a top priority.

EXCURSUS

EUROPEAN BALANCING PLATFORMS MARI AND PICASSO

Successful integration of balancing energy markets by stable operation of European balancing platforms.

The European electricity landscape has taken a significant step forward with the integration of balancing energy markets, facilitated by European balancing platforms. This integration promotes a cost-effective system operation, also increasing social welfare across Europe.

As mentioned in our last Market Report[16], in 2022, two European balancing platforms, the Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation (PICASSO) and the Manually Activated Reserves Initiative (MARI), were launched. They play a crucial role in the cross-border activation of frequency restoration reserves (FRR) with automatic activation (aFRR) and manual activation (mFRR). These initiatives complement existing cross-border collaborations for balancing capacity and imbalance netting, increasing social welfare. Alongside the Trans European Replacement Reserves Exchange (TERRE) and the International Grid Control Cooperation (IGCC), PICASSO and MARI are cornerstones to realising the integrated market for balancing energy in Europe. With the participation of more European TSOs in 2024, the European balancing platforms will establish unified principles and harmonised methodologies, ensuring the efficient functioning of domestic balancing energy markets across Europe. The successful go-live of MARI and PICASSO in 2022 proves the fruitful collaboration among TSOs, promising significant economic benefits in the years to come.

MARI is hosted by Amprion, acting as the Common Service Provider (CSP). It thereby contributes significantly to the realisation of considerable social welfare gains also referred to as economic surplus. An economic surplus of 8.5 million € was generated by the MARI platform in 2023. This number was derived by comparing actual market results with a hypothetical scenario without cross-border exchanges via MARI (decoupled scenario). Beside realising economic surplus, balancing platforms facilitate the short-term mitigation of local market power. Extending balancing platforms seems to be easier to achieve than the admission of a significant amount of new balancing service providers in one single country.

With more TSOs to join MARI in 2024, we anticipate an increase of economic surplus in the coming months.

16 Source: amprion.net/Dokumente/Strommarkt/Marktbericht/2023/Amprion_Market-Report_2022-23.pdf

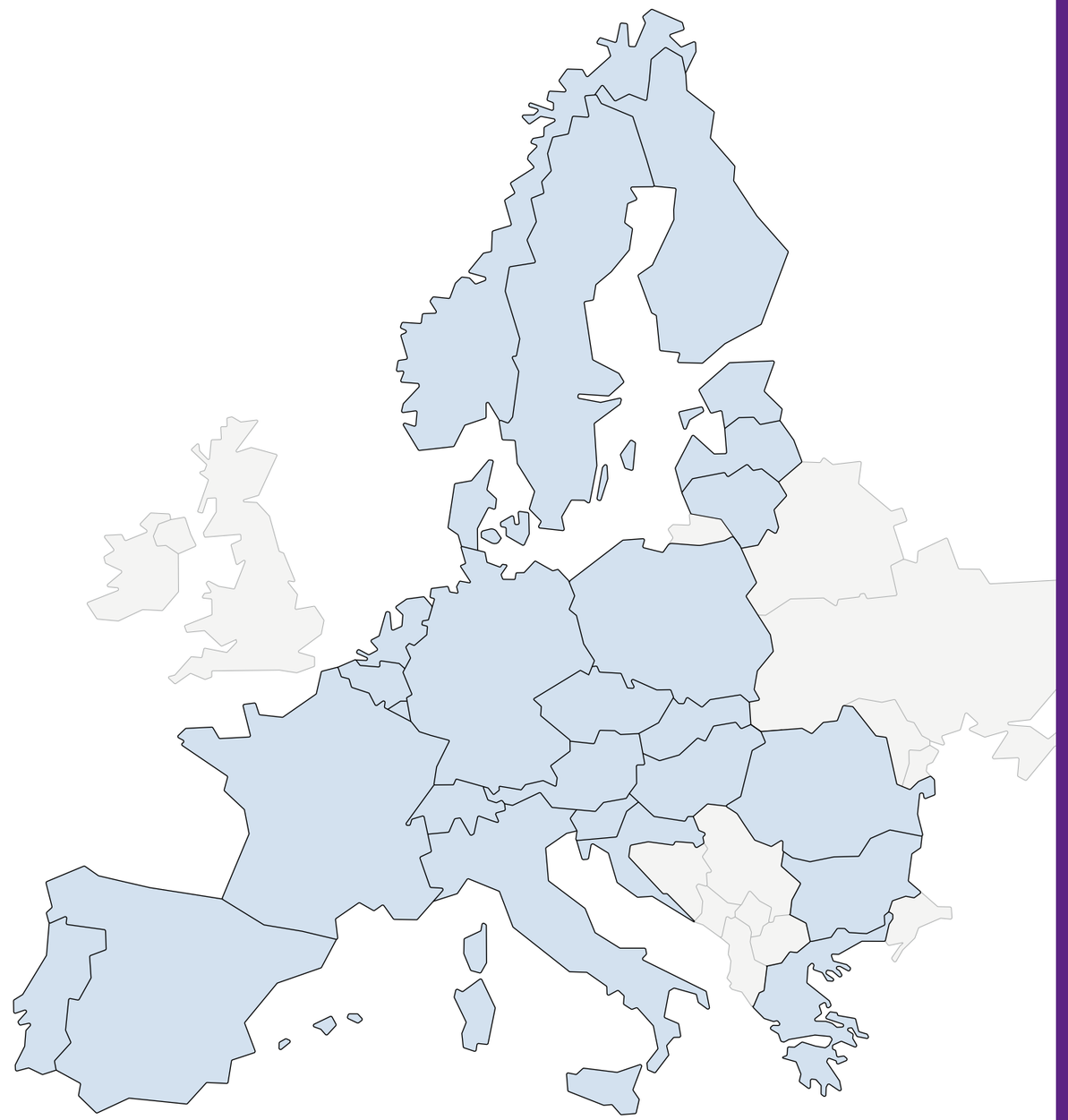


FIGURE 7 Overview of countries connected or to be connected to the MARI and PICASSO platforms

GRID OPERATION ANALYSIS 2023

The generation of electricity causes electrical load flows. If such load flows exceed the technical limitations on particular network elements, taking into account the n-1 criterion[17], the electricity generation pattern has to be changed. This process is called redispatching, where TSOs must reduce electricity generation at dedicated locations in the grid in order to alleviate the electricity flow on constrained network elements[18].

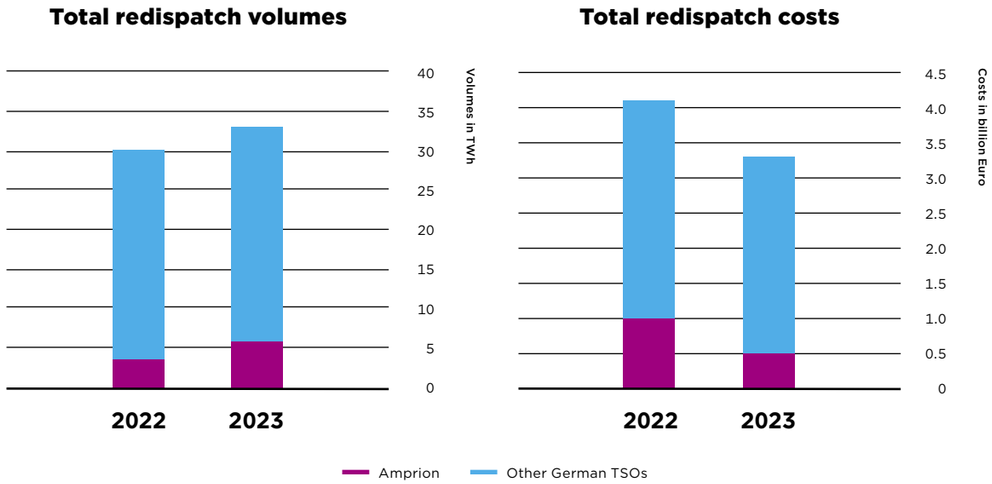


FIGURE 8 Total redispatch volumes and costs for Germany in 2022 and 2023

The significant drop in prices for electricity, hard coal, natural gas and CO_2 emissions has also led to a decrease in congestion management costs.

17 N-1 criterion: Within our transmission grid, each node is connected to other nodes by overhead lines or cables. If an individual line or other equipment, such as a transformer, fails, the electricity can always be transmitted via an alternative route – without causing further disruption or overloading other equipment.

18 To keep electricity generation and demand in balance, electricity generation has to be increased in other, less constrained areas.

In 2023, congestion management costs across Germany amounted to 3.3 billion €, which was below the previous year's level. This development is mainly due to the significant drop in prices for electricity, hard coal and, in particular, natural gas.

In addition, a major grid expansion project the Energy Line Expansion Act – Project 2 ("EnLAG 2"), was successfully completed. The 94 km-long line from Ganderkesee to Wehrendorf stretches across two German federal states, Lower Saxony and North Rhine-Westphalia, and was commissioned in cooperation between TenneT Germany and Amprion. Its completion has significantly relieved Germany's biggest congestion to date, the so-called Emsland lines. As a result, around 600 million € of congestion management costs could be saved. In addition, initiatives to optimise the utilisation of our existing grid and to expand the dynamic line rating in the short term have had a positive impact on the grid.

The increase in feed-in from nuclear power plants in France in 2023, compared to the previous year, along with milder temperatures, led to a reduction in the transit and export-related grid load. At the same time, some power plants from the German Grid Reserve, which are generally positioned at grid-supporting locations, participated in the market throughout the year.

Mild temperatures, combined with energy-saving effects and a general reduction in industrial loads following the gas crisis, led to a lower overall load in Germany and neighbouring countries. This lower electricity demand also led to favourable import-export situations, such as exports to Scandinavia at times of high wind power generation, thereby further reducing the German grid load.

Despite all these favourable factors for congestion management, its volume slightly increased in 2023 compared to the previous year (cf. Figure 8 and 9). The main reasons for this are: 1. the steady expansion of renewable energies and 2. the gradual increase in cross-border transmission capacities as part of the Clean Energy Package and the German "Action Plan Bidding Zone"[19] by the end of 2025.

19 More information available at: bmwk.de/Redaktion/EN/Downloads/a/action-plan-bidding-zone.html

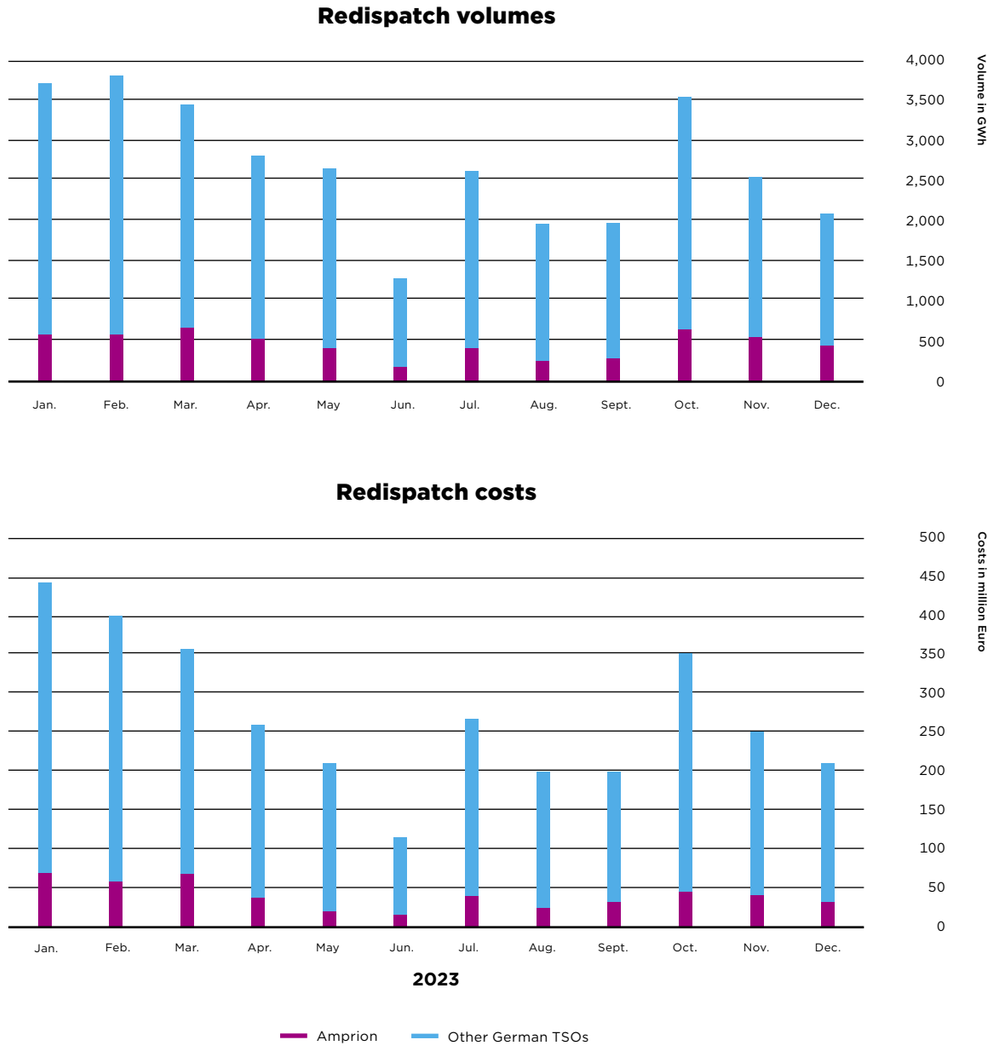


FIGURE 9 Total monthly redispatch volumes and costs[20] for Germany (including RES curtailment)[21]

20 Volumes are presented according to the instructing principle (i.e. in which control area power plants have been started in order to cure redispatch. Amprion does not instruct RES curtailment and this data is therefore missing in the volumes for Amprion). Costs are presented according to the requester principle (i.e. what costs did incur in order to cure the requested redispatch).

21 Disclaimer: The data shown in the graph may differ from redispatch figures published elsewhere (e.g. EMFIP report), as other sources sometimes contain assumptions for additional costs for recent changes in remuneration of remedial actions with larger power plants that have not yet been invoiced. The graph published here contains only the additional costs actually invoiced for remedial actions with larger power plants. The costs of RES curtailment also include assumptions in case of invoice delay.

FUTURE DEVELOPMENTS

GERMAN NETWORK DEVELOPMENT PLAN

Every two years, the four German transmission grid operators develop a Network Development Plan (NDP) that identifies the need for grid expansion within Germany. In the latest NDP 2037/2045 (2023) a carbon-neutral energy system by 2045 is being assumed for the first time. This NDP examines three scenarios for 2037 and continues their development until 2045 to meet carbon neutrality. These scenarios represent a first step to consider the high uncertainties in the underlying planning process. However, due to the dynamic market environment, the assumed and required transport capacities might change again in a future NDP. The scenario framework differs particularly in terms of hydrogen demand and efficiency assumptions. Due to an increase of electrification in building, transport and industry, a growth of gross electricity consumption up to 1,300 TWh is being assumed. For a carbon-neutral electricity supply, the installed renewable energy capacity needs to expand up to 700 GW, corresponding to a fourfold increase compared to today. Storage technologies will support the integration of renewable energies with more than 100 GW. A coal phaseout is considered in all assessed scenarios. In addition, gas power plants will be fuelled with hydrogen in 2045 at the latest. Germany will most likely stay a net importer until 2037.

The need for the transport of electrical energy within Germany is still largely determined by a high feed-in of wind energy in the north and north-east and consumption centres in the west and south of Germany. Based on this scenario framework, transport demand between northern and southern Germany increases significantly until 2037 and remains at a similar level until 2045. Therefore, major parts of the new transmission grid infrastructure need to be built by 2037. Even if all grid projects included in the current legislation[22] were built, large-scale overloads would still exist. The requirement for grid reinforcement and expansion measures therefore needs to increase even further, by about 7,400 km compared to the previous NDP 2035 (2021). This is mainly caused by a significant growth of scenario assumptions in terms of installed renewable energy capacities and in electricity consumption.

The Federal Network Agency had confirmed this NDP by beginning of March 2024. Compared to the proposal of the transmission system operators the confirmation contains an increase of transmission capacities for several high-voltage direct current transmission (HVDC) projects, including an additional project to integrate offshore wind energy and several AC projects.

The current Network Development Plan examines, for the first time, a transmission grid for an entirely carbon-neutral energy sector in Germany.

22 Federal Act determining the need for grid developments – *Bundesbedarfsplangesetz BBPIG*

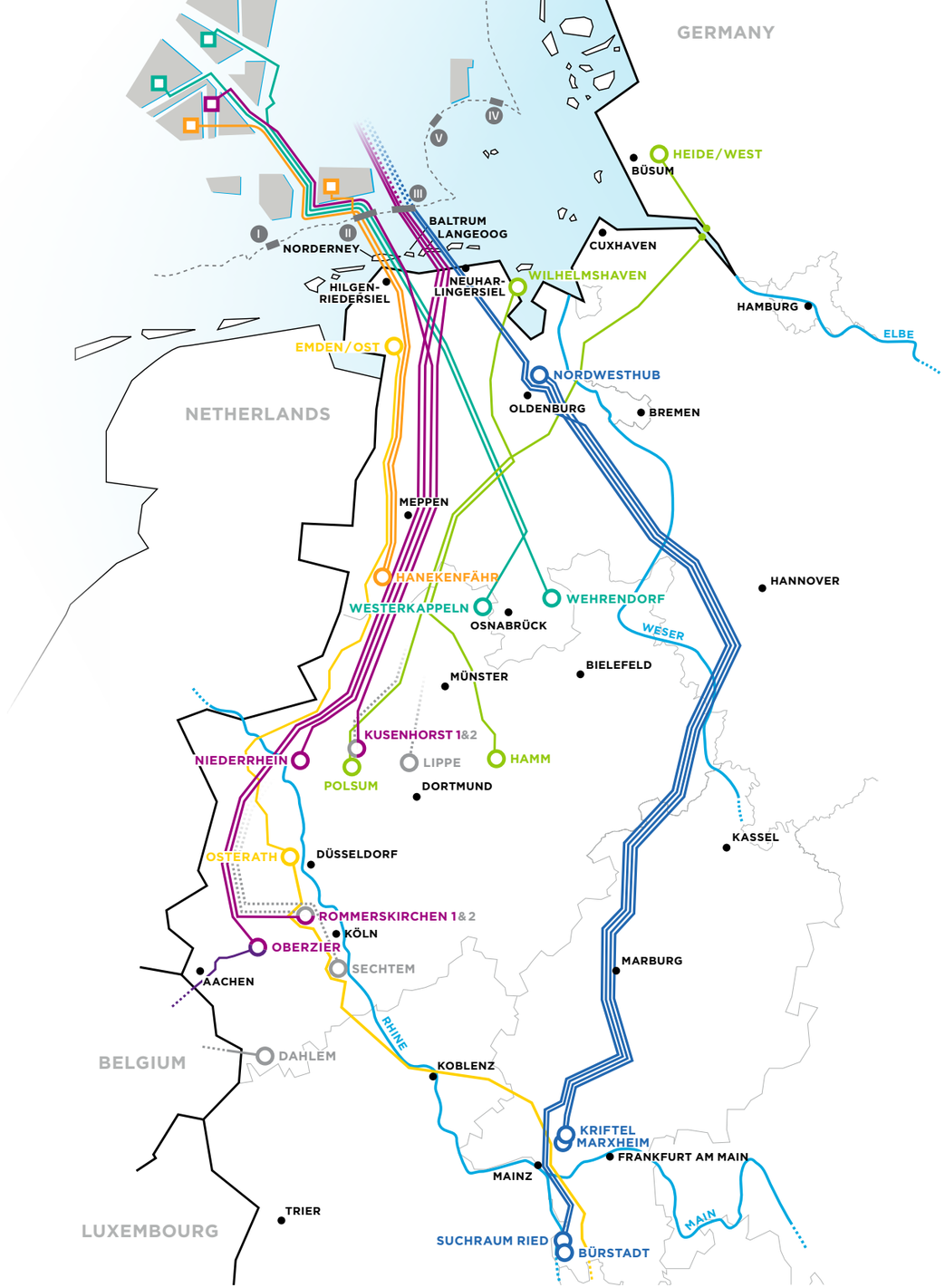


FIGURE 10 Schematic design of the integration of German offshore wind farms[23]

23 Source: bmwk.de/Redaktion/DE/Pressemitteilungen/2023/02/20230227-bmwk-und-uenb-veroeffentlichen-plaene-zur-vernetzung-von-offshore-windparks-in-der-nordsee.html

The Federal Network Agency has approved an additional Amprion HVDC project from Rastede to Marxheim (Taunus) with a capacity of 2 GW. Amprion proposed several further AC projects, some of which were also approved. In addition to offshore systems confirmed in the previous NDP, Amprion will be responsible for another seven. Most of these will be allocated close to industrial sites in western Germany, some even in the Federal State of Hesse. Beyond that, two national offshore connections were confirmed that allow electricity transport between the two onshore grid connection points when offshore wind is not fully feeding into the grid. Amprion is involved in both projects. An overview of the planned grid expansion for offshore integration is provided by Figure 10.

- ALEGrO in operation
- Ultranet, A-Nord
- DolWin4, BorWin4
- BalWin1, BalWin2
- Korridor B
- Windader West
- Rhein-Main-Link
- Further NDP approved projects
- Offshore wind farm area
- Submarine cable gates
- Converter platforms
- Grid connection points (GCP)
- Constraint point
- Cities
- Federal border
- State border
- Running waters

Schematic illustration, updated March 2024
NDP = Network Development Plan

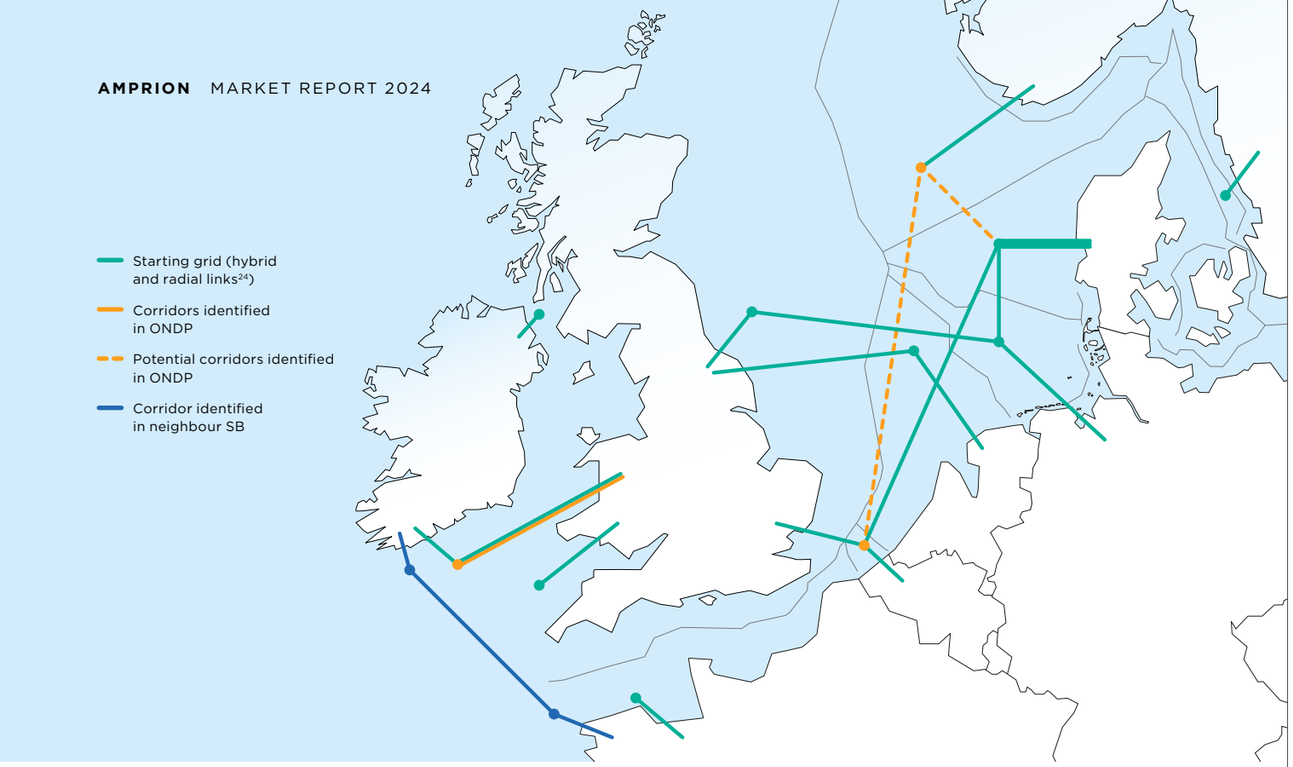


FIGURE 11 ONDP 2050 expansion result in addition to starting grid

ENTSO-E OFFSHORE NETWORK DEVELOPMENT PLANS

ENTSO-E Offshore Network Development Plan assesses necessary offshore infrastructure to integrate offshore wind.

Besides the German national Network Development Plan, on 24 January 2024, ENTSO-E presented the first version of the Offshore Network Development Plans (ONDP)[25]. These plans provide a holistic outlook of the transmission needs and grid development requirements considering the insights of all European TSOs. Each report per European sea basin (SB) delivers data and forecasts on infrastructure requirements until 2030, 2040 and 2050 to efficiently integrate the substantial offshore expansion into the onshore system. All these insights are based on the national non-binding expansion targets for offshore wind and ENTSO-E's overall estimates of European electricity system needs.

For Amprion, the Northern Sea Basin results are of most relevance. A total of 274 GW of offshore wind capacity is planned to be developed by 2040 and 332 GW by 2050. To integrate this offshore wind generation, around 25,000 km of cable routes will become necessary by 2050, corresponding to an investment need of more than 250 billion €, which only covers grid infrastructure without the offshore wind farms. Around 14% of

24 Existing, planned and identified in 2040
25 More information available at: entsoe.eu/outlooks/offshore-hub/tyndp-ondp

the future infrastructure could be planned as hybrid interconnector projects. Figure 11 shows the ONDP expansions in addition to the already planned grid. This development might be subject to changes, especially due to technological developments in the next decade.

Amprion plans new offshore hybrid interconnectors together with European partners.

While we are in the middle of developing the first generation of systems to connect offshore generation in the German Exclusive Economic Zone to our onshore grid, the next generation of offshore systems is already under development.

New hybrid projects, which not only connect wind parks to one domestic grid but also interconnect two countries have the potential to bring significant synergies:

- These set-ups save space in the comparably small and crowded German waters.
- Investment costs can be reduced, as hybrids serve two- or even more purposes.
- Less construction work is needed and therefore the environmental impact is reduced.

Amprion has initiated the consideration of several national and international interconnected projects in the North Sea. We have signed Memorandums of Understanding (MoUs) with our partners in Denmark and Norway to explore possible interconnection schemes. Together with the Danish TSO Energinet and Norwegian TSO Statnett, hybrid projects have been included in the European Ten-Year Network Development Plan[26]. Together we are conducting pre-feasibility studies to identify the most beneficial set-up for such projects. Further to the existing cooperations, exploring the benefits and possibilities of offshore cooperation and interconnection between Germany and Great Britain are of particular interest.

Valuable cooperation and joint North Sea coordination is taking place within the framework of the Offshore TSO Collaboration (OTC), a shadow initiative to the political North Sea Summits. The OTC group aims to ensure continuous cooperation and exchange between the European TSOs in the North Sea. Joint expert papers are intended to consolidate and expand further close cooperation between the international TSOs and deliver input to the ministerial summits, such as in Bruges in May 2024 and in Germany in 2025.

26 More information available at: tyndp2024.entsoe.eu/projects-map

EXCURSUS

PROJECT »A-NORD«

BRINGING NORTH SEA WIND POWER TO ITS DESTINATION

In order to achieve Germany's climate targets, many wind farms will be built in the North Sea in the coming decades. The electricity generated there must be transported in large quantities to where it is needed: to the centres of consumption in the west and south of Germany. The planned A-Nord wind power connection will be an important contribution to this. The A-Nord link is around 300 km long. It is planned as an underground cable using direct current (DC) technology at high voltage (HVDC). The DC connection can transmit up to 2.4 gigawatts of electric power. That is roughly equivalent to the electricity demand of two million people. The northern starting point of A-Nord is located in the city of Emden. Here, on the coast of Lower Saxony and in the North Sea, a lot of wind power is generated. The future on- and offshore wind generation in this region will exceed local demand by around ten times.

Important contribution to transport surplus renewable energy from the north to the southern consumption centres in Germany.

CONNECTION POINT IN THE RHINELAND

A-Nord will transmit electricity from renewable energies to the conurbations on the Rhine and Ruhr. It is urgently needed there, as all coal-fired power stations in the region are intended to be gradually taken off the grid by 2030. Wind power from the north will help in closing this supply gap in future. Further to supplying this local demand at the end point in Osterath, the A-Nord project will be connected to another planned DC line called Ultranet. Both projects taken together will form the Corridor A, one of the main electricity transmission corridors of the energy transition. Via this corridor, North German wind power will be transmitted to the Ultranet end point in Philippsburg. Local demand in this region will therefore also benefit from the new wind power connection. This is particularly important since a nuclear power plant in the region was shut down at the end of 2019, resulting in a local shortage of electrical energy.

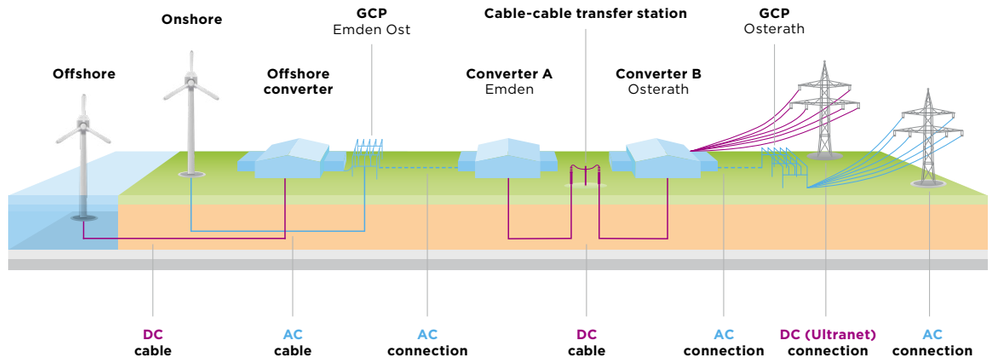


FIGURE 12 Schematic illustration of the A-Nord project

CONVERTERS IN EMDEN AND OSTERATH

For A-Nord, we are laying over 300 km of underground HVDC cables. This technology enables long-distance, large electricity transmission with very low losses. In order to link the HVDC cables to the existing transmission network which predominantly uses alternating current (AC), we need a converter station both at the starting point of A-Nord in Emden-Ost and at the end point in Osterath.

Amprion is the first TSO to connect several important wind power links.

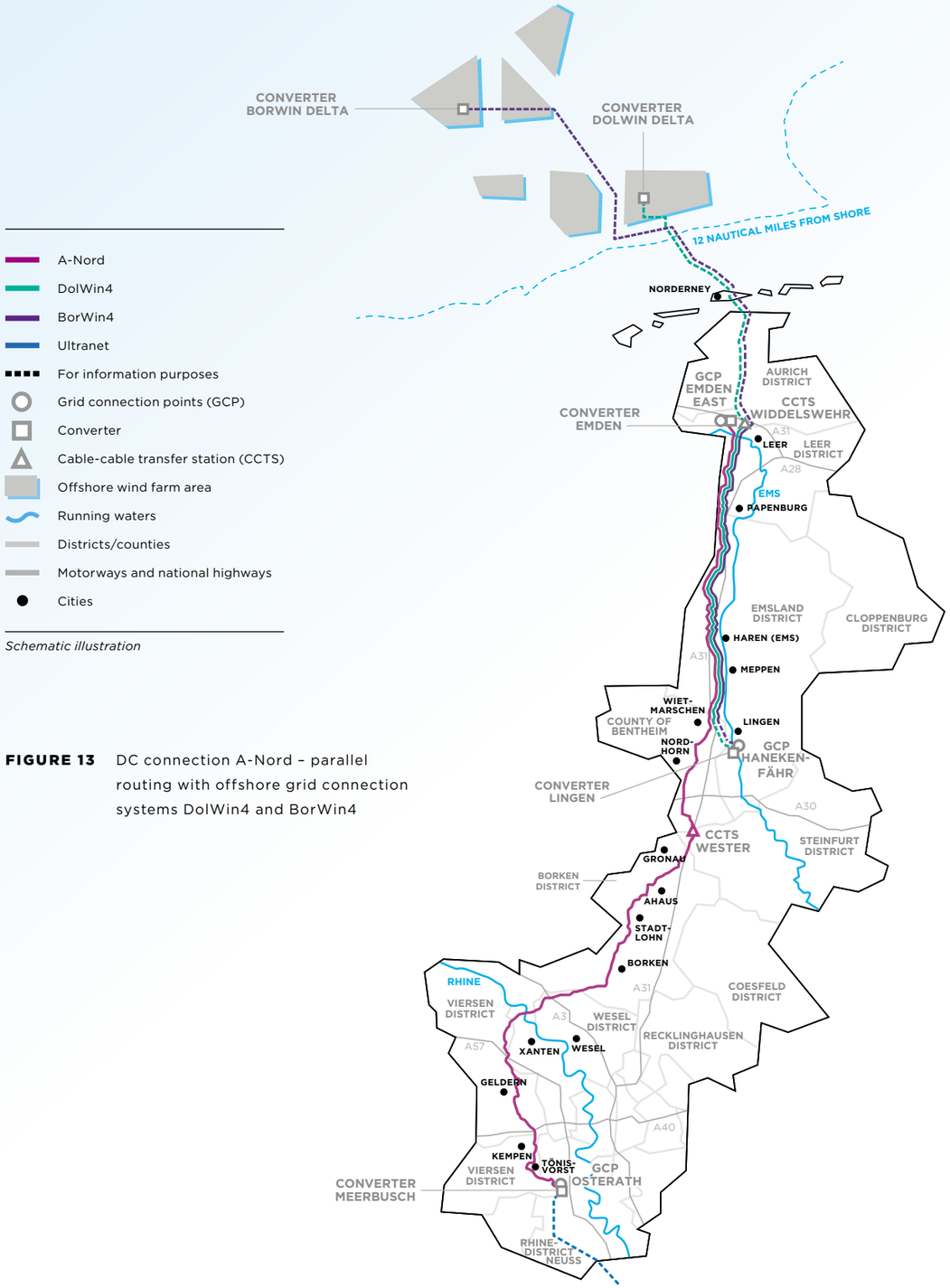


FIGURE 13 DC connection A-Nord – parallel routing with offshore grid connection systems DolWin4 and BorWin4

BUNDLING WITH OFFSHORE SYSTEMS

The two offshore grid connections DolWin4 and BorWin4 will be bundled with the direct current DC connection A-Nord between Emden and Wietmarschen (district of Grafschaft Bentheim). This means that we will also cover construction measures and the operation of the offshore connection systems in the approval procedures for A-Nord. Among other things, we are already laying empty conduits during the construction of A-Nord, into which the underground cables for DolWin4 and BorWin4 will later be pulled. This enables us to reduce the impact on the soil and landscape as well as the economic costs. The paths of A-Nord and the two offshore projects diverge in the Lohne area. From there, A-Nord continues towards North Rhine-Westphalia, while DolWin4 and BorWin4 run eastwards to the Hanekenfähr substation in Lingen (Ems). There we connect them to our transmission network. Amprion is thus the first transmission system operator to connect several important wind power links.

Accelerated grid expansion measures are already paying-off: Construction could start earlier than initially anticipated.

START OF CONSTRUCTION

The Construction of A-Nord was originally scheduled for 2024. However, thanks to adaptations of the national regulatory framework in order to accelerate grid expansion, it was already started in October 2023. Applying an integrated project management approach, we expect the civil engineering work to be completed in just three years. Finally in 2027, up to 2.4 GW of wind power will flow from Emden to the Rhineland.

GERMAN POWER PLANT STRATEGY

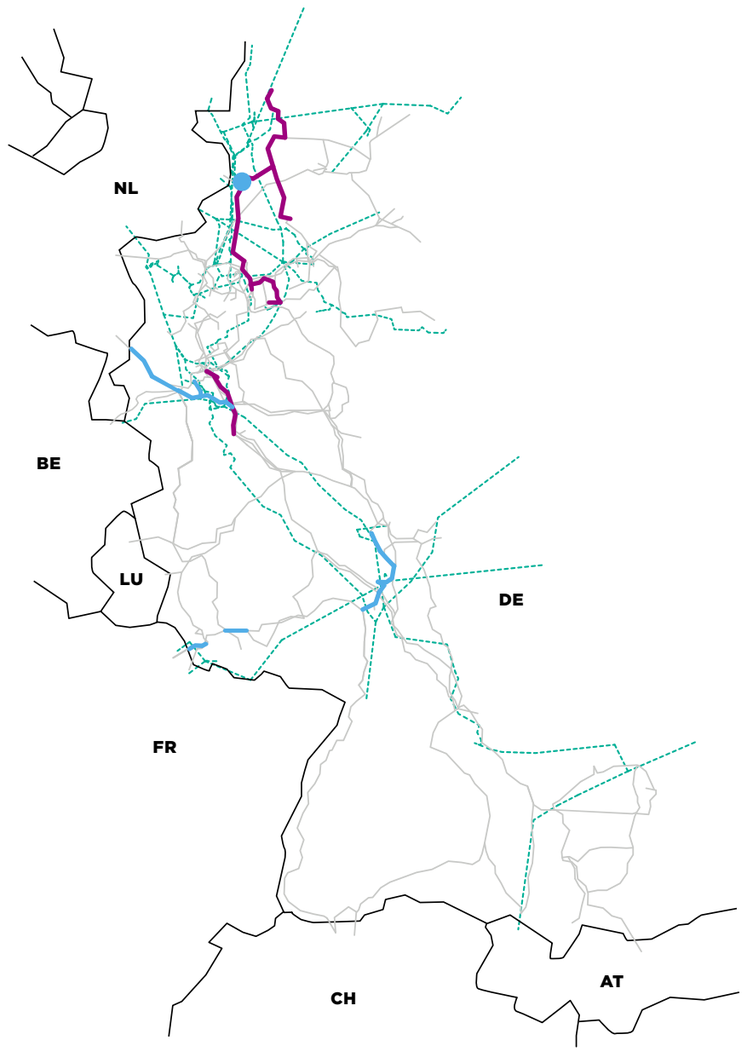
New power plants of more than 20 GW are needed if Germany wants to phase out coal in 2030 as far as resource adequacy is concerned.

The German Network Development Plan as well as the decisions on specific grid expansion projects such as A-Nord rely on scenarios of the future development of load and electricity generation in Germany. Such scenarios are usually based on assumptions, which are in turn based on political targets on the expansion of renewable energies, storage capacity as well as flexible loads and flexible power generators.

As mentioned earlier, the expansion of renewable energies reached a new record in 2023. In order to back up these volatile power generators, there is also a need for flexible loads and power generators. In particular in times of low wind and solar electricity generation, alternative electricity supply sources are required (cf. Figure 2 on page 09). The German Federal Network Agency's resource adequacy monitoring assumes that more than 20 GW of new flexible generation capacity will be built by 2030. Amprion foresees a similar need of flexible generation capacity for a successful phaseout of coal-fired electricity production in 2030 while maintaining resource adequacy. However, the current market environment clearly does not provide sufficient incentives for plant operators to build the necessary number of new plants.

The electricity market in its current form will have to be enhanced in order to provide incentives for sufficient investment in such flexible power plants. The German Federal Ministry for Economic Affairs and Energy is taking action in order to establish such incentives with its planned "Power Plant Strategy"[27]. It announced tenders for 4×2.5 GW of "convertible hydrogen power plants" starting in 2024. These power plants should be gas-fired in the beginning, but be able to switch fuel to hydrogen, after their connection to the planned hydrogen grid in Germany. In addition, 500 MW of directly hydrogen-fired power plants should be built for research purposes. These tenders are an important first step in realising the required flexible power generation capacity of more than 20 GW. They would have to be complemented with further actions in order to achieve the complete phaseout of coal-fired power plants while still ensuring a reliable supply of electricity in Germany and Europe. The planned Power Plant Strategy already foresees such actions by introducing a comprehensive Capacity Remuneration Mechanism (CRM). This CRM will replace the tenders of the Power Plant Strategy and provides a more long-term solution to ensure flexible and reliable electricity supply. It should be operational in 2028 and several potential concepts are currently being discussed for its design.

27 A press release of the German Federal Ministry of Economic Affairs and Energy dated 5 February contains further details.



Top 10 critical network elements (CNEs) in 2023

FIGURE 14 Overlay of the planned hydrogen grid and the grid of Amprion

In order to integrate the new flexible and reliable generation capacities into the electricity system, not only the total amount of new power plants, but also the location of these power plants is of fundamental importance. Looking at the overlay of the planned hydrogen grid and the already heavily burdened network elements of the Amprion grid (cf. Figure 14), it is obvious that some locations are more beneficial for the future grid operation than others. The Power Plant Strategy should consider this via "system-beneficial locations" during the tendering process, for example.

Sector coupling and, in particular, the production of green hydrogen via electrolysis represent another important part of decarbonising the German energy sector. The Grid Development Plan assumes between 26 and 40 GW of new electrolysis in 2037. The location of these new electrolysers is equally or even more important than the location of new power plants. The case study of the previous Market Report[28] shows that even if only some of the electrolysers are located at system-serving locations, a significant reduction in grid congestion can be achieved. The Grid Development Plan already assumes a grid-oriented allocation of electrolysers, which at least does not exacerbate congestion. It also assumes that electrolysers can be used flexibly as switchable loads. However, this is not reflected in the current regulatory framework. For that reason, the German Power Plant Strategy also addresses the location of future electrolysers by announcing a promotion of projects with "system-oriented" locations.

28 Source: amprion.net/Dokumente/Strommarkt/Marktbericht/2023/Amprion_Market-Report_2022-23.pdf

CONCLUSION AND OUTLOOK

Conclusion: No transition without transmission.

Last year again illustrated the changing behaviour of the German electricity system in the course of the energy transition. The share of renewable electricity production from wind and solar continues to increase and so do electricity imports from other European countries to Germany. Amprion supports this changing pattern by developing the European electricity market including balancing platforms and by building the required electricity grid.

The report has also provided evidence for the thousands of additional kilometres of this electricity grid that is required for the energy transition. This will cost several hundred billion euros and can only be covered with the help of private investors. Competitive returns are needed to make network development attractive for such investments. Electricity customers will benefit by receiving CO_2-free electricity at low variable production costs.

Furthermore, the restructuring of the energy system also requires the availability of the necessary components for grid expansion. This can only be achieved through long-term planning and a ramp-up of additional flexible and reliable production capacities, as well as ancillary services providing stability to the electricity system. The Power Plant Strategy and the Roadmap System Stability developed by the German Ministry for Economic Affairs and Energy both envisage some important actions for achieving this target. It is important for these actions to be targeted at achieving a sufficient amount of flexible and reliable electricity production capacities and ancillary services at the right locations in the electricity system.

Outlook: With the EU Grid Action Plan, the EU brings grids to the centre of its agenda for the first time.

The EU Grid Action Plan[29] released by the European Commission in November 2023 emphasises the importance of interconnected and stable electricity grids as the backbone of a well-functioning energy system and thus recognises that timely network expansion is the key to accelerating the energy transition in Europe. With its 14 actions, the Action Plan not only incentivises long-term and coordinated onshore and offshore grid planning, but also makes proposals to facilitate the financing of the investment ramp-up by providing stability and predictability of investments through an appropriate legal and regulatory framework to adequately support the necessary grid development. In addition, the availability of appropriate and sustainable production capacities should also be ensured, and stronger regulatory impetus should be provided, for example through the possibility of anticipatory investments. Amprion shares and supports the goals and actions of the EU Grid Action Plan by developing holistic solutions for accelerated grid development, long-term network planning and European market integration as explained in this report. We hope that the actions included in the plan will be implemented in due time and that the topic of accelerating grid development remains high on the agenda – not only at a domestic level, but also that it receives high levels of attention from the European Commission and the newly elected European Parliament in its upcoming legislative period.

29 COM(2023) 757, 28.11.2023: Communication of the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Grids, the missing link – An EU Action Plan for Grids, see: eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023DC0757

LIST OF ABBREVIATIONS

AC	Alternating Current
ACER	Agency for the Cooperation of Energy Regulators
aFRR	Automatic Frequency Restoration Reserve
CCR	Capacity Calculation Region
CRM	Capacity Remuneration Mechanism
CSP	Common Service Provider
DA	Day-Ahead
DC	Direct Current
EC	European Commission
EEG	Renewable Energy Sources Act
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
FB MC	Flow-Based Market Coupling
FLH	Full-load Hours
FRR	Frequency Restoration Reserve
HVDC	High-Voltage Direct Current Transmission
IGCC	International Grid Control Cooperation
IPA	Integrated Project Management
MARI	Manually Activated Reserves Initiative
mFRR	Manual Frequency Restoration Reserve
MinRAM	Minimum Remaining Availability Margin
MoUs	Memorandum of Understanding
NDP	Network Development Plan
NRA	National Regulatory Authority
OTC	Offshore TSO Collaboration
ONDP	Offshore Network Development Plan
PICASSO	Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation
SB	Sea basin
TERRE	Trans European Replacement Reserves Exchange
TSO	Transmission System Operator
TYNDP	Ten-Year Network Development Plan

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