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Summary

The transmission system operators (TSOs) with control area responsibility plan, build and operate new grids for new energies. In the Grid Development Plan Electricity (GDP), they present the measures for optimising, reinforcing and expanding the German transmission grid. This includes measures on land as well as the offshore grid connection systems in the exclusive economic zone and in the territorial sea in accordance with the legal requirements of the Energy Industry Act (EnWG).

This GDP 2037 / 2045 (2023) looks at the years 2037 and 2045 and thus also at the statutory target year for achieving climate neutrality in Germany. It analyses the grid development demand for three different scenarios for these years. This scenario framework is mainly based on the expansion targets for renewable energy of the Renewable Energy Act (EEG) 2023. The scenarios differ in their assumptions regarding the use of hydrogen, the level of direct electrification and the increase in efficiency. Consequently, they represent a range of potential developments. Moreover, ad-hoc measures for 2030 were analysed to make it easier to respond to the stronger expansion of renewable energy and the likewise increasing gross power consumption in the short and medium term.

In Germany as well as in Europe, an accelerated expansion of renewable energy and a strongly rising and increasingly flexible power demand will point the way towards a decarbonised society in the coming years. It is crucial that power is reliably available and can be used as directly and efficiently as possible. The corresponding expansion and conversion of the transmission grid is therefore a vital prerequisite for a carbon-neutral future. The GDP presents the necessary expansion measures in the transmission grid towards a carbon-neutral grid.

Transport demand grows significantly with the expansion of renewable energy

To achieve carbon-neutrality in Germany until 2045 and to get more indepently in terms of energy supply are reflected in the political targets. Therefore, these political targets are assumend within the scenario framework for the GDP. Compared to the last GDP with the observation periods ending in 2035 and 2040, installed capacity of renewable energy and gross energy consumption in 2037 and 2045 have increased significantly. According to Renewable Energy Act (EEG), the major share of the expansion of renewable energies is supposed to be implemented by the mid-2030s. The aim is to enable carbon-neutral power supply to decarbonize other sectors. The development is accelerating by leaps and bounds. Consequently, this increases the demands on the transmission grid enormously. The demand for power transport from northern to southern Germany is expected to rise significantly to around 87.7 GW by 2037. Between 2037 and 2045 the increase in transport in the scenarios remains at a similar level or increases only from northern to southern Germany moderately. The further expansion of renewable energy can largely be offset by the expansion of flexibilities.

Due to the increasing electrification of the building, transport and industrial sectors, the total gross power consumption increases from about 650 to 700 TWh in 2035 of the previous GDP to 899 to 1,053 TWh in 2037 of the current GDP. Compared to the last GDP, this corresponds to an increase of around 40 to 44%. After 2037, gross power consumption increases further to 1,079 to 1,303 TWh in 2045 according to the scenario framework. To cover this increase, the installed renewable energy capacity will have to be expanded to 638 to 703 GW. This corresponds to almost a fivefold increase in installed renewable energy capacities by 2045 compared to today.

Expansion of renewable energy

Installed capacity in GW	Reference (2020 / 2021)	Target year 2035 (GDP 2021)	Target year 2037 (GDP 2023)	Target year 2045 (GDP 2023)
Photovoltaics	59	110 – 120	345	400 – 445
Offshore wind	8	28 – 34	51 – 59	70
Onshore wind	56	82 – 91	158 – 162	160 – 180

Source: Transmission system operators

In terms of regional distribution, this GDP reveals new trends. As before, southern and now also increasingly western federal states tend to experience a generation deficit in the scenarios, while there is a generation surplus in northern and north-eastern federal states. The demand for transport within Germany is still largely determined by a high feed-in of wind energy in the north and north-east of Germany and the location of the consumption centres in the west and south of Germany. Firstly, load flows occur in the opposite direction – partly due to high generation from photovoltaics in the south, while electrolyers are operational in the north.

The national development of the german energy system are embedded in the European scenario 'Distributed Energy' of the Ten Year Network Development Plan 2022. This plan accounts for the reduction of EU-wide emissions manifested at the European level with the target of climate neutrality by 2050. The Europe-wide balancing of power and consumption is of vital importance for the reliable and demand-based design of a carbon-neutral energy system. This will also reduce the need for flexibility and power generation capacities in Germany.

Hydrogen gains in importance

Compared to earlier GDPs, the assumptions regarding the extent of hydrogen utilisation and the expansion of the hydrogen infrastructure have also increased significantly. According to the approved scenario framework, a comprehensive hydrogen infrastructure is assumed as early as 2037. In 2045, up to 80 GW of electrolysis capacity for domestic hydrogen production is supposed to be integrated into the system. The future hydrogen infrastructure has a major impact on the development needs of the transmission grid. An extended hydrogen infrastructure is a prerequisite for grid-supporting allocation of hydrogen. This GDP adopts electrolysis locations that support the grid – a procedure for which currently no regulatory framework exist. This approach ensures that bottlenecks in the transmission grid can be minimised and the curtailment of renewable energy in times of high generation can be reduced as far as possible. Since the corresponding framework conditions are currently not in place, the approach is associated with high uncertainties from today's perspective. If other criteria are decisive for the allocation in the future, additional bottlenecks in the transmission grid are likely to occur.

Progressive interconnection

With the target of tackling the increasing transport demands at the lowest possible investment and redispatch costs, a higher-level controlling algorithm was used for the first time in the grid analyses. This metaheuristic method made it possible to compare several hundred combinations of expansion options – far more than usual. Combinations of measures were formed from the categories of grid connection points (GLP), corridors for High Voltage Direct Current Transmission lines (HVDC), interconnection of HVDC sites, grid-supporting location of offsite power-to-gas plants (electrolysers) as well as load flow control and AC projects in the vicinity of HVDC and GLP.

The four German TSOs continue to rely on a range of proven, innovative solutions and technologies and consider potentials of future innovative technologies such as modern system management concepts and grid boosters. Transport-bottlenecks identified in the scenarios were not completely removed by grid enhancement and expansion measures, so that between 1.5 and 5.9 TWh of redispatch volume are left. However, no peak capping was applied. This procedure corresponds to the scenario framework approval of the German Federal Network Agency (BNetzA).

In order to be able to react to the increasing demands flexibly and reliably, the TSOs are interconnecting the transmission grid even further. Since the first GDP in 2012, the TSOs have focused on linking AC and DC measures. This GDP now proposes additional measures on linked DC structures onshore as well as offshore measures among each other. Together with the European interconnection, renewable energy can be comprehensively integrated for flexible demand, and redispatch requirements can be reduced. This limits congestion management costs and contributes to a secure energy supply. Furthermore, the flexibility in grid operations gained through DC linking increases the security of supply.

Further expansion demand for a carbon-neutral grid by 2037

The climate neutrality network resulting from this GDP shows a considerable increase in necessary grid enhancement and expansion measures. Considering the increasing transport demand, the measures entrenched in the current Federal Demand Plan are far from sufficient for a demand-based grid.

The scope and cost volume of the expansion grid will therefore increase significantly compared to the previous GDP. Compared to the project portfolio proposed in the GDP 2035 (2021), the present GDP 2037/2045 (2023) identifies new onshore projects with a route length of 5,620 km and additional investments of EUR 52.3 billion. This is particularly attributable to the designation of five additional DC projects, which are necessary to secure the required transport task and are not yet included in the current Federal Demand Plan (BBP). Bundling options with each other or with existing DC projects are mostly possible or are being examined. The new DC projects increase the north-south as well as the east-west transport capacity. Other key drivers for the additional grid development measures are the strong expansion of renewable energy in the north, the dismantling of conventional power plants, the interconnected energy exchange with foreign countries, and the increasing loads in the course of achieving climate neutrality in all sectors.

Regarding to the results of the grid development target grids for the years 2037 and 2045 are almost identical. This is mainly due to the fact that onshore expansion of renewable energy between 2037 and 2045 is almost completed. The moderate increase in onshore renewable energy capacities by 2045 may cause additional bottlenecks in the onshore grid. However, it can be offset by the grid structures in place at that time and correspondingly flexible demand, especially from electrolysers, centralised and decentralised battery storage as well as demand side management. A majority of the carbon-neutral grid must therefore already be implemented in 2037.

Considering these assumptions, the target grid consists of a robust portfolio of grid enhancement and expansion measures that are necessary for all scenarios. All projects presented in GDP 2037/2045 (2023) should therefore be considered to be 'no-regret'. In the scenarios, the designated target grid only differs in terms of the remaining redispatch demand. Currently, there are still high uncertainties due to the not yet fully completed legal planning for the expansion of renewable energy (including at the federal states level), the decarbonisation strategies of the industry or the planning for the future hydrogen economy. It is important to clarified in the following GDP cycles to which extent the remaining redispatch can be further reduced, and especially whether it requires additional moderate grid expansion or other technical measures.

The onshore initial grid comprises AC and DC measures totalling around 6,950 km with an estimated investment volume of EUR 50 billion. For the onshore grid expansion, grid enhancements AC amount to 6,125 km. Furthermore, there are about 180 km of DC enhancement measures. Another 1,714 km are accounted for new AC construction measures and 4,396 km new DC construction measures. In total, the onshore expansion grid for all scenarios includes 12,413 km. For scenarios A/B/C 2037, the investment costs amount to around EUR 106.1 billion. The investment costs for the onshore expansion grid of the A/B/C 2045 scenarios are EUR 0.1 billion higher.

The system stability analyses show considerable additional demand for reactive power compensation as well as for the control of grid disconnections in the form of instantaneous reserve, which already occur in the analysed intermediate scenario 2030. As a consequence, previously reported plants must be prioritised and made available via grid-supporting contributions from third parties (e.g. provision from the distribution grids, from large consumers such as electrolysers, and other system participants, possibly through market procurement). The analyse on transient stability indicates that controllability could no longer be safely guaranteed in individual hours after conceptual fault clearance in case of disturbances. Therefore, in order to maintain system stability, additional solution concepts must be developed beyond the suggested measures. The results are presented in the accompanying document of the stability analyses, and the necessary measures are indicated.

Compared to the first draft of the GDP 2037/2045 (2023), the investment costs in the second draft of the GDP have increased by EUR 12.5 billion. This is mainly attributable to the consideration of additional projects based on additional demand for transformers and substations between the distribution and transmission grid. Other contributing factors include an update of the scope and costs of existing projects as well as the updated requirements for plants for reactive power compensation and for the provision of instantaneous reserve.

The drastic increase in investment costs compared to the previous GDP is caused by the change in the scope of projects and measures as well as the adjustment of standard and project costs resulting from the overall economic development.

Tapping offshore potential comprehensively

The expansion of the installed capacity from offshore-wind will continue even after 2037. Compared to today (7.8 GW), the installed capacity from offshore wind assumed in the scenarios increases by up to 7.5 times to 58.5 GW in 2037. By 2045, it further increases to 70 GW of installed capacity.

To integrate offshore wind generation the TSOs have determined offshore grid connection systems in the North Sea and Baltic Sea with a length of about 6,600 km and a transmission capacity of about 36 GW in scenario A 2037, as well as a length of about 9,300 km with a transmission capacity of about 44 GW in scenarios B 2037 and C 2037. For long-term scenarios A 2045, B 2045 and C 2045, a transmission capacity of about 60 GW results in grid connection systems with a length of 13,310 km (excl. initial grid). Even after 2037, eight more systems with a transmission capacity of 16 GW will be connected.

For the first time, national offshore interconnection is examined, its benefits are presented and a project with two measures is identified. Overall, national offshore interconnection is shown to be a grid-supporting and cost-efficient expansion measure aimed at minimising long-range grid bottlenecks.

The investment volume for the offshore grid expansion until 2037 is about EUR 77 billion for scenario A 2037. Scenarios B 2037 and C 2037 require investments of about EUR 103.5 billion (incl. interconnection). For long-term scenarios A 2045, B 2045 and C 2045, the estimated investment costs are around EUR 145.1 billion (incl. interconnection). Moreover, the investment costs for the offshore grid expansion measures of the offshore initial grid that are already being implemented amount to around EUR 12.4 billion for all scenarios with a route length of 1,580 km.

Based on the offshore grid connection systems confirmed by BNetzA in the GDP 2035 (2021), the additional need for 20 new Offshore grid connection systems with a route length of approx. 8,455 km and an investment volume of EUR 86.7 billion was identified in this GDP 2037/2045 (2023).

Energy corridors for lower spatial requirements

According to § 12b (3a) of the EnWG (German Energy Act), the TSOs need to for the first time identify bundling options for newly identified DC grid expansion measures and the cross-border onshore part of the offshore connection lines. It needs to be shown how these measures can be realised with existing or at least firmly planned routes, either entirely or to a large extent in one power line corridor. Bundling makes it possible to align offshore connection systems and newly identified DC projects in the same route and thus minimise the use of space. According to the HVDC projects already confirmed in the GDP 2035 (2021) or submitted for confirmation in the GDP 2037/2045 (2023), there are three central energy corridors based on the current planning status.

Route kilometres and investment costs of the expansion grid for B / C 2037 (A 2037) offshore and A / B / C 2037 onshore

	Route length in km	Investment volume in EUR billion
Offshore	9,250 (6,610)	103.5 (77)
Onshore	12,413	106.1
Total	21,663 (19,023)	209.6 (183.1)

Source: Transmission system operators

Route kilometres and investment costs for the expansions in scenarios A / B / C 2045

	Route length in km	Investment volume in EUR billion
Offshore	13,310	145.1
Onshore	12,413	106.2
Total	25,723	251.3

Source: Transmission system operators

Shaping the future with determination

The transformation to climate neutrality by one of the world's largest industrial nations can only succeed as a project involving society. It is up to politics, business, science and citizens to successfully shape this transformation together.

A secure, reliable and efficient transmission grid that keeps pace with the expansion of renewable energy makes a significant contribution to the success of the transformation.

The GDP clearly shows what this transformation means. Numerous grid development projects throughout Germany, on land as well as at sea, as enhancement of existing lines and as new construction need to be explained, decided, planned, built and operated. Dedicated skilled workers, available materials at reasonable prices and stable supply chains are a prerequisite for this.

The implementation of the carbon-neutral grid thus requires decisive action and joint commitment – from TSOs and approval authorities, from politicians at federal, state and local level, as well as other stakeholders in the energy transition.

Therefore, the follwing is needed:

- **Faster implementation** of grid expansion. The first important steps to accelerate planning and approval processes have been taken. They must now be swiftly put into practice. In order to integrate the very high output of renewable energy into the power grid by 2037, this GDP presents the carbon-neutral grid that must be implemented to the greatest possible extent as early as 2037.
- More **innovations** to reduce the need for grid expansion. One example is the first-time utilisation of potential through national offshore interconnection.
- More **flexibility**. Appropriate regulatory framework conditions and sufficient incentives must be created so that the flexibility potential of new technologies such as electrolysers can be optimised.This includes system-supporting locations and utilisation methods. The same applies to decentralised technologies such as electric vehicles and heat pumps. In addition to the provision of communication technologies for control, suitable market and grid charging structures are extremely necessary.
- An **integrated system planning** for power, gas and hydrogen. Even if separate grid planning processes continue to make sense, they should be based on jointly agreed scenario key figures in the future.

With its analyses, the GDP not only offers a specific outlook for the power grid of the next decades, but also a continuously updated and well-founded information base for central energy and economic policy decisions. The biennial rhythm ensures that the latest developments are reflected, covering market design and price development to the design of flexibilities or the speed of the expansion of renewable energy sources. Accordingly, the climate neutrality network presented in this GDP will also be further developed in the following GDPs.

Key statements of the chapters

The process of the grid development plan

The demands on the transmission grid are becoming increasingly complex. Decarbonisation through electrification ensures that ever greater amounts of power are consumed and in some cases transported over longer distances. Furthermore, it must be possible to react to volatile renewable energy generation caused by weather conditions and to operate the grid more and more flexible. The continuous development of the power grid is therefore an important component of a successful energy transition.

According to § 12b EnWG, the four german transmission system operators with control area responsibility (50Hertz, Amprion, TenneT and TransnetBW) are obligated to prepare a joint 'Grid Development Plan Electricity' document every two years and submit it to BNetzA for confirmation. The GDP presents the measures for optimisation, enhancement and expansion in the German power transmission grid as well as the offshore connection systems in the exclusive economic zone and in the territorial sea, including the grid interconnection points on land, considering the statutory requirements of the EnWG.

Based on the results of GDP, BNetzA determines which measures are required so that the German transmission grid can fulfil its future tasks. The calculations in the GDP are based on the scenario framework previously prepared by the TSOs and reviewed and approved by BNetzA.

The scenario framework on which this GDP is based considers 2045 and 2037. Considering political targets, it is assumed that Germany will be climate neutral[1] by 2045 at the leatest. The GDP presents a transmission grid for a carbon-neutral energy system[1] in Germany for the first time. It is based on the amendment to the Energy Industry Act. § 12a of the EnWG was amended as follows: 'Three additional scenarios must consider the year 2045 and present a range of probable developments, which are aligned with the legally defined climate and energy policy targets of the Federal Government.'

Therefore, three scenarios were created for each of the two target years: A, B and C. The GDP 2037 / 2045 (2023) calculates the grid developments necessary in six different scenarios.

1 With the GDP, the transmission system operators balance the CO_2 emissions in the domestic power sector. The achievement of targets in other sectors (such as industry, transport or heat) is outside the scope of our study. Moreover, imports or greenhouse gases used elsewhere are not included in the CO_2 balance for Germany.

Scenario Framework: Starting point for the GDP 2037 / 2045 (2023)

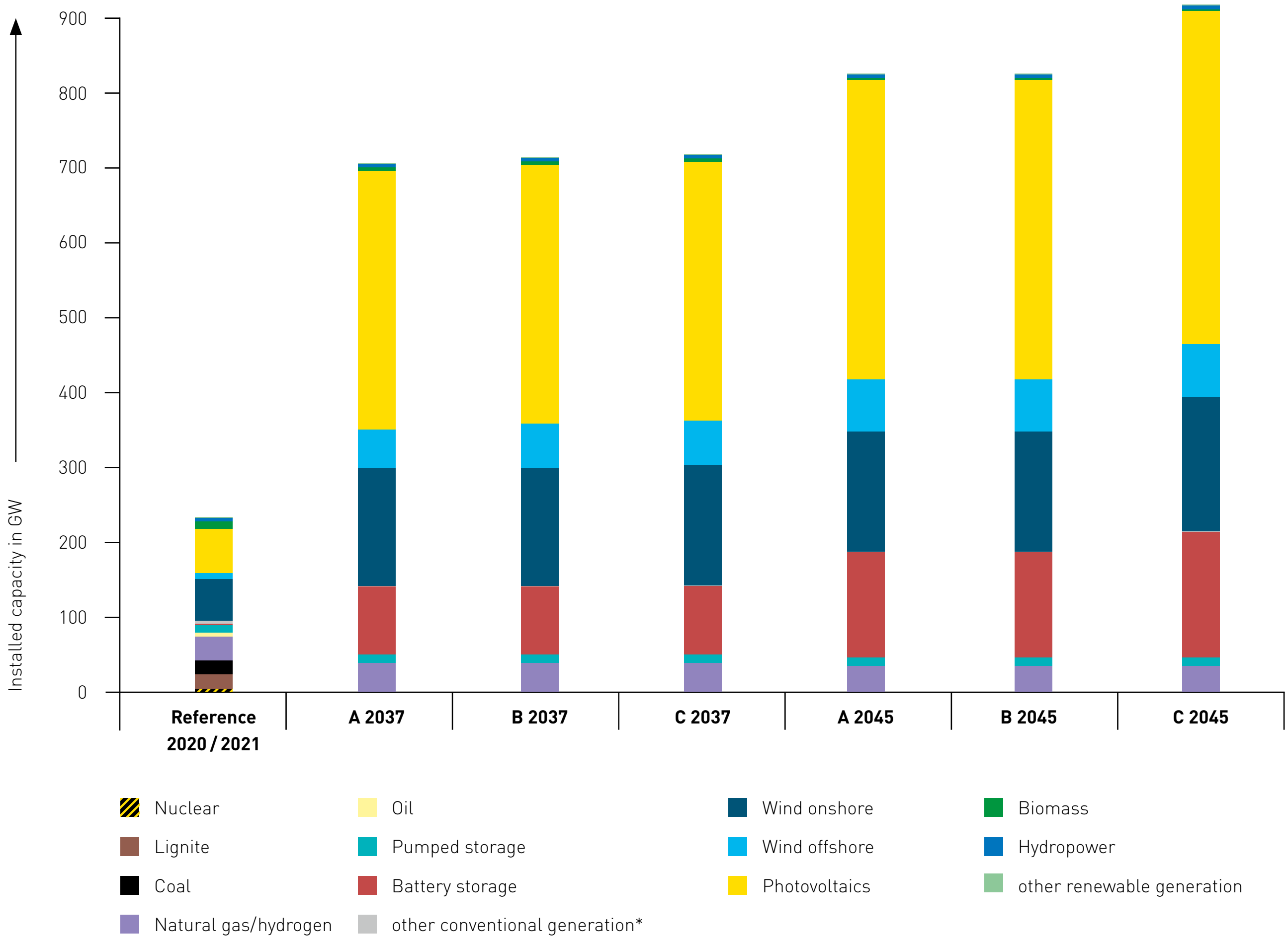
The scenario framework for GDP 2037 / 2045 (2023) considers a carbon-neutral energy system for the first time and thus forms the basis for a carbon-neutral grid in Germany. It considers the expansion targets for renewable energy of Renewable Energy Act 2023.

Scenario A (decarbonisation through higher share of hydrogen):
This scenario is characterised by the comparatively highest hydrogen demand in all scenarios. Hydrogen is increasingly used in some industrial sectors, where the uncertainty regarding potential electrification still seems high today. To meet this demand, a high domestic installed capacity is assumed in this scenario. Gross power consumption increases to around 1,050 TWh in 2045. The renewable capacities correspond to the targets of the Renewable Energy Act (EEG) and the Offshore Wind Power Act (WindSeeG).

Scenario B (decarbonisation through intensive electrification):
Scenario B relies on increased direct electrification in all final energy consumption sectors. Hydrogen is only used in applications where such direct electrification seems unlikely from today's perspective. Efficiency counteracts a strong increase in power consumption. The increase in power consumption is thus limited to just under 1,100 TWh. The renewable expansion path corresponds to the targets of the Renewable Energy Act (EEG) and Offshore Wind Power Act (WindSeeG).

Scenario C (decarbonisation despite lower efficiency):
Scenario C also assumes increased direct electrification in all final energy consumption sectors. Lower efficiency than in scenario B results in higher power consumption of almost 1,300 TWh. This is also accompanied by the need for stronger expansion of renewable energy.

Overview of the distribution of installed capacities per energy source



* other conventional generation plus 50% waste

Source: Transmission system operators

Overview of the scenario key figures

Installed capacity in GW							
Energy source	**Reference 2020 / 2021**	**A 2037**	**B 2037**	**C 2037**	**A 2045**	**B 2045**	**C 2045**
Nuclear	4.1	0.0	0.0	0.0	0.0	0.0	0.0
Lignite	18.9	0.0	0.0	0.0	0.0	0.0	0.0
Coal	19.0	0.0	0.0	0.0	0.0	0.0	0.0
Natural gas/hydrogen*	32.1	> 38.4	> 38.4	> 38.4	> 34.6	> 34.6	> 34.6
Oil	4.7	0.0	0.0	0.0	0.0	0.0	0.0
Pumped storage	9.8	12.2	12.2	12.2	12.2	12.2	12.2
other conventional generation**	4.3	1.0	1.0	1.0	1.0	1.0	1.0
Total conventional generation	**92.9**	**> 51.6**	**> 51.6**	**> 51.6**	**> 47.8**	**> 47.8**	**> 47.8**
Wind onshore	56.1	158.2	158.2	161.6	160.0	160.0	180.0
Wind offshore	7.8	50.5	58.5	58.5	70.0	70.0	70.0
Photovoltaics	59.3	345.4	345.4	345.4	400.0	400.0	445.0
Biomass	9.5	4.5	4.5	4.5	2.0	2.0	2.0
Hydropower***	4.9	5.3	5.3	5.3	5.3	5.3	5.3
other renewable generation****	1.1	1.0	1.0	1.0	1.0	1.0	1.0
Total renewable generation	**138.7**	**564.9**	**572.9**	**576.3**	**638.3**	**638.3**	**703.3**
Total generation	**231.6**	**616.5**	**624.5**	**627.9**	**686.1**	**686.1**	**751.1**
Power consumption in TWh							
Net power consumption	478	828	891	982	999	1,025	1,222
Gross power consumption	533	899	961	1,053	1,079	1,106	1,303
Drivers of sector coupling							
Heat pumps – household and commerce, trade and services, quantity in millions.	1.2	14.3	14.3	14.3	16.3	16.3	16.3
Electromobility – quantity in millions.	1.2	25.2	31.7	31.7	34.8	37.3	37.3
Power-to-Heat – district heating/industry, in GW	0.8	12.6	16.1	22.0	14.9	20.4	27.0
Electrolysis in GW	< 0.1	40.0	26.0	28.0	80.0	50.0	55.0
Further storage and demand-side flexibilities in GW							
Photovoltaic battery storage	1.3	67.4	67.4	67.4	97.7	97.7	113.4
Large-scale battery storage	0.5	23.7	23.7	24.2	43.3	43.3	54.5
DSM – industry and commerce, trade and services	1.2	5.0	7.2	7.2	8.9	12.0	12.0

The presented values are from the approval document and a subsequently agreed increase in pumped storage capacity.
Deviations of these values arise in the course of modelling. Due to the large amount of flexible electrical loads and variables, the exact power consumption will only result from the power market modelling.

* The stated capacities merely include the power plants explicitly allocated with the scenario framework approval, not the additional near-load reserves reflected in the market simulation.

** other conventional generation plus 50% waste

*** Storage water and run-of-river water

**** other renewable generation plus 50% waste

Source: Federal Network Agency

Central assumptions of the scenario framework are:

Power sector in pioneering role: The power sector is highly important for achieving greenhouse gas neutrality in Germany by 2045. In the context of sector coupling, the power sector plays a pioneering role and can contribute significantly to the decarbonisation of other sectors. Direct electrification seems to be the most efficient option to replace fossil fuels in many cases.

Developed hydrogen infrastructure: In cases where direct electrification is associated with higher economic costs or is not technologically feasible, the use of hydrogen or synthetic fuels can be advantageous. The scenario framework assumes a comprehensively developed hydrogen infrastructure by 2037. In the scenarios for 2045, with an installed capacity of between 50 and 80 GW, a significant part of the hydrogen demand in Germany is covered by domestic electrolysis. Bottlenecks in the transmission grid can be minimised by allocating electrolysers to serve the grid. Moreover, due to the proximity to renewable energy plants and a market-oriented operation, the curtailment of renewable energy in times of high generation can be largely reduced.

Electrification of the sectors: Due to the increasing electrification of the heating, transport and industrial sector, gross power consumption is expected to double to 1,300 TWh by 2045 compared to today. The installed capacity of renewable energy will be expanded to 640 to 700 GW for this purpose. This corresponds to almost a fivefold increase in installed capacities from renewable energy compared to today. In this power system in 2045, which is dominated by volatile generation, a high demand for flexibility is needed in terms of generation and load capacity. It is assumed that many power consumers can react flexible to the supply and demand situation and adjust their consumption accordingly. This ensures an integration with an great extent of renewable energy and reduces variable generation costs.

More storage technologies: Demand side management and storage technologies support the balancing and integration of renewable power generation. 12 GW of pumped storage power plants and up to 168 GW of large and small battery storage are assumed. Hydrogen can be used as an energy carrier for seasonal storage of renewable energy.

Phasing out coal and nuclear energy: A complete phase-out of nuclear energy and an end to coal-fired power generation by 2037 is assumed in all scenarios. Conventional power plants will still be needed in Germany to provide secure power generation. To achieve climate neutrality, these plants must be operated exclusively with hydrogen or greenhouse gas-neutral fuels by 2045 at the leatest.

European integration: The Europe-wide balancing of power generation and consumption is of vital importance for an efficient and demand-based carbon-neutral energy system. This will reduce the need for flexibility and power generation capacities in Germany. The national development for Germany is embedded in the European scenario 'Distributed Energy' of the Ten Year Network Development Plan 2022.

Market simulation: Focus on renewable energy and flexible demand

The results of the market simulation highlight the dominant role of renewable energy in Germany's energy mix. In all scenarios, power generation from renewable energy rises to over 1,000 TWh in 2045. The use of conventional power plant capacities, storage facilities and load-side flexibilities is strongly aligned with the volatile generation from renewable energy. Photovoltaics in particular dominate the power system in the summer months and favour the regular use of storage and electrolysers. Gas power plants are used almost exclusively in the winter months. The German power system is supported to a considerable extent by **power generation from renewable energy**, especially in summer. The number of full load hours of gas power plants in the scenarios is in some cases significantly below 1,000 h/a.

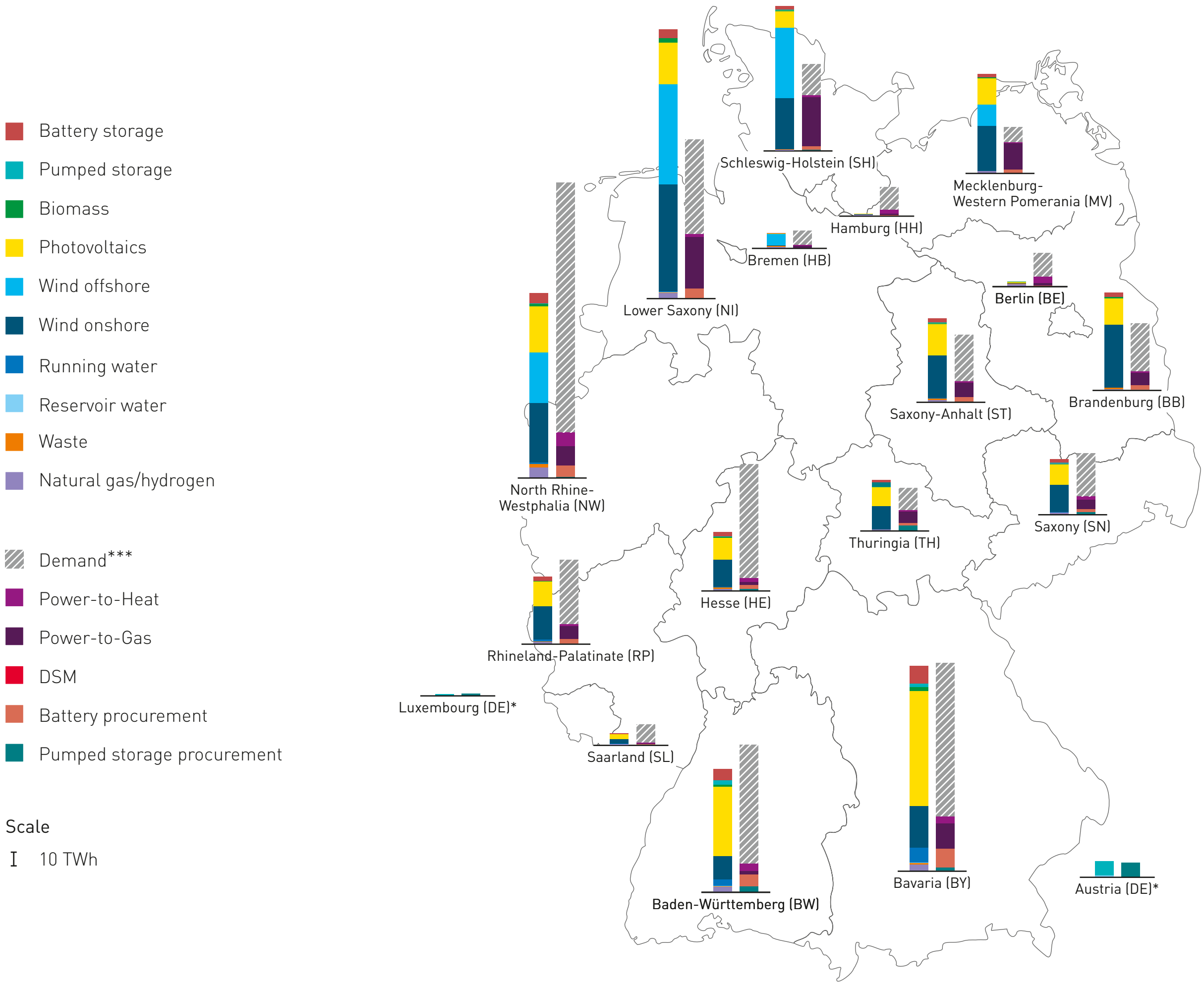
In the various scenarios, Germany develops into a large **net power importer in Europe**. This is primarily attributable to the relatively high domestic power demand and the high installed capacity of renewable energy abroad. The imported power increases significantly from 2037 to 2045, in C 2045 presenting the highest increase. Large amounts of electricity are mainly imported from France, Austria and Scandinavia in the scenarios.

A significant share of the **German hydrogen demand** can be covered by domestic water electrolysis in the scenarios. Because the hydrogen demand is subject to seasonal fluctuations, long-term hydrogen storage or hydrogen imports must be used to operate gas power plants in the winter months.

The demand for **power transport within Germany increases significantly until 2037**. By contrast, there is no longer a significant increase in transport between 2037 and 2045 in the scenarios. Southern and western federal states tend to experience a generation deficit in the scenarios, while there is a generation surplus in northern and eastern federal states. The demand for transport within Germany is largely determined by a high generation of wind energy in the north and the location of the consumption centres in western and southern Germany. In addition, load flows occur in the opposite direction due to situations with high photovoltaic generation in the south.

Depending on the share of carbon-neutral hydrogen for power generation in 2037, the **remaining CO_2 emissions** are reduced. In all three scenarios, the power system is still responsible for low residual emissions in 2045. These emissions are attributable to waste incineration in power plants and must be offset elsewhere to achieve greenhouse gas neutrality.

Energy balance in scenario A 2037

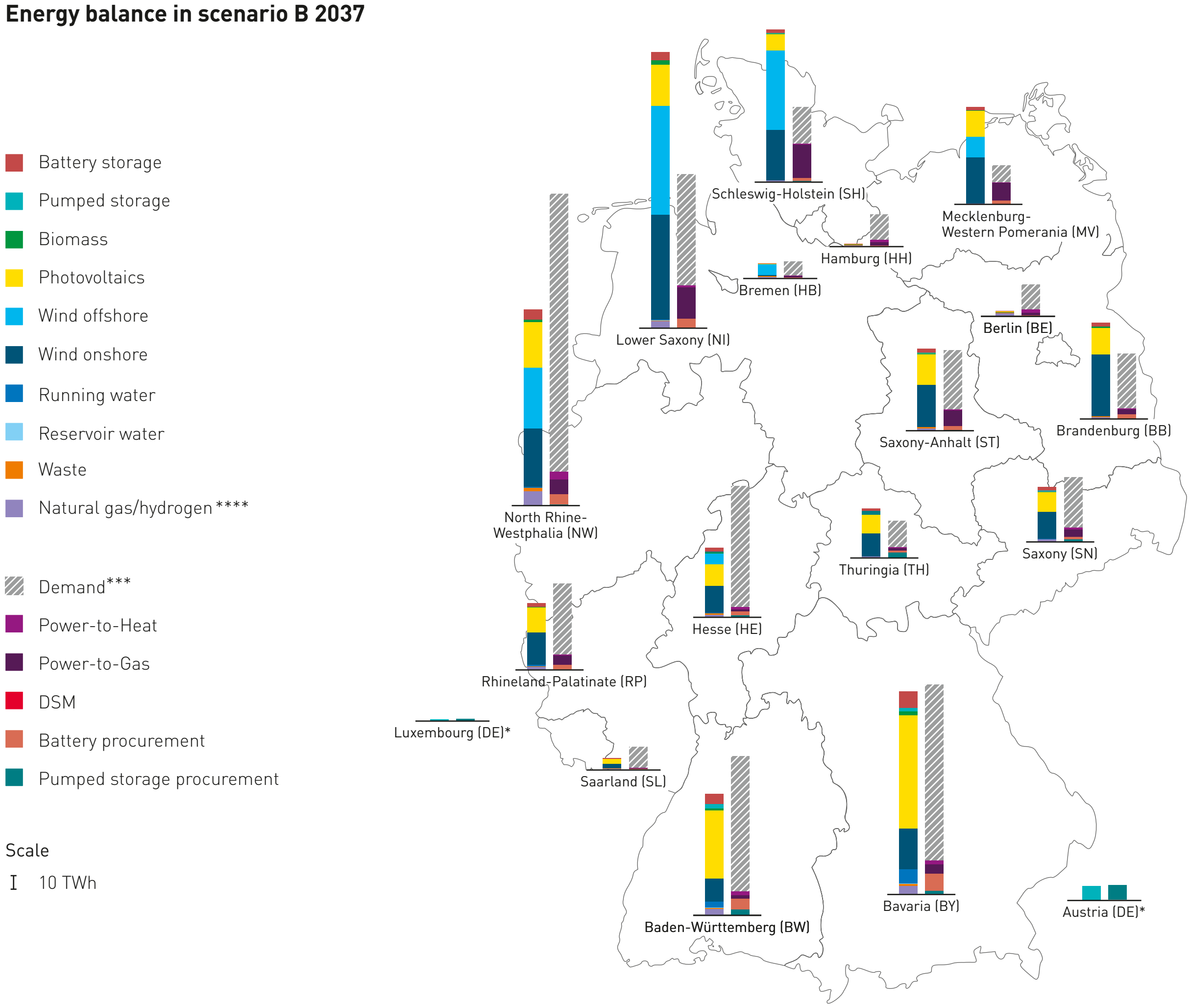


A 2037 in TWh	Natural gas/ Hydrogen	Waste	Reservoir water	Running water	Wind onshore	Wind offshore	Photo-voltaics	Biomass	Pumped storage	Battery storage	Power con-sumption***	PtH	PtG	DSM	Battery procurement	Pumped storage procurement
BW	3.2	0.5	0.1	4.2	15.9	0.0	46.0	1.6	2.8	7.3	79.3	4.8	2.6	-0.1	7.7	3.5
BY	4.0	1.2	0.2	9.9	27.8	0.0	76.8	2.7	2.1	11.9	102.2	4.8	16.9	-0.1	12.5	1.9
BE	1.4	0.2	0.0	0.0	0.3	0.0	0.7	0.1	0.0	0.2	16.1	4.1	1.7	0.0	0.2	0.0
BB	0.6	0.7	0.0	0.0	41.9	0.0	18.0	0.7	0.0	2.8	32.1	0.7	8.7	0.0	2.9	0.0
HB	0.5	0.6	0.0	0.0	0.6	7.6	0.3	0.0	0.0	0.1	9.6	0.6	1.0	0.0	0.1	0.0
HH	0.4	0.1	0.0	0.0	0.3	0.0	0.3	0.1	0.0	0.1	15.3	2.5	1.2	0.0	0.1	0.0
HE	1.0	1.0	0.0	0.3	18.1	0.0	14.7	0.5	0.6	2.7	76.0	2.6	2.0	0.0	2.8	0.7
MV	0.2	0.1	0.0	0.0	31.2	13.9	17.6	0.6	0.0	2.2	10.0	0.5	17.6	0.0	2.3	0.0
NI	3.1	0.6	0.4	0.3	71.6	66.5	28.0	2.8	0.0	5.8	63.2	1.9	34.6	-0.1	6.1	0.0
NW	6.7	2.2	0.3	0.7	39.6	33.7	31.0	1.5	0.1	7.2	166.5	9.0	13.2	-0.1	7.6	0.2
RP	1.1	0.5	0.0	1.0	21.9	0.0	17.0	0.3	0.0	2.8	43.1	1.0	8.9	0.0	2.9	0.0
SL	0.4	0.2	0.0	0.1	3.2	0.0	3.1	0.0	0.0	0.6	12.3	0.4	0.2	0.0	0.6	0.0
SN	1.0	0.1	0.0	0.4	18.3	0.0	13.3	0.5	0.9	2.2	28.6	2.3	6.2	0.0	2.3	1.1
ST	0.8	1.0	0.0	0.1	28.7	0.0	20.7	0.9	0.1	2.7	30.9	0.9	9.8	0.0	2.9	0.1
SH	0.4	0.3	0.0	0.0	34.2	46.9	10.9	0.9	0.1	2.4	20.8	1.1	32.9	0.0	2.6	0.1
TH	0.5	0.1	0.0	0.1	15.5	0.0	12.5	0.4	2.7	1.7	14.9	0.7	7.4	0.0	1.8	3.3
LU (DE)*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0		0.0	0.0	1.2
AT (DE)*	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	9.3	0.0	0.0	0.0		0.0	0.0	9.5
Total**	**25.3**	**9.2**	**2.0**	**17.3**	**368.9**	**168.5**	**310.6**	**13.5**	**19.4**	**52.6**	**746.0**	**37.7**	**164.9**	**-0.5**	**55.3**	**21.7**

* Generation plants abroad with feed-in to the German transmission grid.
** Rounding deviations may occur when the individual values are summed.
*** In this presentation, power consumption comprises net power consumption including all grid losses without considering the adjacent power consumption by power-to-hydrogen and power-to-heat plants (district heating) as well as demand side management. Grid losses in the transmission grid cannot be clearly allocated to the federal states.

Source: Transmission system operators

Energy balance in scenario B 2037



B 2037 in TWh	Natural gas/ hydrogen****	Waste	Reservoir water	Running water	Wind onshore	Wind offshore	Photo-voltaics	Biomass	Pumped storage	Battery storage	Power con-sumption***	PtH	PtG	DSM	Battery procurement	Pumped storage procurement
BW	4.0	0.5	0.1	4.2	15.7	0.0	45.7	1.6	2.7	6.9	91.2	2.8	2.2	-0.2	7.3	3.5
BY	5.4	1.2	0.2	9.9	27.5	0.0	76.3	2.7	2.1	11.2	118.8	2.7	6.0	-0.2	11.8	1.9
BE	1.8	0.2	0.0	0.0	0.3	0.0	0.7	0.1	0.0	0.1	16.9	2.1	1.9	0.0	0.2	0.0
BB	0.8	0.8	0.0	0.0	41.5	0.0	17.9	0.7	0.0	2.6	36.8	0.4	3.5	0.0	2.8	0.0
HB	0.6	0.6	0.0	0.0	0.6	7.5	0.3	0.0	0.0	0.1	9.9	0.3	1.0	0.0	0.1	0.0
HH	0.5	0.1	0.0	0.0	0.3	0.0	0.3	0.1	0.0	0.1	16.9	1.4	2.7	0.0	0.1	0.0
HE	1.4	1.0	0.0	0.3	17.9	7.6	14.6	0.5	0.6	2.5	81.7	1.5	1.6	-0.1	2.7	0.7
MV	0.3	0.1	0.0	0.0	30.9	13.8	17.5	0.6	0.0	2.1	11.4	0.3	12.0	0.0	2.2	0.0
NI	4.1	0.6	0.4	0.3	70.8	73.4	27.8	2.8	0.0	5.5	75.2	1.1	21.3	-0.1	5.8	0.0
NW	9.1	2.3	0.3	0.7	39.2	40.9	30.9	1.5	0.1	6.8	187.4	5.1	10.0	-0.3	7.2	0.1
RP	1.5	0.5	0.0	1.0	21.6	0.0	16.9	0.3	0.0	2.6	47.8	0.6	6.4	-0.1	2.8	0.0
SL	0.5	0.2	0.0	0.1	3.2	0.0	3.0	0.0	0.0	0.5	14.2	0.2	0.2	0.0	0.6	0.0
SN	1.3	0.1	0.0	0.4	18.1	0.0	13.2	0.5	0.8	2.0	34.1	1.3	4.7	0.0	2.1	1.1
ST	1.1	1.0	0.0	0.1	28.4	0.0	20.5	0.9	0.1	2.6	40.3	0.5	10.5	0.0	2.7	0.1
SH	0.6	0.3	0.0	0.0	33.9	53.5	10.8	0.9	0.1	2.3	24.7	0.6	22.3	0.0	2.4	0.1
TH	0.6	0.1	0.0	0.1	15.3	0.0	12.4	0.4	2.5	1.6	18.1	0.4	1.4	0.0	1.7	3.1
LU (DE)*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	1.1
AT (DE)*	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	9.5	0.0	0.0	0.0	0.0	0.0	0.0	9.9
Total**	**33.7**	**9.4**	**2.0**	**17.3**	**365.2**	**196.6**	**308.7**	**13.5**	**19.4**	**49.8**	**854.4**	**21.4**	**108.0**	**-1.0**	**52.3**	**21.7**

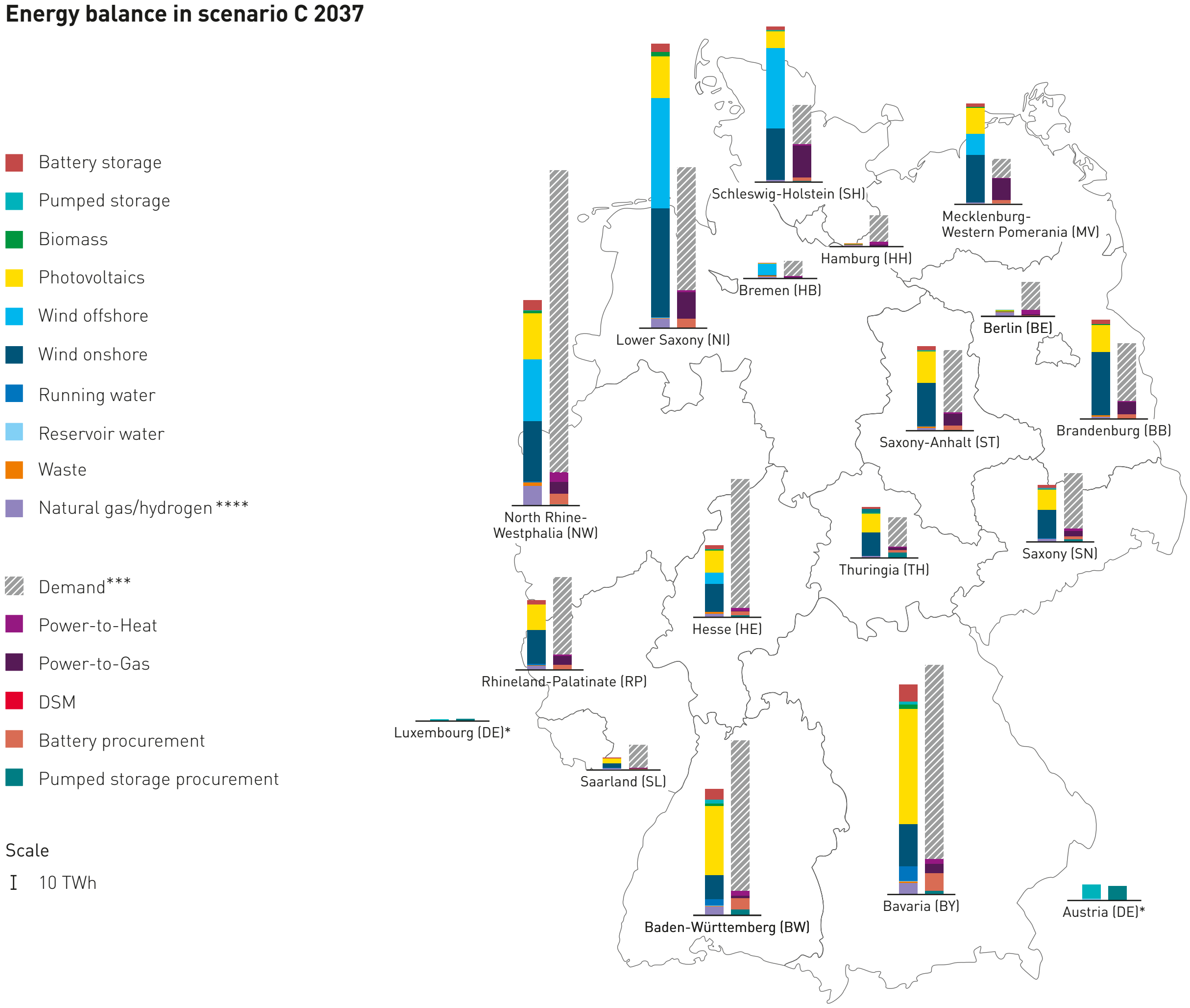
* Generation plants abroad with feed-in to the German transmission grid.

** Rounding deviations may occur when the individual values are summed.

*** In this presentation, power consumption comprises net power consumption including all grid losses without considering the adjacent power consumption by power-to-hydrogen and power-to-heat plants (district heating) as well as demand side management. Grid losses in the transmission grid cannot be clearly allocated to the federal states.

Source: Transmission system operators

Energy balance in scenario C 2037



C 2037 in TWh	Natural gas/ hydrogen****	Waste	Reservoir water	Running water	Wind onshore	Wind offshore	Photo-voltaics	Biomass	Pumped storage	Battery storage	Power con-sumption***	PtH	PtG	DSM	Battery procurement	Pumped storage procurement
BW	5.5	0.5	0.1	4.2	16.4	0.0	46.6	1.6	2.8	7.1	101.2	3.4	1.60	-0.2	7.5	3.6
BY	7.3	1.2	0.2	9.9	28.5	0.0	77.9	2.7	2.1	11.5	131.0	3.4	6.04	-0.3	12.1	1.9
BE	2.4	0.2	0.0	0.0	0.3	0.0	0.7	0.1	0.0	0.2	18.8	2.7	0.97	0.0	0.2	0.0
BB	1.2	0.8	0.0	0.0	42.6	0.0	18.3	0.7	0.0	2.7	38.8	0.5	8.38	0.0	2.8	0.0
HB	0.8	0.6	0.0	0.0	0.6	7.6	0.3	0.0	0.0	0.1	10.5	0.4	0.43	0.0	0.1	0.0
HH	0.7	0.1	0.0	0.0	0.3	0.0	0.3	0.1	0.0	0.1	18.1	1.8	0.74	0.0	0.1	0.0
HE	2.1	1.0	0.0	0.3	18.7	7.6	14.9	0.5	0.6	2.6	87.0	1.9	0.53	-0.1	2.7	0.7
MV	0.5	0.1	0.0	0.0	32.1	14.0	17.9	0.6	0.0	2.1	12.7	0.4	14.55	0.0	2.3	0.0
NI	5.7	0.6	0.4	0.3	73.4	74.3	28.4	2.8	0.0	5.6	82.7	1.3	18.08	-0.1	5.9	0.0
NW	12.8	2.3	0.3	0.7	40.4	41.4	31.5	1.5	0.1	7.0	203.4	6.3	8.43	-0.3	7.3	0.1
RP	2.3	0.5	0.0	1.0	22.5	0.0	17.2	0.3	0.0	2.7	52.0	0.7	6.37	-0.1	2.8	0.0
SL	0.7	0.2	0.0	0.1	3.3	0.0	3.1	0.0	0.0	0.5	15.3	0.3	0.19	0.0	0.6	0.0
SN	1.7	0.1	0.0	0.4	18.9	0.0	13.5	0.5	0.8	2.1	37.2	1.6	3.72	-0.1	2.2	1.1
ST	1.5	1.1	0.0	0.1	29.2	0.0	21.0	0.9	0.1	2.6	42.0	0.7	8.22	0.0	2.8	0.1
SH	0.8	0.3	0.0	0.0	34.8	54.1	11.0	0.9	0.1	2.4	26.6	0.8	21.68	0.0	2.5	0.1
TH	0.8	0.1	0.0	0.1	15.9	0.0	12.6	0.4	2.6	1.6	19.8	0.5	1.86	0.0	1.7	3.2
LU (DE)*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	1.2
AT (DE)*	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	9.5	0.0	0.0	0.0	0.0	0.0	0.0	9.9
Total**	**46.6**	**9.5**	**2.0**	**17.3**	**377.8**	**199.0**	**315.1**	**13.5**	**19.4**	**50.7**	**928.2**	**26.5**	**101.8**	**-1.3**	**53.4**	**21.8**

* Generation plants abroad with feed-in to the German transmission grid.
** Rounding deviations may occur when the individual values are summed.
*** In this presentation. power consumption comprises net power consumption including all grid losses without considering the adjacent power consumption by power-to-hydrogen and power-to-heat plants (district heating) as well as demand side management. Grid losses in the transmission grid cannot be clearly allocated to the federal states.
**** Includes utilisation of reserves near consumption areas.

Source: Transmission system operators

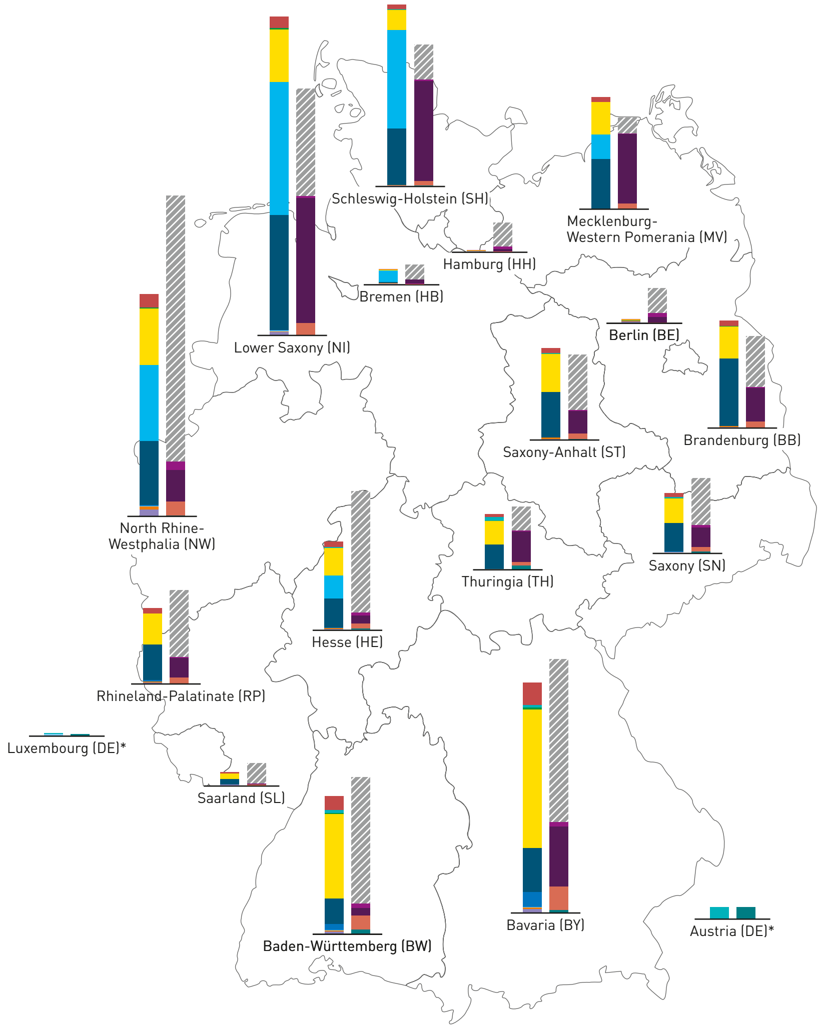
Energy balance in scenario A 2045

- Battery storage
- Pumped storage
- Biomass
- Photovoltaics
- Wind offshore
- Wind onshore
- Running water
- Reservoir water
- Waste
- Natural gas/hydrogen

- Demand***
- Power-to-Heat
- Power-to-Gas
- DSM
- Battery procurement
- Pumped storage procurement

Scale

I 10 TWh



A 2045 in TWh	Natural gas/ Hydrogen	Waste	Reservoir water	Running water	Wind onshore	Wind offshore	Photo-voltaics	Biomass	Pumped storage	Battery storage	Power con-sumption***	PtH	PtG	DSM	Battery procurement	Pumped storage procurement
BW	1.6	0.4	0.1	4.2	16.9	0.0	55.9	0.7	2.1	9.0	83.7	3.0	4.7	-0.2	9.5	2.6
BY	2.2	1.1	0.2	9.9	29.1	0.0	91.8	1.2	1.8	14.6	107.8	3.0	39.8	-0.2	15.4	1.5
BE	0.9	0.2	0.0	0.0	0.3	0.0	0.8	0.0	0.0	0.2	16.3	2.5	3.7	0.0	0.2	0.0
BB	0.3	0.7	0.0	0.0	44.4	0.0	21.2	0.3	0.0	3.6	33.9	0.4	22.4	0.0	3.8	0.0
HB	0.3	0.5	0.0	0.0	0.7	7.7	0.4	0.0	0.0	0.1	9.7	0.4	2.5	0.0	0.1	0.0
HH	0.1	0.1	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.1	15.6	1.6	1.8	0.0	0.1	0.0
HE	0.3	0.9	0.0	0.3	19.3	15.0	18.1	0.2	0.5	3.4	80.5	1.7	5.4	-0.1	3.6	0.5
MV	0.0	0.1	0.0	0.0	32.6	16.2	21.4	0.3	0.0	3.0	10.5	0.3	46.1	0.0	3.2	0.0
NI	1.8	0.6	0.4	0.3	76.3	87.8	34.5	1.3	0.0	7.4	71.4	1.2	82.6	-0.1	7.8	0.0
NW	4.0	2.2	0.3	0.7	42.2	50.0	37.6	0.7	0.1	8.6	176.1	5.6	20.9	-0.2	9.1	0.1
RP	0.7	0.5	0.0	1.0	23.4	0.0	20.7	0.1	0.0	3.5	44.3	0.6	13.2	0.0	3.7	0.0
SL	0.2	0.2	0.0	0.1	3.5	0.0	3.6	0.0	0.0	0.7	13.7	0.2	0.2	0.0	0.7	0.0
SN	0.3	0.1	0.0	0.4	19.0	0.0	16.1	0.2	0.6	2.7	31.0	1.4	13.2	0.0	2.9	0.8
ST	0.3	1.0	0.0	0.1	30.1	0.0	24.9	0.4	0.1	3.6	36.4	0.6	15.0	0.0	3.8	0.1
SH	0.2	0.3	0.0	0.0	37.3	65.3	13.1	0.4	0.1	3.0	23.2	0.7	66.2	0.0	3.2	0.1
TH	0.1	0.1	0.0	0.1	16.3	0.0	15.4	0.2	2.1	2.2	16.0	0.5	20.1	0.0	2.3	2.5
LU (DE)*	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.9
AT (DE)*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.6	0.0	0.0	0.0	0.0	0.0	0.0	7.4
Total**	**13.3**	**9.0**	**2.0**	**17.3**	**391.7**	**242.0**	**375.8**	**6.0**	**15.4**	**65.9**	**801.4**	**23.5**	**357.8**	**-1.0**	**69.3**	**16.4**

* Generation plants abroad with feed-in to the German transmission grid.

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Source: Transmission system operators

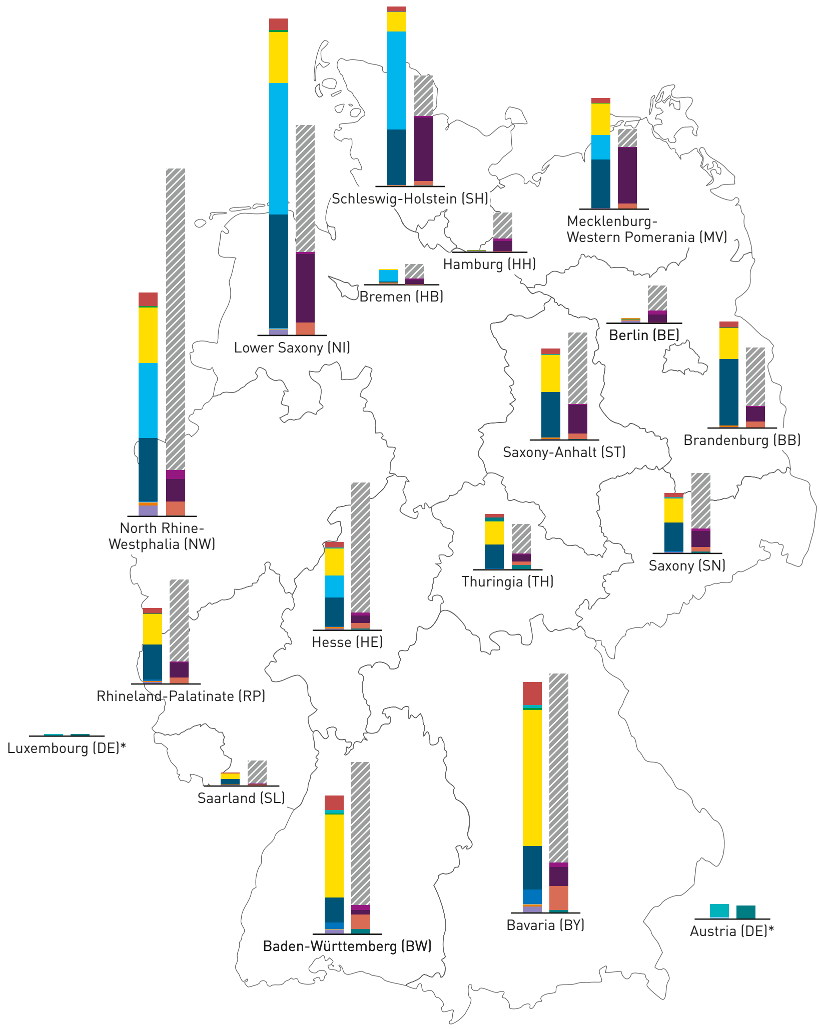
Energy balance in scenario B 2045

- Battery storage
- Pumped storage
- Biomass
- Photovoltaics
- Wind offshore
- Wind onshore
- Running water
- Reservoir water
- Waste
- Natural gas/hydrogen

- Demand***
- Power-to-Heat
- Power-to-Gas
- DSM
- Battery procurement
- Pumped storage procurement

Scale

I 10 TWh



B 2045 in TWh	Natural gas/ Hydrogen	Waste	Reservoir water	Running water	Wind onshore	Wind offshore	Photo-voltaics	Biomass	Pumped storage	Battery storage	Power con-sumption***	PtH	PtG	DSM	Battery procurement	Pumped storage procurement
BW	2.4	0.5	0.1	4.2	16.7	0.0	54.9	0.7	2.3	9.3	94.6	3.1	2.9	-0.2	9.8	2.9
BY	3.9	1.2	0.2	9.9	28.7	0.0	90.1	1.2	1.9	15.1	125.1	3.0	12.4	-0.3	15.9	1.6
BE	1.5	0.2	0.0	0.0	0.3	0.0	0.8	0.0	0.0	0.2	16.8	2.4	5.2	0.0	0.2	0.0
BB	0.5	0.7	0.0	0.0	43.9	0.0	20.8	0.3	0.0	3.7	38.9	0.4	9.7	0.0	3.9	0.0
HB	0.5	0.6	0.0	0.0	0.7	7.6	0.4	0.0	0.0	0.1	9.8	0.4	3.0	0.0	0.1	0.0
HH	0.2	0.1	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.1	17.1	1.6	7.1	0.0	0.1	0.0
HE	0.8	1.0	0.0	0.3	19.1	14.8	17.7	0.2	0.5	3.5	86.2	1.7	5.1	-0.1	3.7	0.6
MV	0.1	0.1	0.0	0.0	32.2	16.1	21.0	0.3	0.0	3.1	11.9	0.3	37.2	0.0	3.3	0.0
NI	3.1	0.6	0.4	0.3	75.3	86.7	33.8	1.3	0.0	7.6	83.8	1.2	45.5	-0.2	8.0	0.0
NW	6.7	2.2	0.3	0.7	41.7	49.5	36.9	0.7	0.1	8.9	199.6	5.7	15.0	-0.4	9.4	0.1
RP	1.1	0.5	0.0	1.0	23.1	0.0	20.3	0.1	0.0	3.6	54.3	0.6	9.9	-0.1	3.8	0.0
SL	0.4	0.2	0.0	0.1	3.5	0.0	3.6	0.0	0.0	0.7	15.4	0.2	0.2	0.0	0.7	0.0
SN	0.6	0.1	0.0	0.4	18.8	0.0	15.8	0.2	0.7	2.8	36.5	1.5	10.7	-0.1	2.9	0.9
ST	0.5	1.0	0.0	0.1	29.7	0.0	24.4	0.4	0.1	3.7	47.1	0.6	18.8	0.0	3.9	0.1
SH	0.3	0.3	0.0	0.0	36.8	64.6	12.8	0.4	0.1	3.1	26.9	0.7	42.0	0.0	3.3	0.1
TH	0.2	0.1	0.0	0.1	16.1	0.0	15.1	0.2	2.2	2.3	19.5	0.5	4.6	0.0	2.4	2.7
LU (DE)*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.9
AT (DE)*	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	8.5	0.0	0.0	0.0	0.0	0.0	0.0	8.5
Total**	**22.7**	**9.1**	**2.0**	**17.3**	**386.9**	**239.2**	**368.7**	**6.0**	**17.0**	**67.8**	**914.8**	**23.7**	**229.7**	**-1.4**	**71.4**	**18.5**

* Generation plants abroad with feed-in to the German transmission grid.
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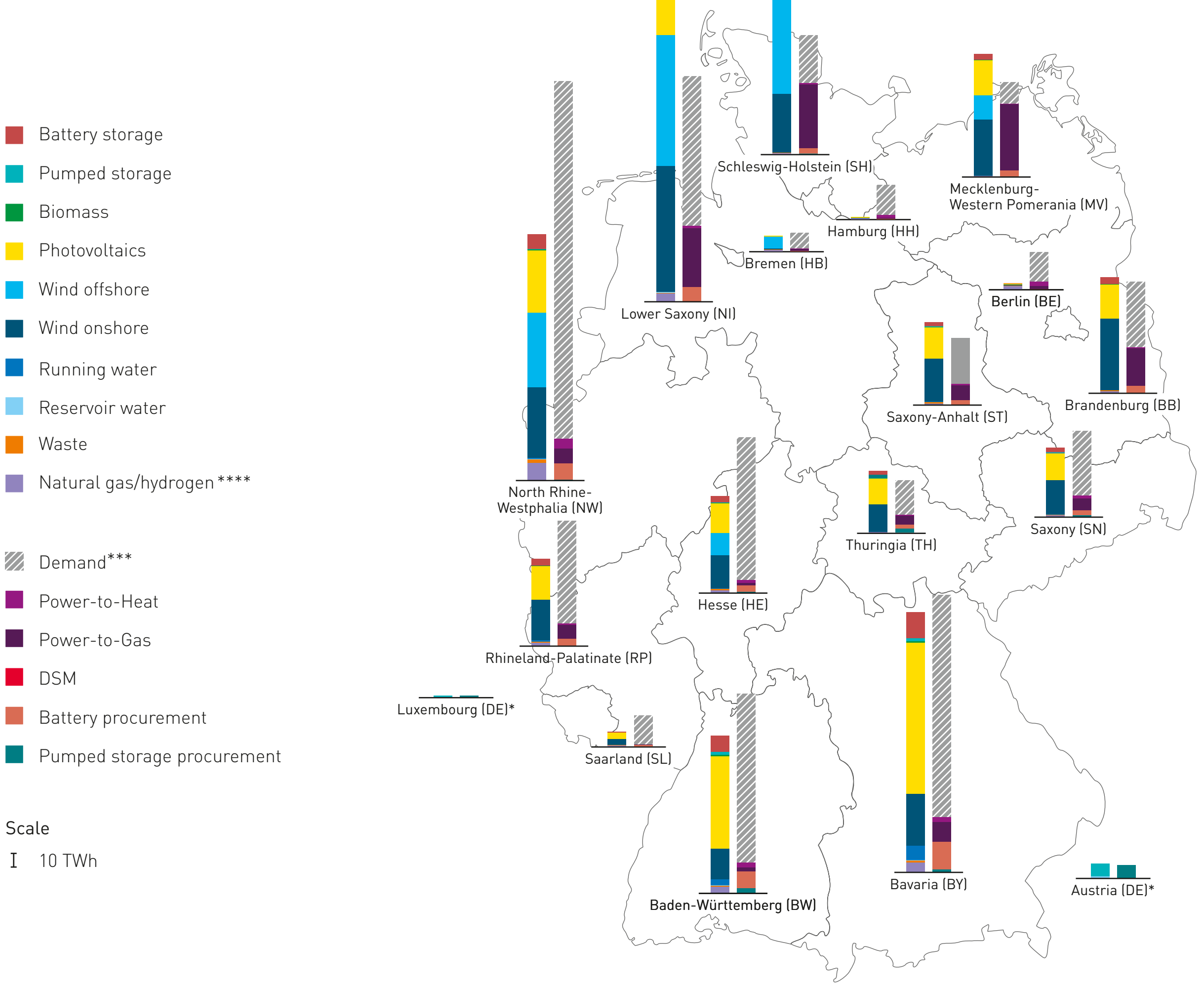
Source: Transmission system operators

Energy balance in scenario C 2045



C 2045 in TWh	Natural gas/ hydrogen****	Waste	Reservoir water	Running water	Wind onshore	Wind offshore	Photo-voltaics	Biomass	Pumped storage	Battery storage	Power con-sumption***	PtH	PtG	DSM	Battery procurement	Pumped storage procurement
BW	4.2	0.5	0.1	4.2	20.6	0.0	61.9	0.7	2.2	10.8	112.9	3.5	2.6	-0.3	11.3	2.8
BY	6.2	1.2	0.2	9.9	34.8	0.0	101.0	1.2	1.8	17.5	148.5	3.5	13.2	-0.4	18.4	1.5
BE	2.2	0.2	0.0	0.0	0.4	0.0	0.9	0.0	0.0	0.2	19.7	2.7	2.1	0.0	0.2	0.0
BB	0.9	0.8	0.0	0.0	47.7	0.0	23.1	0.3	0.0	4.4	43.8	0.5	25.3	-0.1	4.6	0.0
HB	0.7	0.6	0.0	0.0	0.7	7.7	0.4	0.0	0.0	0.1	10.7	0.4	1.0	0.0	0.1	0.0
HH	0.4	0.1	0.0	0.0	0.3	0.0	0.4	0.0	0.0	0.1	19.9	1.8	0.8	-0.1	0.1	0.0
HE	1.7	1.0	0.0	0.3	22.1	14.9	20.0	0.2	0.5	4.1	95.7	1.9	1.7	-0.1	4.3	0.5
MV	0.2	0.1	0.0	0.0	37.6	16.2	23.6	0.3	0.0	3.7	14.3	0.4	44.4	0.0	3.9	0.0
NI	5.1	0.6	0.4	0.3	84.1	87.4	38.3	1.3	0.0	8.9	100.2	1.4	39.5	-0.2	9.4	0.0
NW	11.5	2.3	0.3	0.7	47.2	49.8	41.8	0.7	0.1	10.2	239.2	6.5	10.3	-0.5	10.8	0.1
RP	2.1	0.5	0.0	1.0	26.8	0.0	22.9	0.1	0.0	4.3	68.8	0.7	9.4	-0.1	4.5	0.0
SL	0.7	0.2	0.0	0.1	3.9	0.0	4.0	0.0	0.0	0.8	19.2	0.3	0.2	0.0	0.8	0.0
SN	1.1	0.1	0.0	0.4	22.8	0.0	17.7	0.2	0.7	3.3	43.6	1.7	7.8	-0.1	3.5	0.8
ST	1.2	1.0	0.0	0.1	32.6	0.0	27.5	0.4	0.1	4.4	57.2	0.7	13.0	-0.1	4.6	0.1
SH	0.6	0.3	0.0	0.0	39.4	65.0	14.5	0.4	0.1	3.6	32.2	0.8	42.8	0.0	3.7	0.1
TH	0.4	0.1	0.0	0.1	18.6	0.0	17.0	0.2	2.2	2.7	23.0	0.5	6.0	-0.1	2.9	2.6
LU (DE)*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.91
AT (DE)*	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	8.4	0.0	0.0	0.0	0.0	0.0	0.0	8.3
Total**	**39.2**	**9.3**	**2.0**	**17.3**	**439.5**	**241.0**	**414.9**	**6.0**	**16.6**	**78.9**	**1.080.2**	**27.2**	**220.1**	**-2.1**	**83.1**	**18.0**

* Generation plants abroad with feed-in to the German transmission grid.
** Rounding deviations may occur when the individual values are summed.
*** In this presentation. power consumption comprises net power consumption including all grid losses without considering the adjacent power consumption by power-to-hydrogen and power-to-heat plants (district heating) as well as demand side management. Grid losses in the transmission grid cannot be clearly allocated to the federal states.
**** Includes utilisation of reserves near consumption areas.

Source: Transmission system operators

Offshore grid: Comprehensive development and progressive interconnection of potentials

The GDP and the Site Development Plan form a coherent set of plans with the geographical planning of the coastal states. The implementation of these statutory requirements frequently leads to **(chronological) overlaps** in the process of preparing the GDP and Site Development Plan. The process of updating the Site Development Plan was completed on 20/01/2023. The TSOs considered the Site Development Plan stipulation in the first draft of the GDP 2037 / 2045 (2023). However, the Site Development Plan 2023 lacks geographical and temporal stipulations that are necessary for achieving the statutory expansion targets for offshore wind for the years 2035 and 2045 according to the WindSeeG. Considering the fact that offshore grid connection systems take a long time to be realised, the necessary fundamentals for confirming the expansion targets through specific projects in a timely manner is therefore currently lacking. In agreement with the Federal Network Agency, the second draft of GDP 2037 / 2045 (2023) is therefore largely based on the draft of Site Development Plan 2023 dated 1 July 2022. This applies especially to the geographical allocation of areas, border corridors and the planned completion dates for offshore grid connection systems after 2031.

Expansion volume of offshore grid connection systems

Based on the offshore grid connection systems confirmed by Federal Network Agency, in the GDP 2035 (2021), the additional need for 20 new offshore grid connection systems with a route length of approx. 8,455 km and investment costs of EUR 86.7 billion were identified in this GDP 2037 / 2045 (2023).

For the offshore expansion grid in the North Sea and the Baltic Sea, this results in a length of

- about 6,600 km with a transmission capacity of about 36 GW in scenario A 2037,
- about 9,300 km with a transmission capacity of about 44 GW in scenarios B 2037 and C 2037,
- and a length of 13,300 km with a transmission capacity of about 61.2 GW for long-term scenarios A 2045, B 2045 and C 2045.

The corresponding grid connection points (GLP) on land were identified. The investments for the offshore grid connection systems in the offshore grid expansion are based on specific cost rates and are of a preliminary nature.

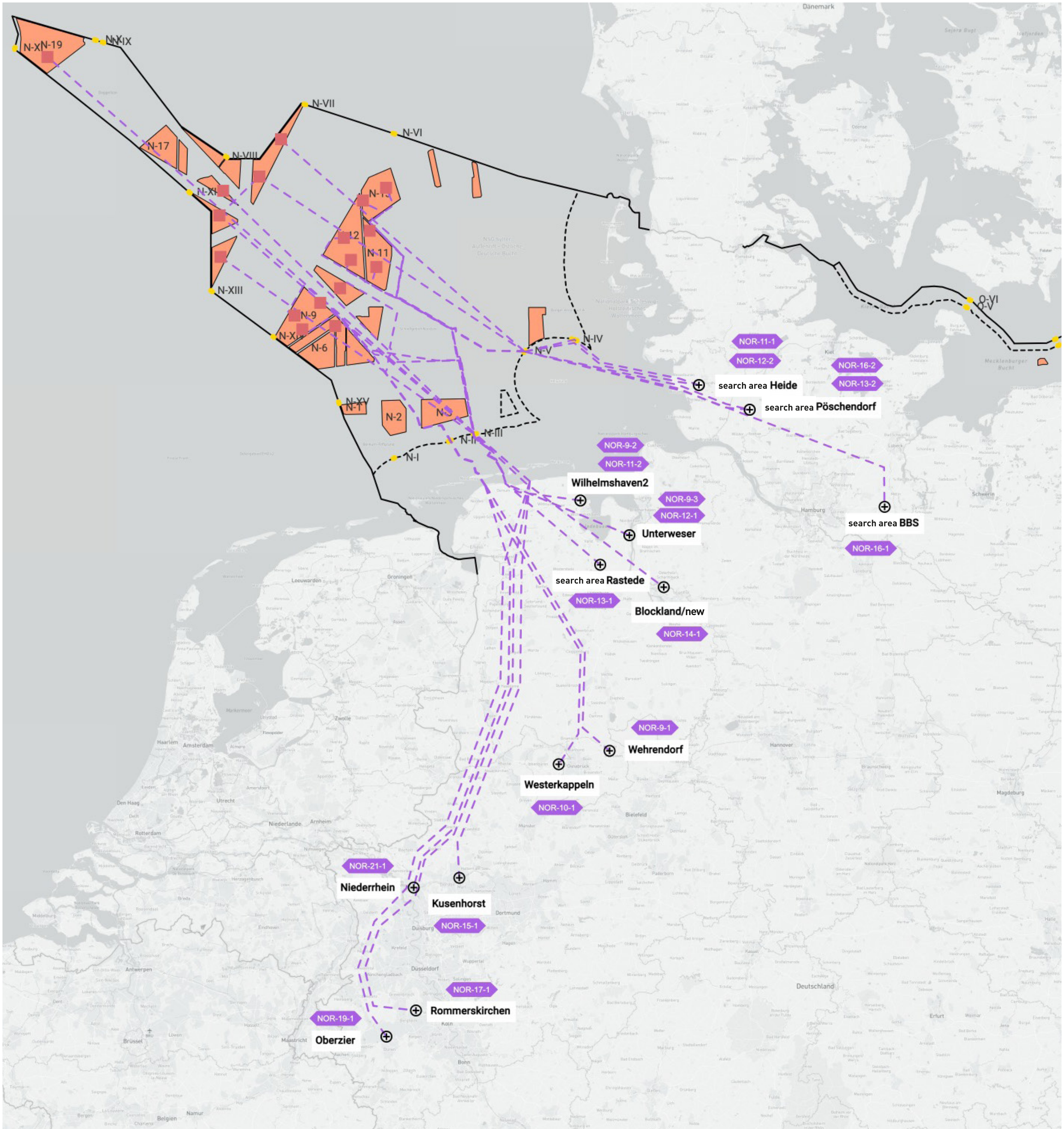
- For scenario A 2037, the estimated investment volume for the offshore expansion grid amounts to around EUR 77 billion by 2037.
- Scenarios B 2037 and C 2037 require investment costs of about EUR 103.5 billion.
- For long-term scenarios A 2045, B 2045 and C 2045, the estimated investment costs are around EUR 145.1 billion.
- Moreover, the investment costsfor the offshore grid expansion measures of the offshore initial grid that are already being implemented amounts to around EUR 12.4 billion for all scenarios.

For the generation capacities to be installed for offshore wind of the approved scenario framework, all required transmission lines respectively offshore grid connection systems were determined. As a result, the number and thus the required investments for the 2037 and 2045 scenarios go beyond the expansion path for offshore wind depicted in the 2023 Site Development Plan. Accordingly, they represent a possible path to achieving the further statutory expansion targets of at least 40 GW by 2035 and at least 70 GW by 2045.

For the first time, the GDP 2037 / 2045 (2023) considers **national offshore interconnection**. Additionally, it presents the corresponding benefits and identifies a project with two measures. The offshore interconnection refers to the offshore connections between offshore grid connection systems. An offshore transmission capacity will be created between two onshore GLPs of the offshore grid connection systems. This additional transmission capacity can be used as a flexible bypass to relieve the onshore transmission grid, thus minimising redispatch interventions. Overall, national offshore interconnection is shown to be a grid-supporting and cost-efficient expansion measure aimed at minimising long-range grid bottlenecks. Further core results of the study on national offshore interconnection and the offshore interconnection study on international interconnection needs are published in a separate report.

The implementation of a high number of offshore grid connection systems in a short period poses a great challenge in terms of the manufacturer's market, logistics and approval procedures. This applies especially to the long offshore and onshore cable routes to be implemented as well as the corresponding planning, approval and construction times.

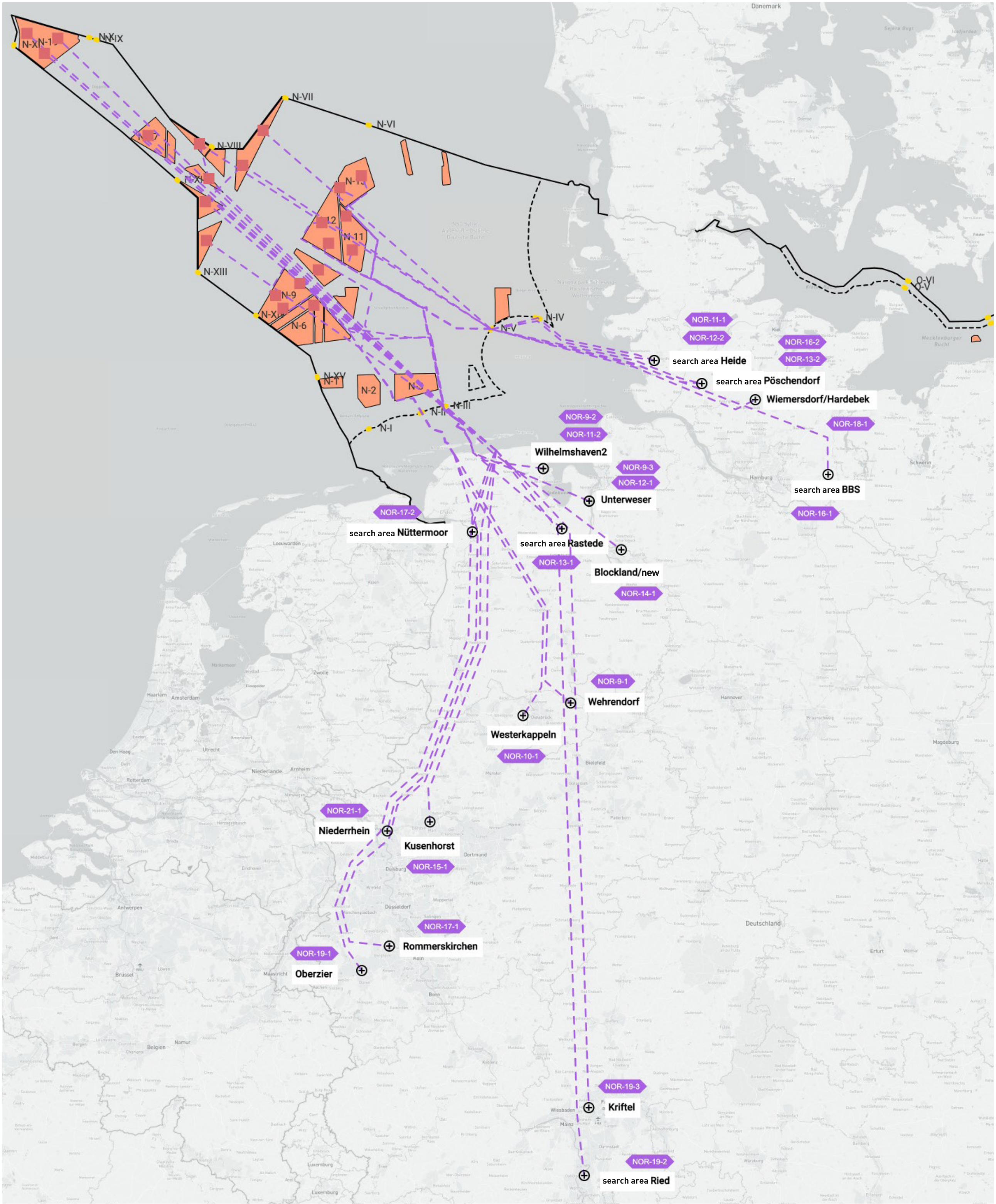
Measures of the North Sea offshore expansion grid in scenario A 2037



DC grid expansion
AC grid expansion
Project name
Offshore wind farm area
Converter platform
Transformer platform
Grid link point
Border corridor
Boundary of the territorial sea
Boundary of the exclusive economic zone

Source: Transmission system operator / map basis © Mapbox, © OpenStreetMap (ODbL), BSH (© GeoSeaPortal)

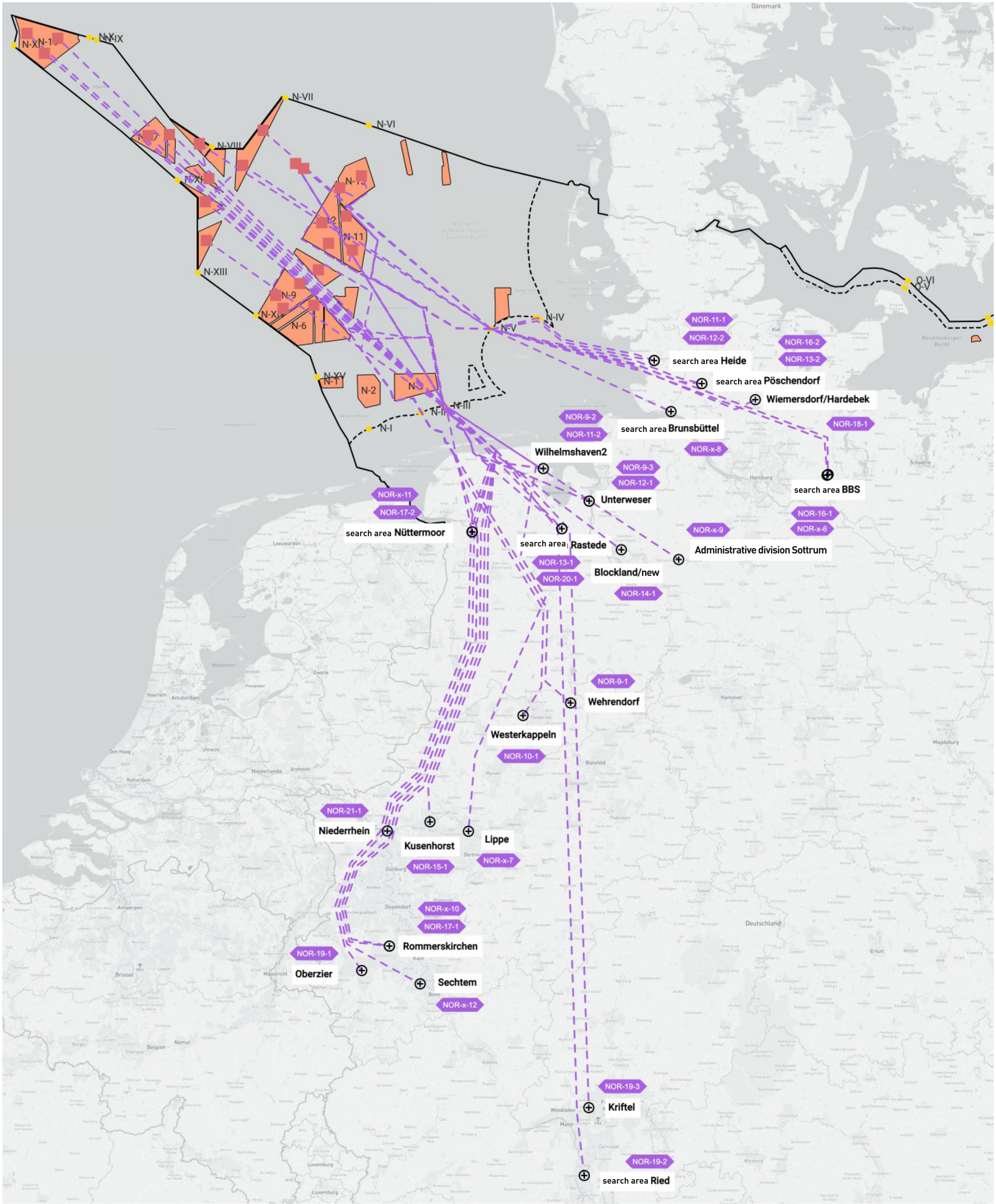
Measures of the North Sea offshore expansion grid in scenarios B / C 2037



DC grid expansion
AC grid expansion
Project name
Offshore wind farm area
Converter platform
Transformer platform
Grid link point
Border corridor
Boundary of the territorial sea
Boundary of the exclusive economic zone

Source: Transmission system operator / map basis © Mapbox, © OpenStreetMap (ODbL), BSH (© GeoSeaPortal)

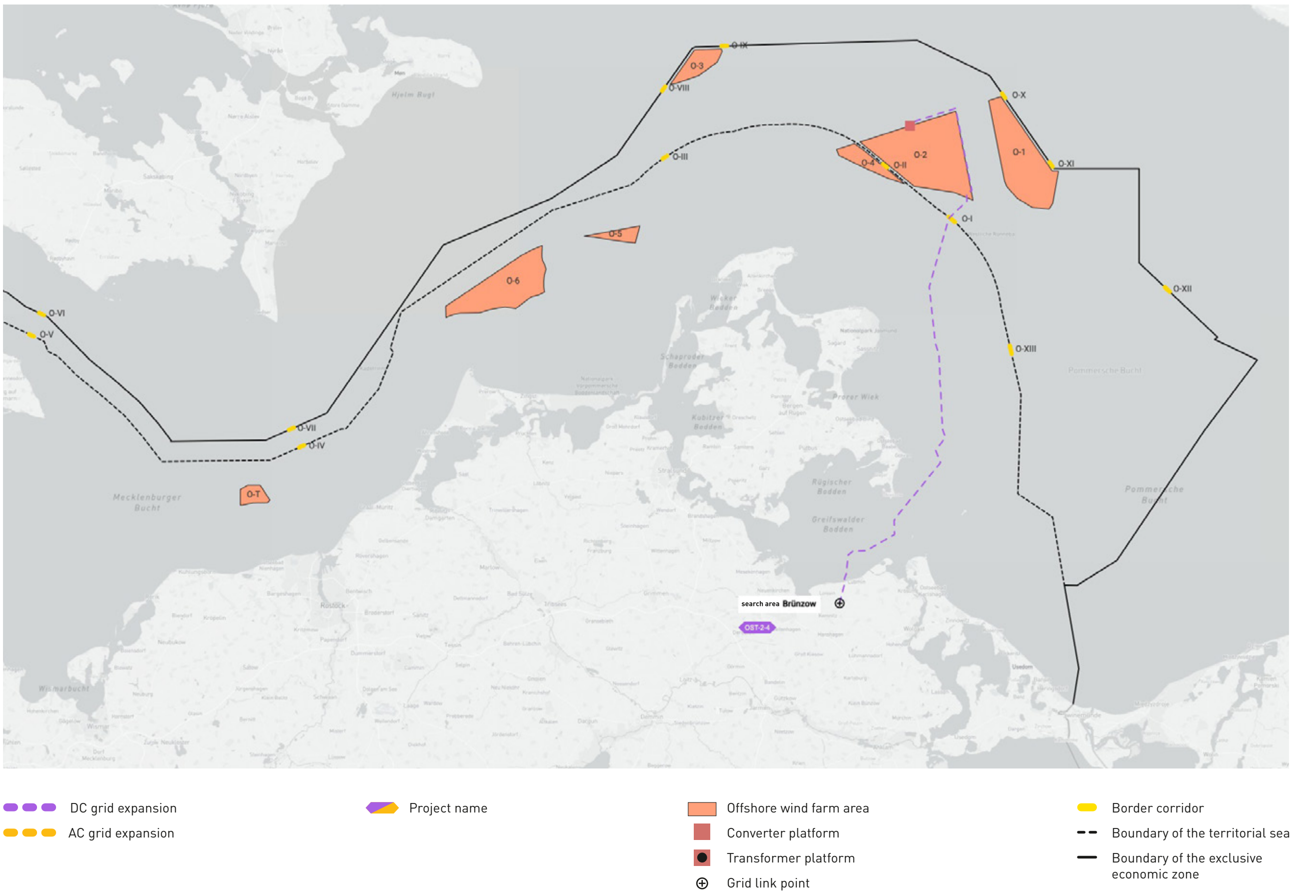
Measures of the North Sea offshore expansion grid in scenarios A / B / C 2045



DC grid expansion
AC grid expansion
Project name
Offshore wind farm area
Converter platform
Transformer platform
Grid link point
Border corridor
Boundary of the territorial sea
Boundary of the exclusive economic zone

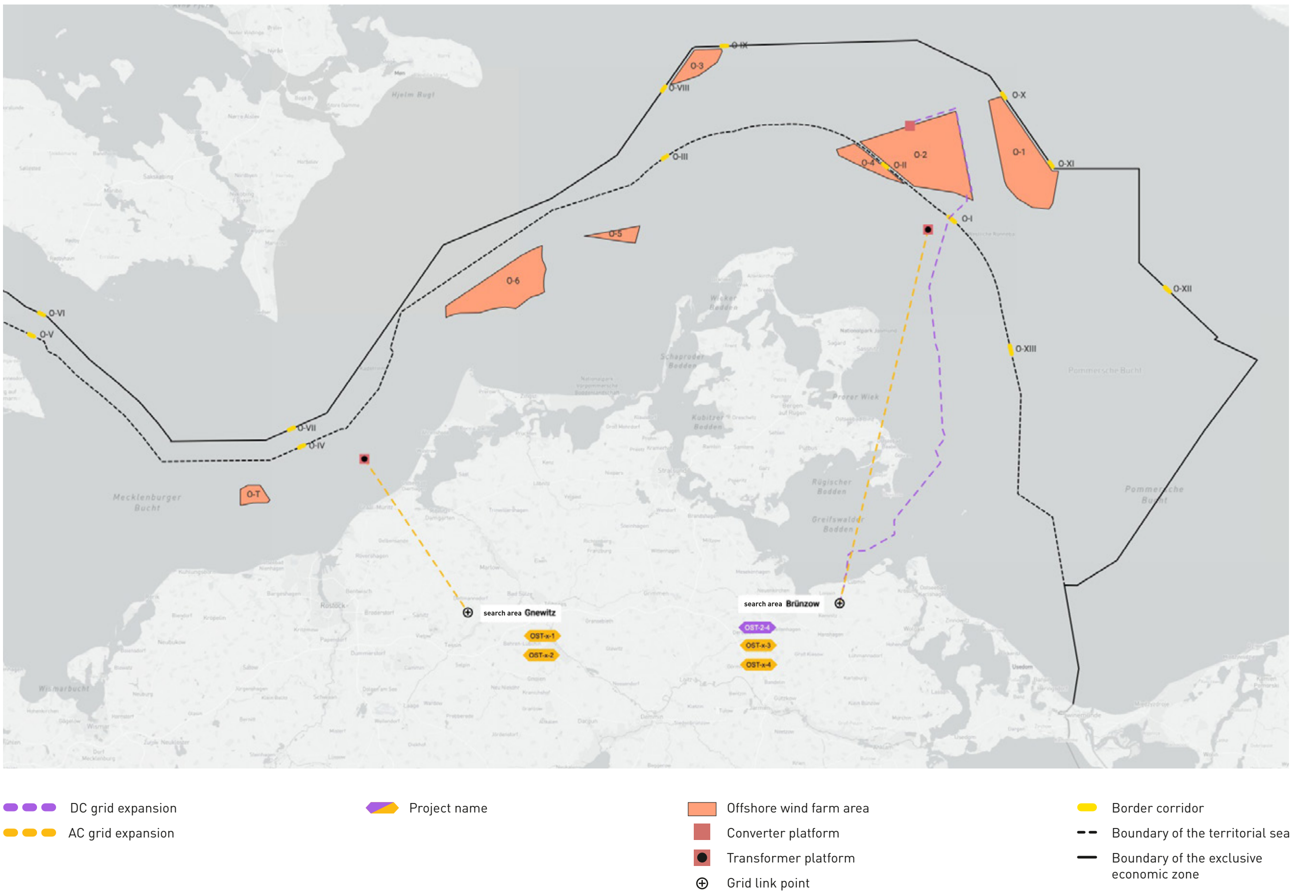
Source: Transmission system operator / map basis © Mapbox, © OpenStreetMap (ODbL), BSH (© GeoSeaPortal)

Measures of the Baltic Sea offshore expansion grid in scenarios A / B / C 2037



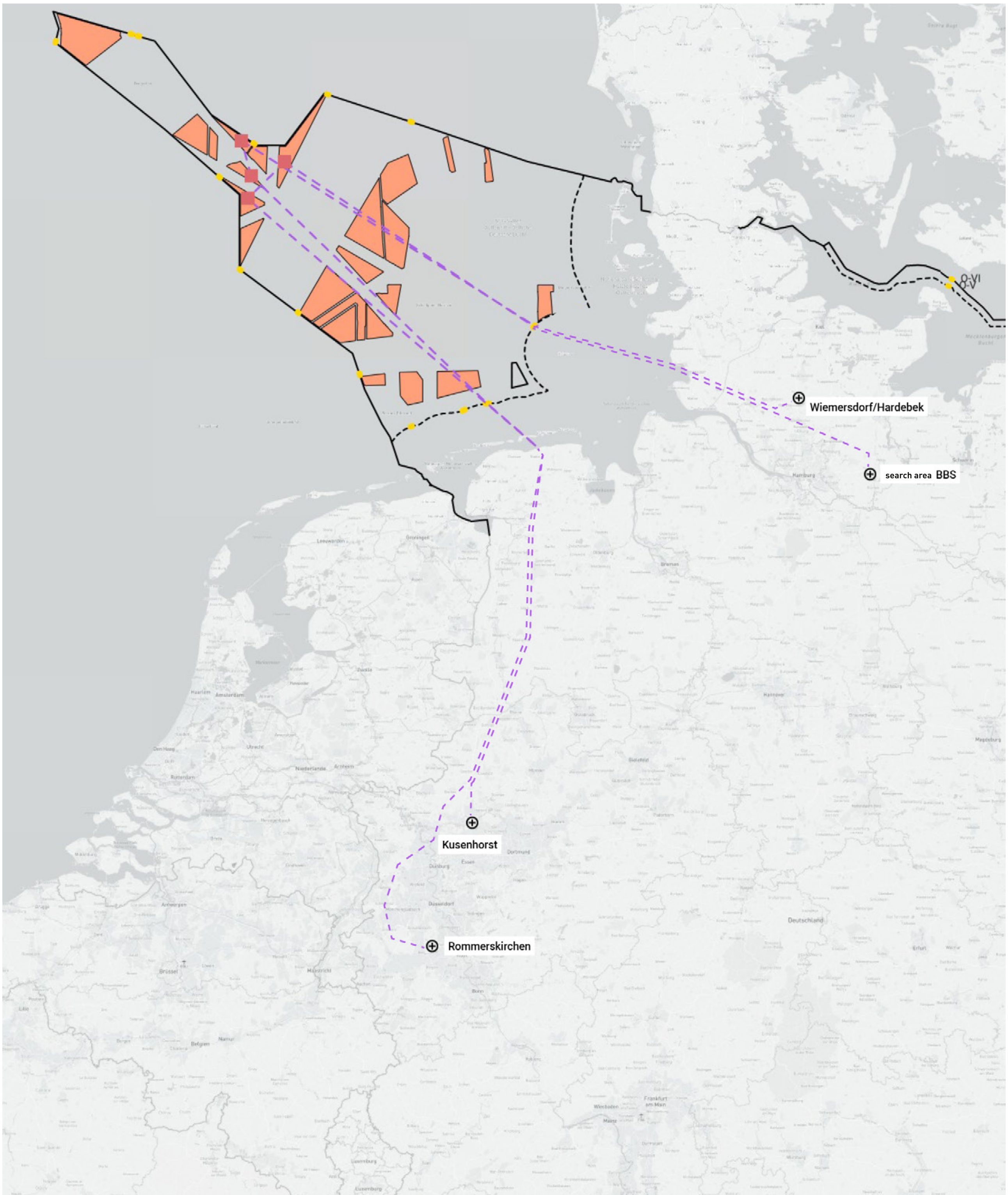
Source: Transmission system operator / map basis © Mapbox, © OpenStreetMap (ODbL), BSH (© GeoSeaPortal)

Measures of the Baltic Sea offshore expansion grid in scenarios A / B / C 2045



Source: Transmission system operator / map basis © Mapbox, © OpenStreetMap (ODbL), BSH (© GeoSeaPortal)

National offshore grid



Source: Transmission system operator / map basis © Mapbox, © OpenStreetMap (ODbL), BSH (© GeoSeaPortal)

Onshore grid: Considerable need for expansion of a carbon-neutral network by 2037

The statutory plans already foresee the majority of the necessary expansion of renewable energy by the mid-2030s. As a result of the substantial **increase in domestic German transport demand to around 87.7 GW by 2037**, a significant part of the onshore climate neutrality grid needs also be implemented by then. Until 2045, the load flow from northern to southern Germany almost remains at a similar level. The further expansion of renewable energy between 2037 and 2045 can be largely offset by the expansion of flexibilities, especially electrolysers, centralised and decentralised battery storage as well as demand side management. Due to the massive expansion of photovoltaic, significant load flows in opposite direction will also occur for the first time. While they partly require additional regional measures, the long-range transport can be fulfilled by the transmission grid, which has so far primarily been expanded for transport from northern to sourthern Germany.

The transmission grid must be reconstructed in such a way that it can already integrate an installed capacity of between 565 and 576 GW of renewable energy by 2037. Compared to today, it must also cover almost double the gross power consumption of around 900 to 1,050 TWh.

The result shows:

- All the projects of the Federal Demand Plan 2022 are necessary for scenarios A / B / C 2037 as well as all scenarios with the target year 2045. The necessity of these measures is thus confirmed in the GDP 2037 / 2045 (2023). However, in light of the increasing transport task, they are far from sufficient for a demand-based grid.

- Compared to the confirmed grid from the GDP 2035 (2021), the need for grid enhancement and expansion in GDP 2037 / 2045 (2023) increases by about 7,400 km of additional measures in the A / B / C 2037 and A / B / C 2045 scenarios (see Chapter 5.2.5).
  Of these measures, approx. 2,800 km are accounted for by new DC construction and enhancement measures (five additional DC projects), 1,300 km for new AC construction measures (approx. 20 additional AC projects) and 3,300 km for grid enhancement measures. The ratio of DC to AC new construction is 1.6.

- The onshore initial grid comprises AC and DC measures totalling around 6,950 km with estimated investment costs of EUR 50 billion. For the onshore grid expansion, grid enhancements in the AC segment amount to 6,125 km. Furthermore, there are about 180 km of DC enhancement measures. Another 1,714 km are accounted for new AC construction measures and 4,396 km for new DC construction measures. In total, the onshore expansion grid for all scenarios considers a total lentgh of about 12,413 km. For scenarios A / B / C 2037, the investment costs amount to around EUR 106.1 billion. The investment costs for the onshore expansion grid of the A / B / C 2045 scenarios are EUR 0.1 billion higher. Compared to the first draft of the GDP 2037 / 2045 (2023), the investment costs have increased by approx. EUR 12.5 billion. This is mainly attributable to the consideration of additional projects based on additional demand for transformers and substations between the distribution and transmission grid. Other contributing factors include an update of the scope and costs of existing projects as well as the updated requirements for plants for reactive power compensation and for the provision of instantaneous reserve.

- Compared to the project portfolio proposed in the GDP 2035 (2021), the present GDP 2037 / 2045 (2023) identifies new onshore projects with a route length of 5,620 km and additional investments of EUR 52.3 billion.

- The results of the grid analyses show an identical carbon-neutral grid for **all scenarios**. This grid only differs in terms of the remaining redispatch demand. The climate neutrality grid consists of a robust portfolio of grid enhancement and expansion measures under the proposed assumptions. The TSOs assume that these measures are necessary in the sense of a ‘no-regret’ approach in the GDP 2037 / 2045 (2023) scenarios.

- Due to the long timeframe until 2045 and the corresponding uncertainties, identified congestion was not completely eliminated by grid enhancement and expansion measures. Therefore, **a redispatch volume of 1.5 to 5.9 TWh remains in the scenarios**. A further reduction in congestion is conceivable by exploiting the potential of future innovative technologies. Thus, the curative redispatch potential for scenario B 2037 was explicitly investigated in this GDP.

To evaluate suitable grid topologies, the TSOs have refined their simulation tools, for example by using **heuristic** tools. It ensures more efficient and comprehensive investigation of the potential solutions and facilitates the comparison and evaluation of a large number of grid expansion combinations.

Considering a potentially significant increase in the expansion of renewable energy as early as 2030 and the correspondingly increased short to medium-term load on the transmission grid, the German transmission system operators have identified additional suitable measures **(ad hoc measures)** that can already be implemented in the short to medium term to mitigate the expected situation. These measures were assessed and identified based on the scenario and grid model of the long-term analysis according to § 34 of the Coal-fired Power Generation Termination Act (KVBG) for the year 2030.

Lengths of initial and expansion grid in the GDP 2037 / 2045 (2023)

Figures in km	AC enhancement		DC enhancement		AC new construction	DC new construction	Total
	Connection/ rewiring	Replacement/ parallel new construction	Connection/ rewiring	Replacement/ parallel new construction			
Initial grid	919	2,081	321	560	599	2,466	6,945
Expansion grid							
A 2037	2,279	3,846	0	179	1,714	4,396	12,413
B 2037	2,279	3,846	0	179	1,714	4,396	12,413
C 2037	2,279	3,846	0	179	1,714	4,396	12,413
A 2045	2,279	3,846	0	179	1,714	4,396	12,413
B 2045	2,279	3,846	0	179	1,714	4,396	12,413
C 2045	2,279	3,846	0	179	1,714	4,396	12,413
Initial and expansion grid							
A 2037	3,198	5,927	321	739	2,312	6,861	19,358
B 2037	3,198	5,927	321	739	2,312	6,861	19,358
C 2037	3,198	5,927	321	739	2,312	6,861	19,358
A 2045	3,198	5,927	321	739	2,312	6,861	19,358
B 2045	3,198	5,927	321	739	2,312	6,861	19,358
C 2045	3,198	5,927	321	739	2,312	6,861	19,358

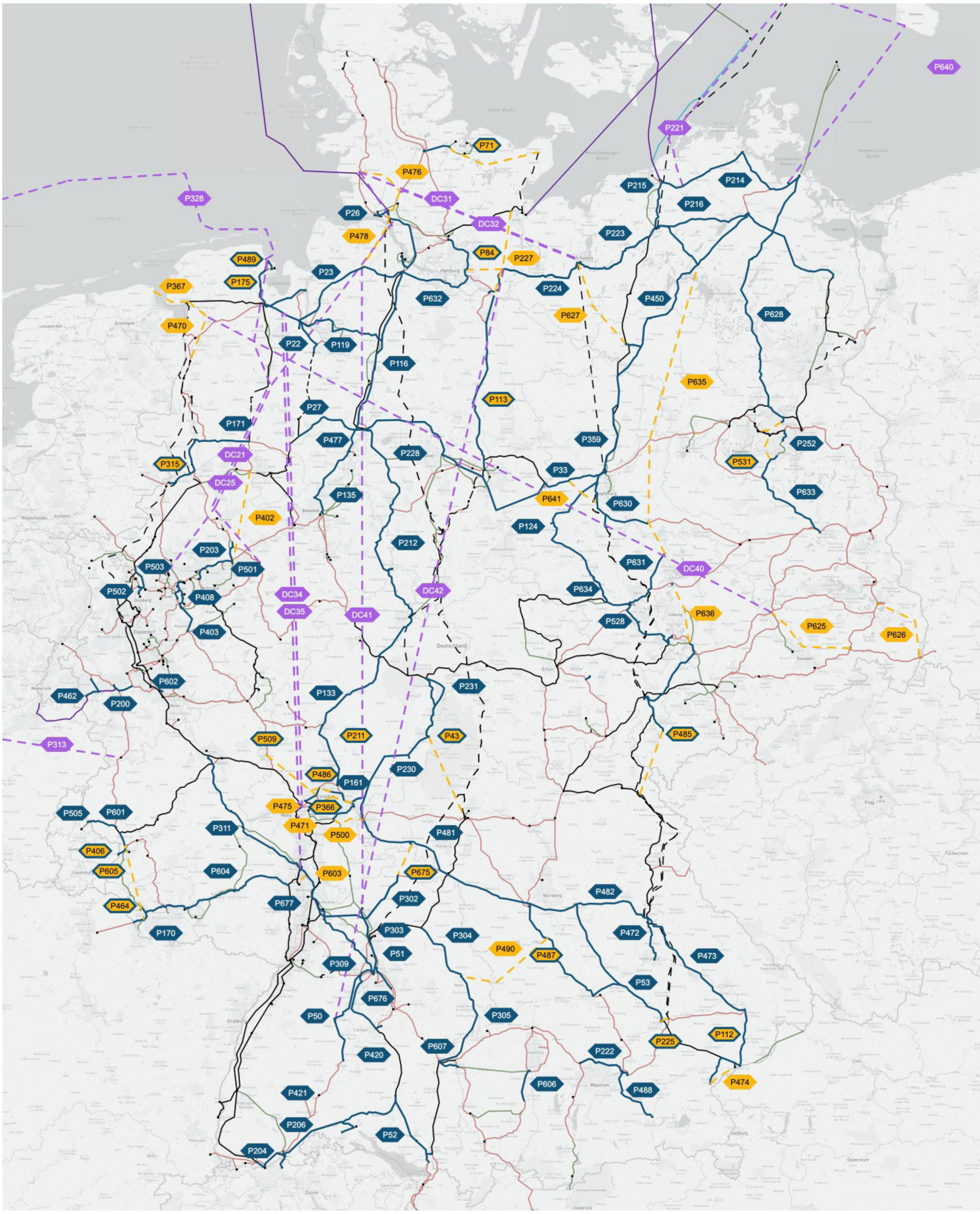
Source: Transmission system operators

Potential bundling options of new onshore DC projects and offshore grid connection systems

Regarding to § 12b (3a) of the EnWG (German Energy Act), the TSOs are obligated for the first time to specify bundling options for newly identified DC grid expansion measures and the cross-border onshore part of the offshore connection lines. It needs to be shown how these measures can be realised with existing or at least firmly planned routes, either entirely or to a large extent in one power line corridor.

Bundling makes it possible to align offshore connection systems and newly identified DC projects in the same route and thus minimise the use of space. According to the HVDC projects already confirmed in the GDP 2035 (2021) or submitted for confirmation in the GDP 2037 / 2045 (2023), there are three central energy corridors based on the current planning status. Due to the lack of landing points for individual offshore projects to date, the implementation of bundling for these systems still needs to be specified in more detail.

Onshore grid expansion scenarios A / B / C 2037, A / B / C 2045, only power line construction projects*



AC grid enhancement
DC grid enhancement
AC grid expansion
DC grid expansion

Grid enhancement in the initial grid
Grid expansion in the initial grid

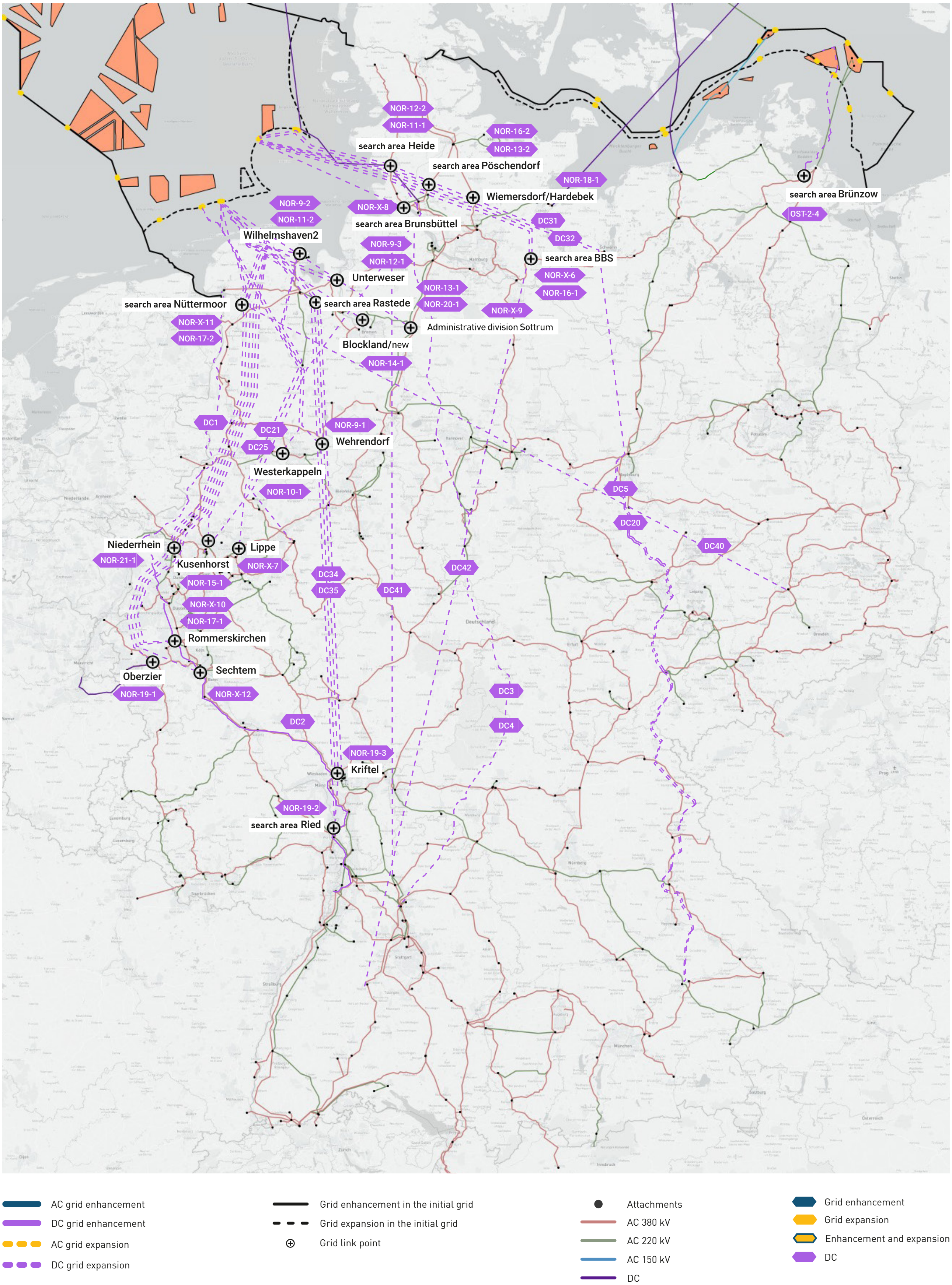
Attachments
AC 380 kV
AC 220 kV
AC 150 kV
DC

Grid enhancement
Grid expansion
Enhancement and expansion
DC

*The presentation of the new construction projects shows the starting and end points, but no specific routes. They will only be determined in downstream approval procedures.

Source: Transmission system operator / map basis © Mapbox, © OpenStreetMap (ODbL)

Potential bundling of the new DC projects and the offshore grid connection systems in A / B / C 2045



Source: Transmission system operator / map basis © Mapbox, © OpenStreetMap 222

Innovations: progressive interconnection

The demand on the transmission grid is becoming increasingly complex. In the future, the transmission grid must particularly meet the requirements caused by higher volatility of renewable energy generation as well as long-distance transport routes. To ensure that the **transformation to a carbon-neutral energy system** succeeds, the four TSOs are relying on a range of innovative solutions and technologies.

The TSOs are investigating technical solutions as well as operating concepts that facilitate an increase in the transport capacity of the existing grid infrastructure without compromising system stability. In the context of grid optimisation, weather-dependent overhead line operation as well as the rewiring to **high-temperature conductor cables** are also considered in this grid development plan.

Furthermore, the transmission system operators have again implicitly assumed potentials of future innovative technologies based on **curative system management**, which need to be tested in pilot projects. The first **grid boosters** are expected to be ready to go into operation in 2025. Further curative measures for potential piloting are under consideration.

For the restructuring of the energy system and the associated changes in the demands on the transmission grid, HVDC technology enables low-loss transmission of high power over long distances. Operational experience with HVDC technology in Germany and Europe has so far mainly been limited to point-to-point connections. By the end of this decade, additional HVDC transmission lines are expected to be implemented in Germany. The upgrade to **linked DC structures** makes it possible to leverage further grid flexibility potential, while the accompanying technological standardisation offers opportunities to reduce the associated investment costs in the process. Moreover, linked DC structures have the potential to increase the reliability of energy transmission. They can be designed to create redundant transmission systems. In order to make such an approach feasible, technological, operational and regulatory barriers still need to be eliminated, as do other risks, for example with regard to liability issues. With that in mind, the transmission system operators are pursuing the strategy of planning future linked systems with technological fallback options.

Parallel to the grid development plan, 50Hertz, Amprion and TenneT are investigating the international interconnection potential and potential offshore grid topologies in a joint offshore study. The offshore study shows that **national offshore interconnection** offers an option to leverage additional HVDC grid flexibility at minimum cost and thus reduce the need for redispatch. Furthermore, an international offshore interconnection demand has been identified for Germany, which can be efficiently tapped by interconnecting German offshore grid connection systems with foreign offshore grid connection systems.

The current **regulatory framework** does not provide sufficient incentives for cost-efficient and technology-neutral innovations in the transmission grid or for digital and climate-friendly solutions. Therefore, a regulatory framework for innovative solutions in the transmission grid independent of specific technologies is needed on the way to climate neutrality. There is a need to address these challenges and close the economic viability gap of new technologies.

For a carbon-neutral energy system by 2045, the power, gas and hydrogen sectors should be considered jointly and interlinked more closely. **Integrated system planning** makes it possible to leverage synergy potentials. The target should be to ensure robust infrastructure planning of the gas, hydrogen and power sectors.

Public consultation for GDP 2037 / 2045 (2023)

The consultation for the GDP 2037/2045 (2023) by the TSOs took place from 24 March to 25 April 2023. During this period, the TSOs received 288 submissions, of which 207 were different opinions. The difference is based on the co-sign function. More than half of the comments came from private individuals. But plenty of companies in the energy sector and public authorities also participated in the consultation. The TSOs also received comments from citizens' initiatives and environmental protection associations.

The TSOs categorised the comments in the first draft and examined them in detail. Subsequently, they revised and supplemented the grid development plan accordingly. Further explanations on the raised issues were added to the respective chapters, and the project profiles in the appendix were supplemented where necessary. The comments address a wide range of aspects – here is a selection:

While the previous consultation showed that quite a few people care about achieving the 1.5 degree target, this year many contributors wanted to make sure that there is no 'mislabelling' in the term 'climate neutrality network'.

Many consultation contributions refer to the input data of the scenario framework. For example, the weather year 2012 on which the calculations are based is considered outdated. In the future, more extreme weather conditions are expected. In addition to heat, the cooling factor should also be considered more urgently. For the next scenario framework, the TSOs will examine whether other weather parameters can be applied in the future.

In connection with the input data, many comments also noted that a wider spread of the scenarios would be desirable. If all three paths – A, B and C – lead to the same target grid, the influence of the respective factors is not discernible. The almost identical target grid of this GDP in all three pathways shows that the measures contained here are imperative. Sensitivity calculations, for which the TSOs have no mandate within the framework of the GDP, can be used to assess the effects of various influence factors.

Security of supply is coming more to the fore as a topic in this consultation than before. Private individuals are particularly concerned about whether the power supply will be secure in future. Security of supply analyses are carried out within the scope of the Federal Network Agency: national monitoring report on security of supply according to § 51 (3) and 63 (2)(2) EnWG and at the European level within the scope of the ERAA. The investigation security of supply is not within the scope of the GDP.

The top issue from the economic and political spheres is electrolyser allocation. Many companies have ambitious climate targets and depend on the corresponding energy infrastructure for their implementation.

Cities and municipalities are also registering their needs. As there are still many uncertainties here, different solutions are conceivable. The TSOs have received a lot of support for their approach in this consultation.

Many comments called for a stronger interconnection of power and gas infrastructure. This makes sense for efficient planning of the energy system. The TSOs are making a constructive contribution to integrated system development planning.

Counties and municipalities as well as interest groups are interested in which criteria the TSOs have used for HVDC bundling.

The following overview outlines the different participation steps and the respective issues in the planning of the transmissin grid.

Further information on specific projects can be found on the websites of your respective TSO and the BNetzA:

- 50Hertz Transmission GmbH: www.50hertz.com
- Amprion GmbH: www.amprion.net
- TenneT TSO GmbH: www.tennet.eu
- TransnetBW GmbH: www.transnetbw.de
- Federal Network Agency: www.netzausbau.de

Participation in the planning process of the transmission grid

GDP Cycle 10 months

Grid development

Scenario framework

Development
by transmission system operators

Inspection and approval
by the Federal Network Agency

GDP first draft

Development and publication
by transmission system operators

GDP second draft

Revision and transfer to BNetzA
by transmission system operators

Review / confirmation & submission of environmental report
by the Federal Network Agency

Federal Demand Plan

by the federal legislator

Federal sectoral planning / spatial planning & planning approval procedure

Structural implementation

Participation

Scenario framework consultation

by the Federal Network Agency

» What are the future prospects of the various scenarios? «

- **Development forecast of the energy industry**
- Power consumption, fuel costs, prices for CO_2 certificates
- Energy-related economic and political framework conditions
- Regional distribution of the generation plants

Consultation for GDP first draft

by transmission system operators

» What principles are used to identify the necessary measures? «

- **Determining the transport requirements of the various scenarios**
- Methodology and result of the market modelling
- Methodology and result of the grid analysis
- NOVA criteria
- Sustainability of the plans

Consultation for GDP second draft

by the Federal Network Agency

» How did the Federal Network Agency verify the measures? «

- **Result of the preliminary assessment by the Federal Network Agency**
- Environmental report of the Federal Network Agency in addition to the results of the GDP
- Stipulation of expansion needs
- Stipulation of start and end points

Participation in formal proceedings

by BNetzA or competent stateauthorities; Public participation by transmission systemoperators and public interest groups

» What is the exact line route? Which technology is being used – where and why? «

- Approval procedure
- Underground cable / overhead line
- Route
- Environmental protection and nature conservation
- Distances to residential buildings
- Applied technology
- Compensation and replacement measures
- Tourism

Source: Transmission system operators