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Carbon driven energy equilibrium at the municipal scale – Energy Equilibrium

Framework conditions for energy infrastructure in (Northern) Germany

ZEBAU GmbH

Interreg Baltic Sea Region
Co-funded by the European Union
ENERGY TRANSITION
Energy Equilibrium

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1 Expansion path of renewable energies

1.1 Development to date

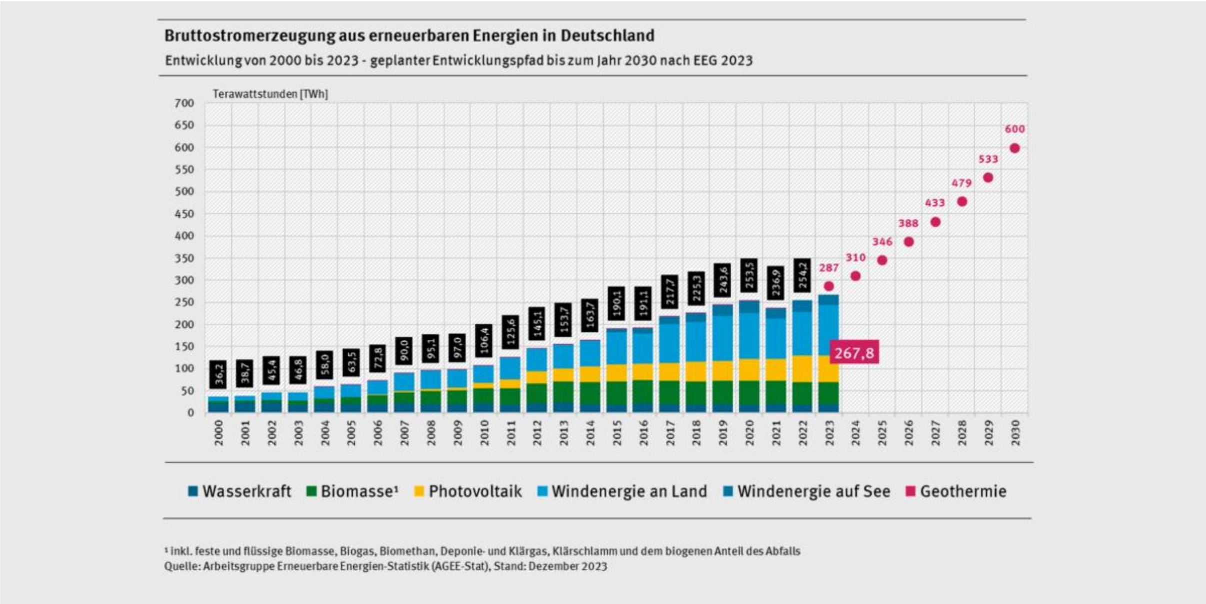

Figure 1: Gross electricity generation from renewable energies in Germany (Source: Umweltbundesamt; published: https://www.erneuerbareenergien.de/energiemarkt/energiemaerkte-weltweit/mehr-als-die-haelfte-des-2023-verbrauchten-stroms-aus-erneuerbaren)

In recent years, electricity generation from renewable energies has risen continuously. While 46% of electricity in Germany was generated from renewable sources in 2022, this figure rose to 52% in 2023. This trend continued significantly in 2024 with 59 % of electricity produced by renewable energy sources (ENERGIEN 2023; „SMARD | Der Strommarkt im Jahr 2024“ 2025).

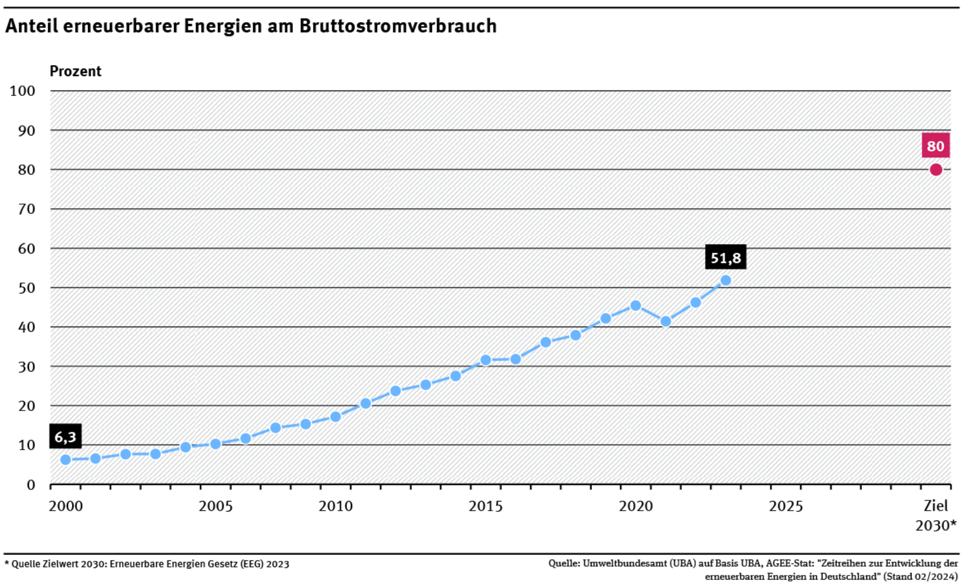

Figure 2: Development of the share of renewable energies in gross electricity generation in Germany (Source: Umweltbundesamt; published: https://www.umweltbundesamt.de/indikator-anteil-erneuerbare-am)

1.2 Expansion plans

Germany aims to generate 100% of its electricity requirements from renewable energies by 2035. By 2030, the target is 80% of production from renewable energies. By 2030, 115 GW of renewable electricity is to be generated from onshore wind power plants, 30 GW from offshore wind power plants and 215 GW from photovoltaic systems. At the end of 2023, 61 GW was produced from on-shore wind, 8.5 GW from off-shore wind and 81.8 GW from photovoltaic systems (Bücker 2024). According to an extrapolation with the expansion rate from 2022 and 2023, only the target for photovoltaic systems looks achievable. If the rate of expansion remains the same, 219 GW of electricity will be produced from photovoltaic systems in 2030. Wind onshore will only reach 78 GW and wind off-shore only 10.8 GW (own calculations).

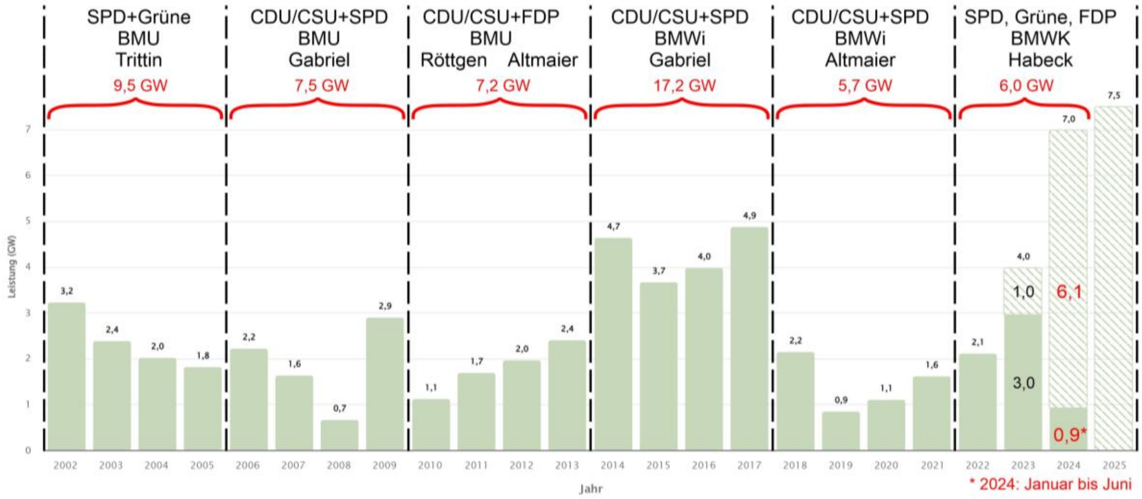

Figure 4: Annual expansion of wind onshore capacity in Germany (Source: Energy-Charts.info; published: https://x.com/energy_charts_d/status/1813835091405144098/photo/1)

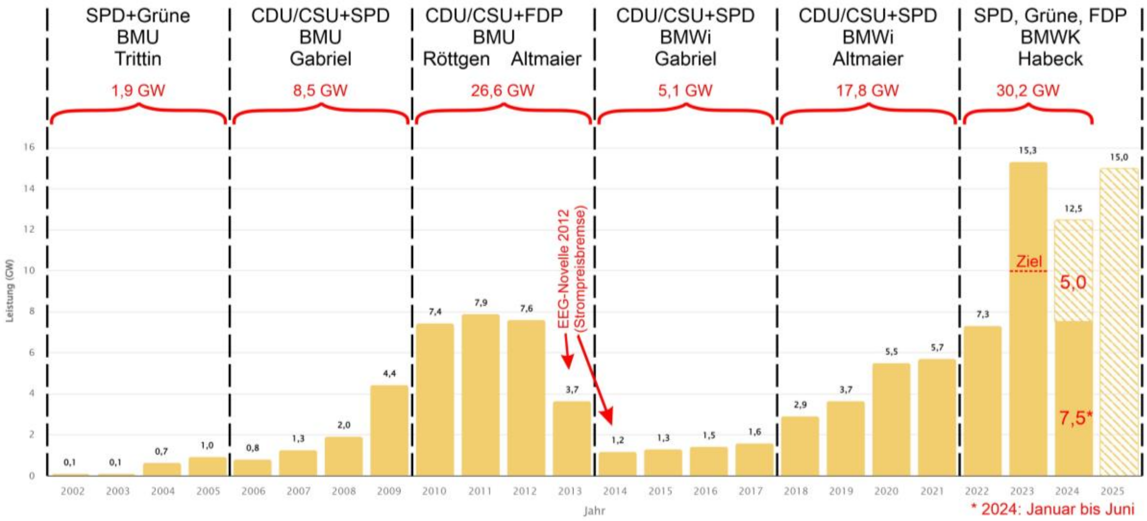

Figure 3: Annual expansion of photovoltaic capacity in Germany (Source: Energy-Charts.info; published: https://x.com/energy_charts_d/status/1813831484651999558/photo/1)

1.3 Challenges

1.3.1 Volatility and storage requirements

Renewable energies and their volatility pose one of the greatest challenges for the transformation of electricity production. In order to bridge days when neither the wind is blowing nor the sun is shining, options must be created to store the previously produced energy and release it again when required. It is important to ensure that enough energy can be stored to cover the energy requirements of several days. According to the German government's power plant strategy, gas-fired power plants, which will be able to run on hydrogen in the future, will play a major role. They are foreseen to provide 12,5 GW of balancing energy in the future (Action 2024). (Link)

If too much energy is produced due to high levels of wind and solar power in addition to the energy generated by conventional power plants, renewable energy sources would have to be switched off to avoid overloading the electricity grid (see 1.3.2 Lockdown and redispatch). This is unpleasant, as this potential energy is lost and can result in a negative electricity price on the electricity market because supply significantly exceeds demand. In the first three hours of the negative electricity price, renewable energy plants are still entitled to their feed-in tariff, which means that switching off these plants makes little sense for the operators („§ 51 EEG" 2023; „§ 51a EEG" 2023). However, the opportunity this presents is particularly interesting for operators of storage systems. In phases of negative electricity prices, storage systems can store the electricity. They do not have to pay for the electricity but receive money for storing it. When the electricity price moves back into positive territory, the electricity can be fed out and a profit generated. This makes storage systems an interesting investment. Consumers who are adapted to the supply can also benefit from negative electricity prices. (see 3.3.3)

In future, more storage facilities are to be built, conventional power plants are to be shut down more and more, and the flexibility of electricity use is to be increased, which in theory should reduce the negative electricity price and make it less frequent („Was sind negative Strompreise und wie entstehen sie?", o. J.).

1.3.1 Previous lockdown and redispatch

Until now, wind power and photovoltaic systems have sometimes been switched off at times of high production so as not to overload the electricity grid and cause it to crash. This means that energy that could be stored is lost, and at times of higher energy demand but lower production, fossil power plants are needed to cover the demand. However, if there is sufficient capacity, the curtailed energy could be stored and released when required. This would reduce the need for fossil-fuelled balancing energy and significantly increase the share of renewable energies in the electricity mix („Was sind negative Strompreise und wie entstehen sie?", o. J.).

In addition to curtailment, redispatch measures are also an important building block in the energy supply system. Redispatch refers to the regulation of feed-in from energy-producing power plants. Power plants report the planned energy production schedule for the following day at 15-minute intervals. If the load on the electricity grid changes due to spontaneous and unexpectedly high or low production or demand, the power plants must change their feed-in. In Germany, most wind turbines are located in the north, but the majority of energy is required in the west and south-west. If, for example, a strong wind blows in the north while the sun is shining at the same time, too much energy is produced there, and the electricity system is overloaded. Due to a lack of infrastructure, the energy cannot yet be fully transported to the south in line with demand. An imbalance arises behind the grid bottleneck, i.e. in the west/south of Germany, which has to be compensated for by adding power plants. There are three possibilities for redispatching: redispatching within a control area, i.e. within the system of a transmission system operator, redispatching across control areas, i.e. between two or more TSOs, and cross-border redispatching, i.e. balancing by buying or selling foreign energy. The redispatch process is divided into three phases. In the first phase, the grid operator must use instruments such as countertrading, balancing energy or load shedding. In the second phase, the grid operator may regulate conventional power plants to a minimum. Only in the third and final phase may the grid operator switch off renewable energy plants (Henning 2021).

A natural fluctuation can be seen in recent years with a constant increase in costs, redistributed energy and feed-in management. In the first half of 2024, the amount of energy that was redispatched was 20,813 GWh. In comparison: in 2023, this figure was 34,297 GWh („QuartalszahlenQ4_2023.pdf", o. J.; „Erneuerbare Energien in Zahlen" 2024). The fluctuations are mainly due to different weather conditions, but also to the expansion of renewable energies.

Withholding energy comes at a price. According to the Federal Network Agency's grid congestion reports, redispatch caused costs of €3.086 billion in 2023 („QuartalszahlenQ4_2023.pdf", o. J.).

2 Energy Infrastructure

2.1 Transmission network

Figure 5: Control areas of the four transmission system operators (TSOs) in Germany; as of 2019. (Source: Francis McLloyd; published: https://de.wikipedia.org/wiki/Datei:Regelzonen_mit_%C3%9Cbertragungsnetzbetreiber_in_Deutschland.png)

The German transmission grid is divided into four zones. This results from the historical distribution of the grid operators. Since 2010 only, there have been interconnection stations between the transmission grids. The task of the transmission system operators is to ensure the secure transmission of demand and guarantee security of supply.

The 4 areas are divided as following:

- The federal state of Baden-Württemberg is completely supplied by Transnet BW.
- The middle west and south-western parts of Bavaria are supplied by Amprion.
- 50 Hertz supplies eastern Germany including Berlin and in addition the city of Hamburg.
- Tennet takes care of the remaining areas, connecting the north of Germany with the south without interruption.

The electricity is transmitted through the supra-regional transmission grids with a voltage of 220 kV or more. There are a total of 38,500 kilometres of high-voltage lines in Germany that transport the electricity („Netztransparenz > Über uns > Aufgaben", o. J.).

Renewable energy plants with a capacity of less than 100 kW must supply their electricity directly to the TSOs, while plants with a capacity of more than 100 kW must hit the market and sell their electricity themselves on the electricity market („Übertragungsnetzbetreiber (ÜNB)", o. J.).

The four transmission system operators have four specific tasks. Operational management and grid congestion management, i.e. ensuring grid stability and EU-wide trading at coupling points in the Europe-wide transmission grid. Frequency maintenance, which means consistently maintaining the frequency at 50 Hertz. This is important as otherwise the electricity system would collapse. To achieve this, loads may have to be switched on or off or the balancing energy changed. The third task is voltage maintenance. Like the frequency, the voltage must also be kept stable. Loads are also switched on and off for this purpose (see also 3.3.4). This also includes the so-called reactive consumption. The final task of the transmission system operators is to restore the supply. This means that the TSOs must ensure that the grid can be rebuilt as quickly as possible in the event of a collapse and that secure transmission is guaranteed in line with demand („Netztransparenz > Über uns > Aufgaben", o. J.).

To adapt the transmission grid to the current challenges, several measures will be necessary over the next few years. These include the expansion of high-voltage direct current transmission lines, the expansion of renewable energy production as well as the storage of these volatile energy sources and better control of electricity demand to feed out electricity as required and not have to switch on unnecessary loads in order to prevent the grid from collapsing.

These measures are also based on the grid expansion plan. The grid expansion plan is created based on the scenario framework. The scenario framework, in turn, is calculated from the previous and forecast demand of recent and future years. The grid expansion plan thus establishes the demand for power lines and checks this against the currently existing lines. In cases of doubt regarding expansion measures, the Federal Network Agency takes over the project management („Netzentwicklungsplan Strom | Netzentwicklungsplan", o. J.).

2.2 Distribution system operators / municipal utilities in Northern Germany

Figure 6: Distribution network operator (Source: VNBdigital, the joint internet platform of the electricity distribution system operators (DNB); published: https://www.bdew.de/energie/vnbdigital-gemeinsame-internetplattform-gestartet/)

In Germany, distribution grid operators are subordinate to the transmission grid operators. They transport the electricity from the high-voltage lines to the households. The voltage level is 230 V. Energy from smaller power plants is also fed directly into the distribution grid, for example from photovoltaic or wind power plants.
In northern Germany, Hamburg is supplied by one distribution grid.

Schleswig-Holstein's rural areas are also supplied by one distribution grid, while small towns have their own distribution grids, most of which are maintained by the respective municipal utilities.

The picture in Mecklenburg-Vorpommern is similar to that in Schleswig-Holstein. The rural areas are supplied by two large distribution networks, while the towns are also largely supplied by their own municipal utilities.

2.3 Centres of electricity demand

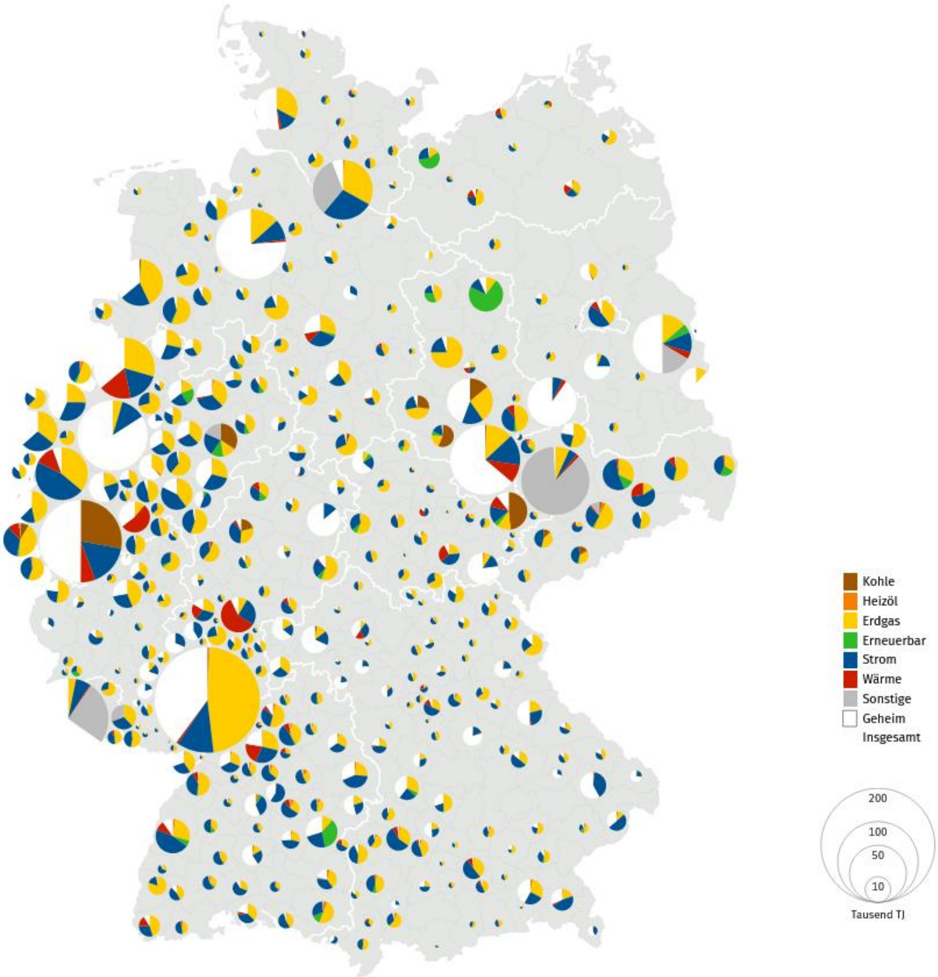

Figure 7: Energy consumption in industry 2022 by energy source (Source: Federal Office of Statistics; published: https://service.destatis.de/DE/karten/EnergieverbrauchIndustrie2022.html)

In Germany, the industrial sector consumed 667 TWh of final energy in 2022 (Wilke 2024). There are regional differences. For example, comparatively little energy is consumed in the north-east and south-east, while the west of Germany has a particularly high demand.

At the same time, with only 22% of final energy from renewable energy sources, there is still a high proportion of fossil energy sources in overall energy production (Wilke 2024).

The production of renewable energy in the north and the utilisation and provision of this energy in central and southern Germany also poses a major challenge. North Rhine-Westphalia and the region around Leipzig and Halle (Saale) in particular have high energy requirements. Little energy is required in central Germany, the north-east and south-east of Germany („Karte Energieverbrauch in der Industrie“, o. J.).

2.4 Power plant locations and the largest areas of onshore and offshore wind energy and PV systems

Figure 8: Coal-fired power plants in Germany; source: https://energiewinde.orsted.de/energiepolitik/kohlekraftwerke-karte-aus-stieg-datum)

The previous power plant locations of lignite and hard coal-fired power plants show a similar picture to the electricity demand centres. On a western axis that stretches from Hamburg in the north of Germany via the west to the south. Most of the power plants are located in North Rhine-Westphalia. In the east, there are some sites in the region around Leipzig and west of Dresden. The power plants still connected to the electricity grid are operated with an output of about 76,7 GW („Bundesnetzagentur - Kraftwerksliste" 2024).

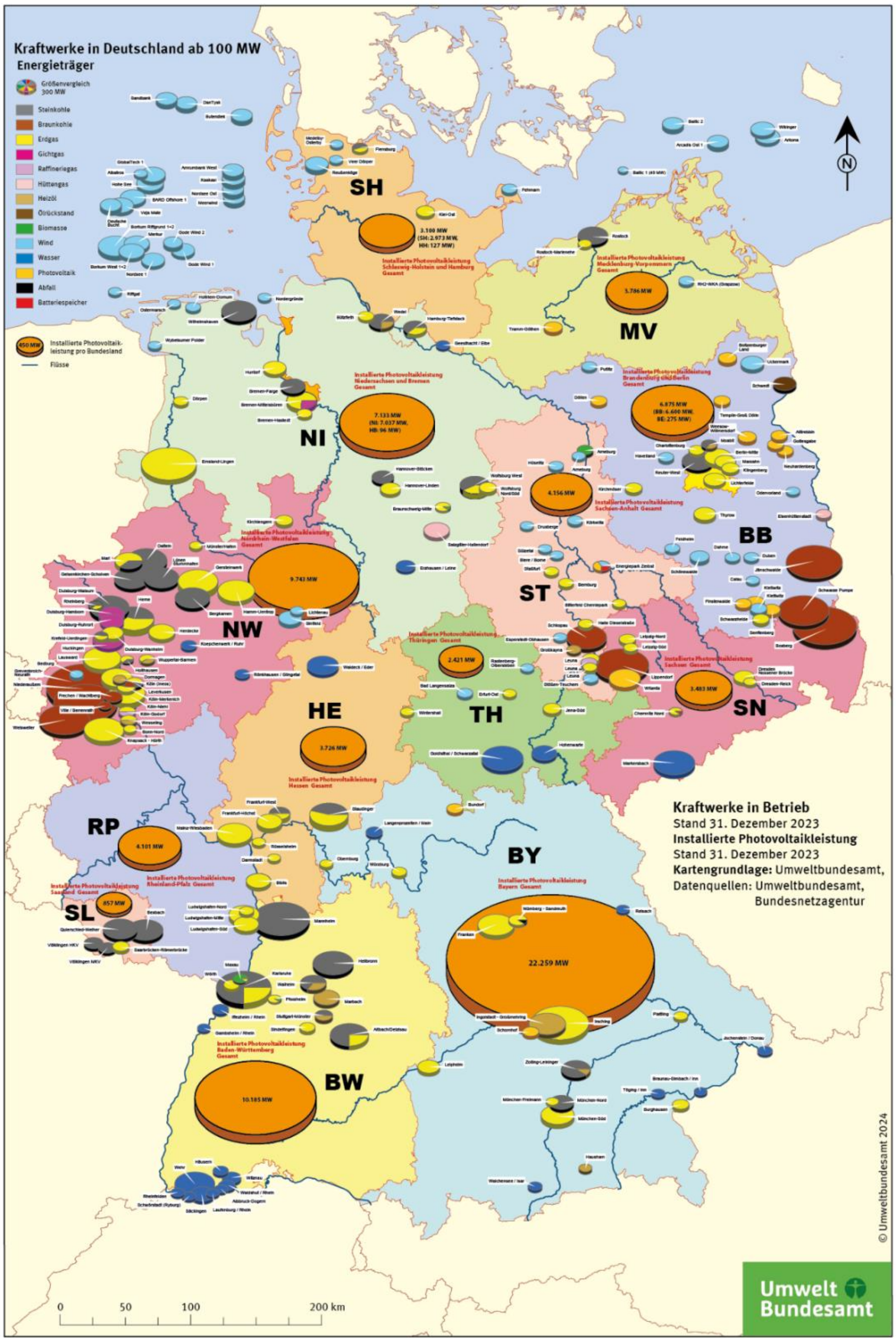

Figure 9: power plants and photovoltaic power in Germany; source: Umweltbundesamt; published: https://www.umweltbundesamt.de/bild/kraftwerke-photovoltaikleistung-in-deutschland)

In Germany, 97,3 GW are currently installed photovoltaic power plants and 72,4 GW wind turbines, 9,2 from off-shore production and 63,2 from on-shore (Hermann 2024). Further expansion of onshore and offshore wind energy plants is planned for the coming years. Electricity provider RWE, for example, plans to expand a wind farm with a total capacity of 1.6 GW over the next few years (RWE 2024). According to the German government's targets, a total output of 30 GW is to be installed by 2030 and 70 GW by 2045 from offshore plants alone (Bücker 2024).

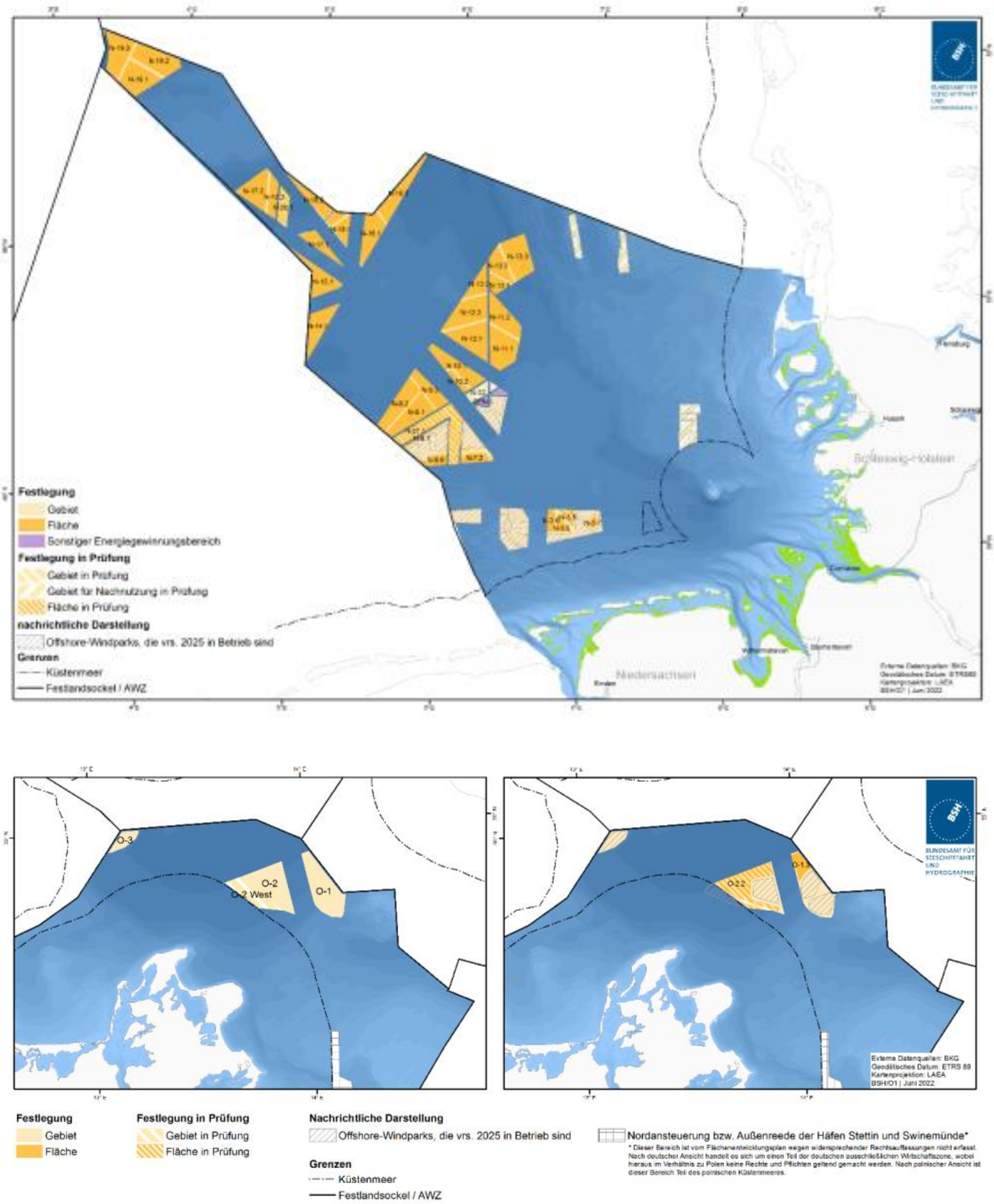

Figure 10: Determinations of areas and spaces in the EEZ of the North Sea and the Baltic Sea; source: Draft area development plan, 1.7.2022; Federal Office of Shipping and Hydrology)

Most off-shore areas are located in the North Sea, with isolated off-shore parks in the Baltic Sea. Most onshore areas can also be found on the North Sea coast, with large wind farms in Schleswig-Holstein and Lower Saxony. Most photovoltaic systems, on the other hand, are located in southern Germany.

2.5 "Electricity motorways"

Figure 11: Map of pipeline projects in Germany according to the Federal Requirements Plan Act (BBPlG 2013); source: Alexrk2; published: https://de.wikipedia.org/wiki/Suedlink#/media/Datei:Karte_BBPlG-Vorhaben.png)

In order to compensate for the challenge of the imbalance in electricity production and demand, as explained in the previous sections, large electricity lines, so-called electricity motorways, are needed across Germany. To this end, existing power lines are to be expanded and their capacity increased, and completely new electricity motorways are to be built (Lewicki 2023).

The largest project is the Südlink electricity motorway. Consisting of 2 direct current lines, it will bridge a distance of 700 kilometres and connect 10 million households. A maximum of 4 GW of electrical power will be transported at a voltage level of 525 kV („SuedLink“, o. J.).

The project is divided into 15 sections to make planning and authorisation easier. This will also make construction easier. Some of the planned sections are already under construction. Some of the planning approval projects are still pending, but the project has already been approved in accordance with the Grid Expansion Acceleration Act („SuedLink", o. J.).

Another important power line will be the NordLink connection. Over a length of 623 kilometres, two direct current lines will run from the south of Norway to Wilster in the north of Germany. The aim is to connect northern German wind power plants with Norwegian pumped storage power plants in order to simplify the storage of volatile renewable energy production („NordLink", o. J.).

By combining the NordLink and SüdLink lines, electricity stored in Norway can be easily transported to Bavaria to supply the country with electricity even at times of low energy production.

The "Gregy - Greek Egypt Interconnections" project is also planned. The aim is to build a power line from Egypt via Greece to the EU. This will primarily transport electricity from photovoltaic systems in North Africa to the EU and southern Germany. Lines to Italy are also already being planned. The aim is to utilise solar power from North Africa in Europe, but also to produce green hydrogen in Egypt in order to export it to the EU („‚GREGY' Interconnector", o. J.).

Another project is the hydrogen transmission line from major off-shore wind farms in the northern Sea. (See 2.7. AquaVentus)

2.6 Large-scale storage infrastructure

There are several large storage facilities in northern Germany. These are primarily pumped storage power plants and battery storage systems.

Figure 12: Installed net capacity of pumped storage and battery storage in Germany 2024 (Source: Energy-Charts.info; published: https://x.com/energy_charts_d/status/1809475949311783285/photo/1)

The expansion of further pumped storage plants is limited due to the geographical conditions and the necessary interventions in the landscape.

The capacities of the battery storage plants have been further expanded in recent years, so that in 2024 they will exceed the capacities of the pumped storage plants in Germany and the capacities used by Germany in Austria and Switzerland for the first time („Installierte Leistung | Energy-Charts", o. J.).

2.6.1 Pumped Storages

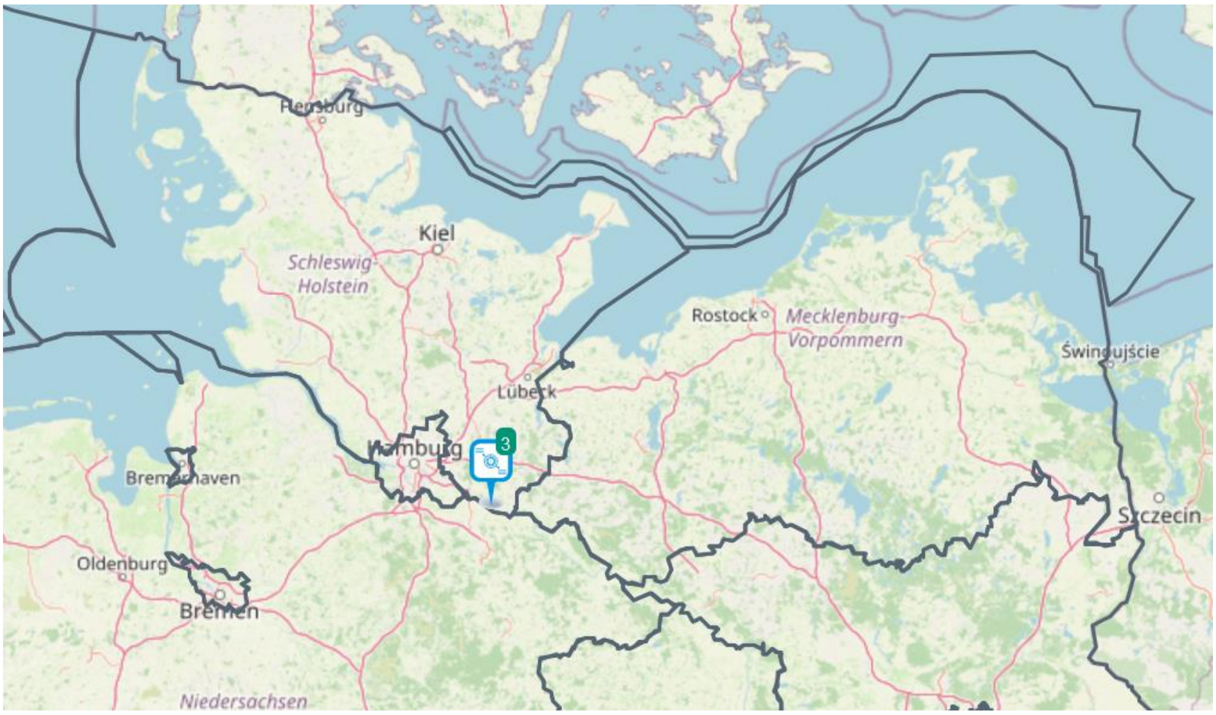

Figure 13: Locations of pumped storage power plants; source: Energy-Charts.info; published: https://energy-charts.info/map/map.htm?l=de&c=DE&country=DE&pp-source=bnetza&pp-bitmap=000000100&zoom=6&lat=55.597&lng=14.679

One pumped storage power plant can be found south-east of Hamburg in Geesthacht (see figure above). Operated by Vattenfall, the storage facility has been in operation since 1958. With an output of 119,1 MWe, it is the only storage power plant in northern Germany. 3 million m³ of water are pumped into the upper reservoir with a height difference of 80 metres or discharged into the river Elbe, which acts as the lower reservoir. When the upper basin is full and the turbines are operating at full capacity, the power supply can be guaranteed for 4.5 hours („Power plants: Geesthacht - Vattenfall", o. J.).

Another pumped storage power plant was planned in Lägerdorf in Schleswig-Holstein. The operator of the former gravel pits, HOLCIM, and the energy supplier E.ON commissioned a feasibility study. The results of which confirmed the technical feasibility but questioned the economic viability of the plant. As a result of this study, the project was cancelled by mutual agreement. A 70 MW plant with an output of 3.5 GWh was planned. Both the small difference in altitude and the poor geological conditions were problematic. The chalk soil does not allow comparisons with other projects and individual solutions would have had to be found, which would probably have driven the price up to threefold. Even with a low electricity price of less than 1 ct/kWh, the operation of this plant would not have been economically feasible. The plan was to produce renewable electricity from a nearby wind farm. This will probably not be built either. Further discussions took place between the parties involved to find other solutions so far without success („Holcim (Deutschland) AG und E.ON AG stellen Machbarkeitsstudie für Pumpspeicherwerk Lägerdorf vor" 2013).

2.6.2 Battery Storages

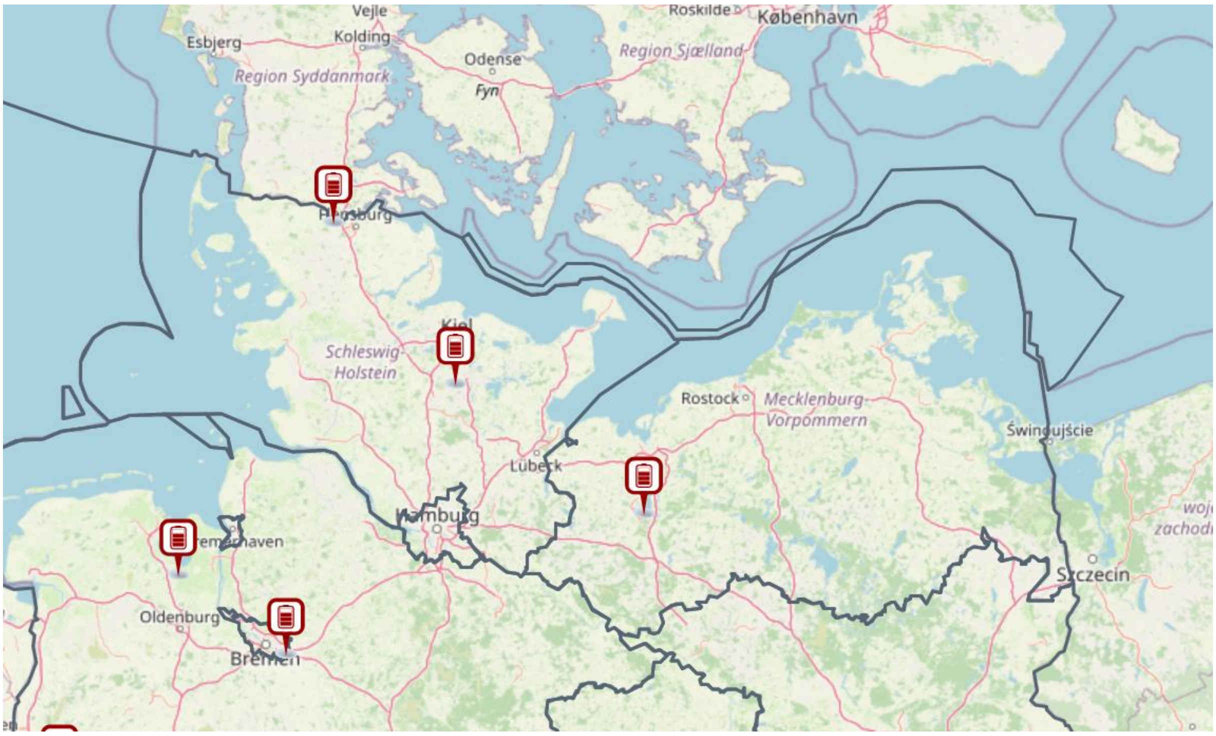

Figure 14: Locations of battery storage facilities; source: Energy-Charts.info; published: https://energy-charts.info/map/map.htm?l=de&c=DE&country=DE&pp-source=bnetza&pp-bitmap=000000100&zoom=6&lat=55.597&lng=14.679

The situation is different for battery storage systems. There are currently three large storage facilities in northern Germany.

A storage facility with an output of 15 MW and a capacity of 15 MWh in Bordesholm near Kiel, which is operated by Versorgungsbetriebe Bordesholm GmbH, made history at the end of 2019. In a pilot test, it was possible to supply the region self-sufficiently for one hour thanks to the regional production of renewable electricity in conjunction with the storage facility (Doppler-Roth 2019).

There is another battery storage facility in Jardelund near Flensburg. The storage facility operated by the ABE Group has an output of 48 MW and a capacity of 50 MWh („Batteriespeicher in Jardelund | ABE-Gruppe", o. J.).

WEMAG, a municipal energy supplier in the Schwerin area, has been operating a battery storage facility with an output of 5 MW since 2014; a second storage facility with an output of 10 MW and a capacity of 15 MWh is planned („Zweites WEMAG-Batteriespeicherkraftwerk geht in Schwerin ans Netz | www.wemag.com" 2017).

Further systems are planned. The largest battery storage facility under construction is located in Bollingstedt in the north of Schleswig-Holstein with a capacity of 239 MWh, operated by EcoStor. The ground-breaking ceremony was held in Bollingstedt-Gammelund on 19 April 2024. The battery storage facility is scheduled to be connected to the grid in 2026. The company is planning another battery storage facility of the same size with a capacity of 238 MWh in Schuby, not far from Bollingstedt („Projektseite Bollingstedt | ECO STOR", o. J.; „Projektseite Schuby | ECO STOR", o. J.).

Purple Energy is planning four further large-scale storage facilities in northern Germany with a total capacity of 48 MWh (ENERGIEN 2024).

Aquila Clean Energy EMEA is starting to build the first of 14 planned battery storages in Germany with a total capacity of 900 MW. In Strübbel, Schleswig-Holstein the company will build this 50 MW / 100 MWh storage unit close to the northern sea, providing ideal framework conditions for storing renewable energy („Aquila Clean Energy" 2024).

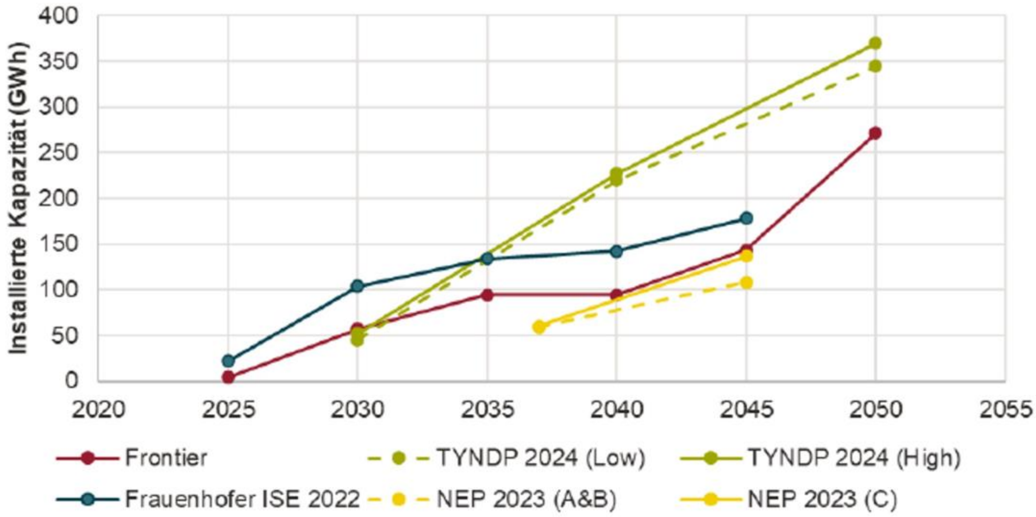

Figure 15: Expected expansion of battery storage in Germany (Source: Frontier Economics; published: https://www.kyon-energy.de/blog/wie-der-ausbau-von-batteriegrossspeicher-die-energiekosten-in-deutschland-um-12-milliarden-euro-senken-wird)

Overall, there is a clear ramp-up in the expansion of battery storage systems. This is shown by various studies on the expected expansion of large-scale battery storage systems in Germany.

The car manufacturer Volkswagen also wants to enter the market. Battery storage systems made from old car batteries are planned for the next few years, initially with a capacity of 350 MWh. In the future, the capacity is to be increased to up to 1 GWh. The first plant is due to be connected to the grid in 2025. Due to a lack of returns of used car batteries, this storage facility will initially be operated with brand-new batteries and will gradually switch to used car batteries in the future. The location of this plant is not yet known (Korb 2024).

2.7 Hydrogen / Electrolyser

Storing energy in the form of hydrogen has also become increasingly popular in recent years. Storage facilities are to be built in the coming years, especially in eastern Lower Saxony, where the potential is particularly high due to storage in salt caverns that were previously used commercially and the good connection to seaports. In Krummhörn, the company Uniper is planning a hydrogen storage facility with a capacity of 200,000 m³ in an underground salt cavern („HPC Krummhörn | Uniper", o. J.). Such a storage facility is also planned in Stade. Storengy Deutschland is planning two storage facilities, the first of which is to be connected to the grid in 2030 and the second in 2034. 7500 tonnes per storage facility will be enough to meet the needs of the local steelworks for two weeks (Mohl 2024). Here too, the hydrogen is to be stored in salt caverns that were previously used for commercial purposes. This location is particularly beneficial due to the 'EU hydrogen backbone' hydrogen network planned in this area („EHB", o. J.). The Lhyfe company would also like to benefit from this. A 10 MW electrolyser is to be built in Brake (Lower Saxony) in the area of the Lower Weser („Lhyfe" 2024). Other electrolysers and hydrogen projects in northern Germany can be found at the following locations:

- Hamburg Moorburg, electrolyser with 100 MW capacity, completion end of 2027 („Port of Hamburg" 2024)
- AquaVentus, hydrogen project in the North Sea, total capacity of 10 GW, several sub-projects with hydrogen pipelines and electrolysers in connection with offshore wind turbines, completion in the mid-2030s (RWE 2021).
- DoingHydrogen, electrolyser with 100 MW capacity in Rostock-Laage, completion 2027 (vc_superadmin 2023).

Figure: https://www.windindustrie-in-deutschland.de/unternehmensmeldung/enertrag-projekte-mit-insgesamt-210-mw-elektrolyse-als-ipcei-projekte-vorausgewaehlt

On 22 July 2024, FNB Gas e.V. submitted the joint application of the transmission system operators for the hydrogen core network for Germany to the Federal Network Agency. The total length of the optimised core network according to the application is 9,666 km. Of this, 802 km are accounted for by lines from 16 other potential hydrogen network operators (distribution network operators). The core network consists mainly of converted natural gas pipelines (approx. 60%). The investment costs amount to € 19.7 billion. The feed-in and feed-out capacities amount to around 100 GW and 87 GW respectively („FNB Gas", o. J.).

The northern German states of Schleswig-Holstein, Hamburg, Mecklenburg-Vorpommern, Lower Saxony and Bremen agreed on a hydrogen strategy together with several stakeholders in 2019. In this strategy, framework conditions are to be developed together with the stakeholders and the expansion of the hydrogen infrastructure is to be coordinated in four fields of action („norddeutsche Wasserstoffstrategie", o. J.).

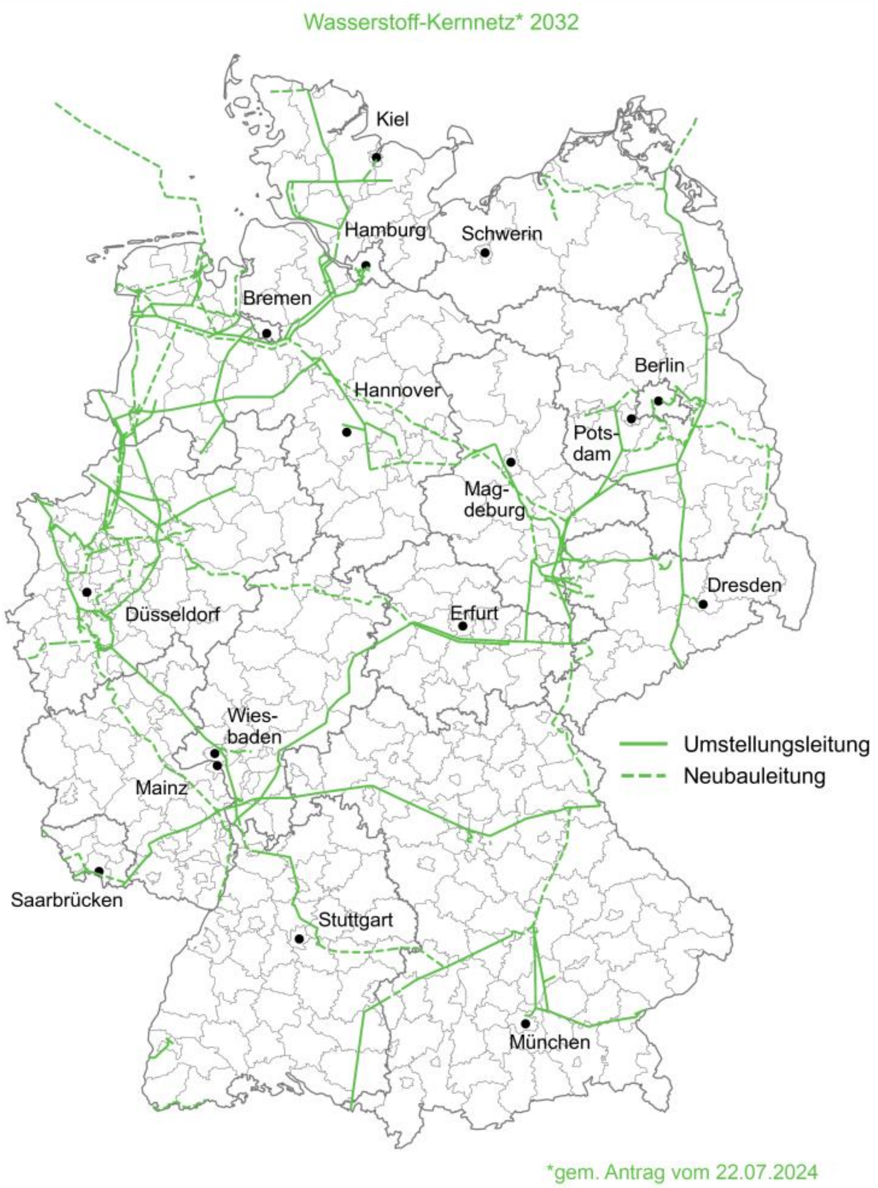

Figure: Hydrogen core network planned by 2032 (source: FNB Gas e.V.; published: https://fnb-gas.de/wasserstoffnetz-wasserstoff-kernnetz/)

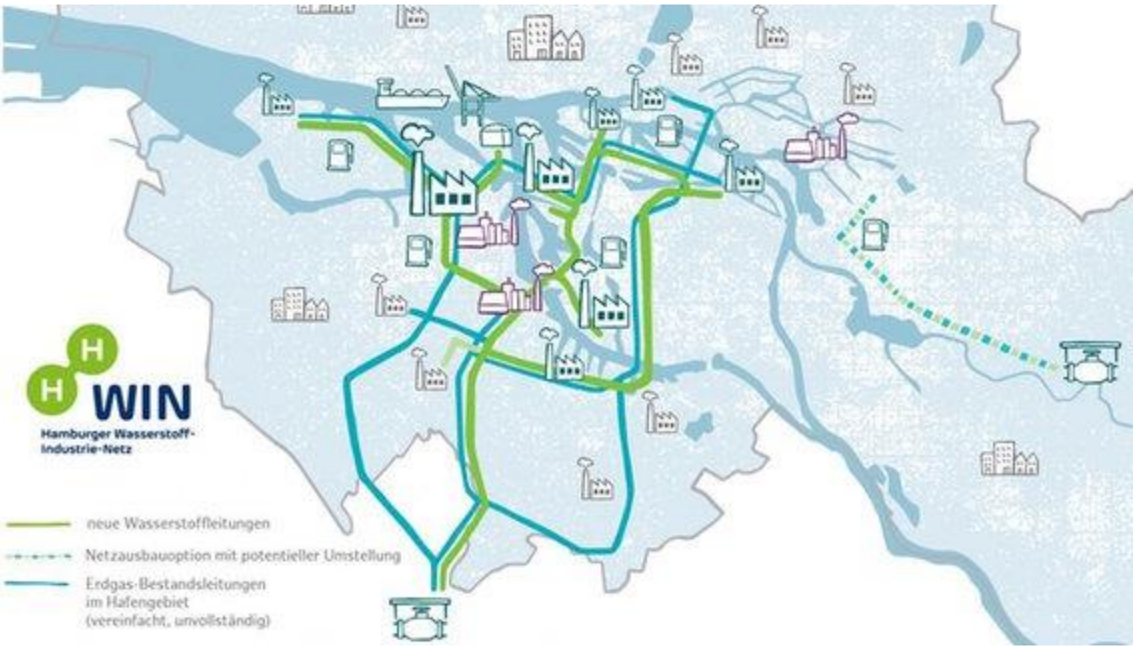

Figure 16: Hamburg hydrogen industry network (source: Hamburg hydrogen industry network; published: https://www.ndr.de/nachrichten/hamburg/Hafen-bekommt-Wasserstoff-Leitungsnetz-Baustart-2023,wasserstoff386.html)

Meanwhile, in Hamburg, a former coal power plant in Moorburg is to be equipped with an electrolysis plant. The electrolyser with a capacity of 100 MW is being built by Hamburger Energiewerke and the company Luxcara and is being subsidised with € 250 million by the City of Hamburg and the federal government. The plant will be operated by the company Gasnetz Hamburg. A 40 km long hydrogen distribution network is also planned as part of the project. Construction is due to start in 2025 and the electrolyser should be completed by 2027 (BUKEA und BWI 2024).

The German government's power plant strategy published in February 2024 is also important for the expansion of hydrogen storage and the use of green hydrogen. Five gas-fired power plants with a total capacity of 12.5 GWh are to be built by 2030 to make the electricity market more flexible and ensure sufficient balancing energy. These are to be converted to run on hydrogen in the years 2032-2038 (Action 2024).

2.8 Power-to-Heat

Power-to-heat systems also play an important role in achieving climate targets. They can replace fossil primary energies in the provision of heat. Six plants are planned or already in operation for this purpose. The transmission system operator 50Herzt plays a decisive role here. In order to keep the electricity grid stable and create further flexibility options, 50Hertz is financing the construction of power-to-heat plants. When electricity production is high, heat is produced from the electricity, which is then fed into the existing district heating grids („Power-to-Heat: aus Strom wird Wärme" 2022).

A plant with a heat output of 80 MW was realised in Wedel near Hamburg and part of the Hamburg district heating system in 2023 (Hamburger Energiewerke, o. J.).

Other plants can be found in Hamburg-Billstedt with a capacity of 5 MW (energie-experten, o. J.), Parchim, with a capacity of 2 MW (ENERGIEN 2021), Stralsund with a capacity of 6.5 MW (Gustedt 2021), Rostock with a capacity of 20 MW (Stadtwerke Rostock, o. J.) and in New Brandenburg with a capacity of 30 MW (Maksimenko 2019). The operators of the plants are mostly the local energy suppliers, in Hamburg, for example, Hamburger Energiewerke.

2.9 Flexibilization of Production / Power-to-X

Flexibilisation of production can be achieved through so-called Power-to-X processes. This refers to the conversion of energy and storage in the form of other substances, such as hydrogen. Storage in hydrogen is the most common form of Power-to-X process. Other types are the production of synthesis gases or ammonia to produce fuels for the traffic and transport sector that can be burnt in a climate-neutral way (BauNetz, o. J.).

Research in Germany is focussing on hydrogen and its production, transport and storage. Hydrogen will primarily be used for processes that have a high thermal energy requirement. These include, for example, steel or glass production. The still expensive electrolysis process and the need for rare metals and earths in the construction of the electrolysers have so far posed challenges for this process. Some PtX projects are being subsidised by KfW, a German development bank. The PtX Development Fund and the PtX Growth Fund enable European companies based or operating in Germany to apply for funding (KfW, o. J.).

Specifically, several projects are planned in northern Germany in connection with ammonia terminals. However, this does not involve a plant for the production of ammonia, but rather terminals that can store and store imported ammonia. In the Hamburg harbour area, a terminal is planned to be commissioned by 2027 to import and store ammonia in Hamburg (Port of Hamburg 2022). Something similar is to happen in Brunsbüttel in Schleswig-Holstein. From 2026, up to 300,000 tonnes of ammonia are to be imported and distributed annually at an RWE plant (RWE, o. J.). In Wilhelmshaven, bp is planning an ammonia terminal with an annual capacity of 130,000 tonnes. The terminal is scheduled for completion in 2028 (bp, o. J.).

3 Reasons for investing in storage infrastructure

3.1 Market situation and price development

When looking at the market situation of the various storage systems, battery storage systems still play a pioneering role. Due to the expansion of renewable energies, the ramp-up of battery storage systems will increase steadily over the next few years. This is also supported by the current price trends for battery storage systems themselves and the falling installation costs for renewable energies. In 2013, a battery storage system still cost over $806 per kWh; in 2024, the price was around per $115 kWh (BloombergNEF 2024). The size of the storage systems plays a decisive role in the prices. As a rule of thumb, the larger the storage system, the more favourable the price per kWh. The total market share of battery storage systems is estimated at USD 114,05 billion (Fortune Business Insights 2024). This currently equates to EUR 110.91 billion.

The picture is somewhat different for electrolyser systems. Here, too, a further increase in expansion and the number of systems is expected in the coming years. As of December 2023, there are 92 electrolysers from 17 manufacturers in Germany. The global market share in 2023 is USD 2.8 billion, or EUR 2.72 billion. Market growth is also forecast here in the coming years. Falling prices for electrolysis systems and, as with battery storage systems, the increasing growth in renewable energies will also play a role. Rising demand for green hydrogen, particularly for heavy industry, aviation and shipping, will also make electrolyser systems more attractive (Global Market Insights, o. J.).

Both storage solutions will most likely continue to grow in the coming years and thus increase their market share. As a result, prices per kWh will fall and electricity from renewable energies can be stored more easily.

3.2 Legal situation and current storage strategy

The authorisation procedures for storage solutions in Germany vary depending on the type of energy storage system. The construction of battery storage systems generally only requires a simple planning application procedure, which is approved in accordance with the provisions of the German Building Code (BauGB) (BMI, o. J.-a) and the respective state building regulations. In addition, electrolysers must be inspected in accordance with the Federal Immission Control Act (BImSchG) (BMI, o. J.-b). Pumped storage power plants must be authorised in accordance with the Water Resources Act (WHG) (BMI, o. J.-c). This is also required for heat storage facilities that work with substances hazardous to water.

Special consideration is given to the various storage facilities for electricity. Storage facilities are not legally regarded as such. Although the term appears occasionally in legal texts, storage facilities are regarded as consumers at the moment of storage and as producers at the moment of withdrawal. This repeatedly causes confusion, particularly regarding grid charges and the EEG levy. The industry is calling for a clear and standardised regulation („Rahmenbedingungen Stromspeicher Deutschland“, o. J., 7 ff.).

This topic is also addressed in the electricity storage strategy of the Federal Ministry of Economic Affairs and Climate Protection (BMWK) on December 8th, 2023. The cancellation of double grid charges for electricity storage systems will be suspended until 2029. The EEG surcharge for electricity storage systems is also to be changed to prevent double costs and the loss of subsidies due to grey electricity shares in the electricity grid. Overall, the electricity storage strategy does not only consist of changes to the legal framework; a total of 18 fields of action are being considered. These range from financial incentives for construction and operation to the removal of legal barriers to authorisation and support for research. Financial incentives are to be achieved by reducing construction cost subsidies. These must be paid by operators of electricity storage systems to the grid operators in order to be connected to the grid. In future, no construction cost subsidies are to be paid at system-relevant grid connection points. The research field of action should be promoted with a focus on bidirectional charging, especially for the batteries of electric vehicles. Together with intelligent electricity systems such as smart meters, consumption is to be controlled depending on the load and the grid is to be further relieved (BMWK 2023).

(For further information about the electricity storage strategy follow this link)

3.3 Business models

3.3.1 Ensure the operation of the transmission networks through storage:

Grid operators have to ensure the stable operation of the energy grid at a frequency of 50 Hertz. This challenge has increased in recent years due to the intermittency of renewable energy systems. To ensure a stable grid, power plants have had to be shut down at times when energy production exceeds energy demand. This influences public opinion on the energy revolution and reduces the potential of renewable power plants. Grid operator 50Hertz is therefore building power-to-heat plants in several of its areas of responsibility. This increases the share of renewable energy in the heat supply and keeps power plants running where they would've been shut down in the past. This also has an impact on the price of heat, as renewable energy is used during periods of surplus production, resulting in a lower price per kWh. Therefore, the implementation of storage solutions or Power-to-X facilities can have a positive impact not only on grid operators, but also on end consumers (Baumgarte, Glenk, und Rieger 2020).

3.3.2 Increase their own use by storing self-generated electricity:

Another business case for energy storage is the use of self-generated electricity, which can then be stored. This increases the self-sufficiency of the local power grid. When energy production is higher than energy demand, this excess energy can be stored for times when energy production is lower than demand. This not only facilitates self-sufficiency, but also reduces costs in the local energy system. At times when energy demand is higher than production, electricity prices are usually higher. Not having to buy electricity because of storage will lead to lower energy costs in general. This is particularly the case for battery storage due to its fast payback time (Schmitt 2023).

The municipality of Bordesholm in northern Germany pushed the limits of self-sufficiency in November 2019. For one hour, the municipality disconnected itself from the regional energy grid and tested its supply using renewable energy sources and a large 15 MWh storage unit. The test was successfully supported by the Technical University of Cologne (Waffenschmidt u. a., o. J.).

3.3.3 Improve the selling price on volatile markets by storing self-generated electricity:

It is particularly interesting for private investors to build storage units to improve the selling price of (self-generated) electricity. In case of high energy production from volatile renewable energy systems, the energy can be stored in the storage unit, either by using own renewable power plants or by buying the energy when market prices are lower due to overproduction. When energy demand is higher than production, the stored energy can be sold when prices are higher due to high demand. This potential can be further enhanced when electricity prices are negative (Baumgarte, Glenk, und Rieger 2020).

3.3.4 Receive compensation for stabilizing the transmission networks through storage:

With higher volatility in the energy system due to increased use of renewable energy sources, stabilising the frequency and voltage level of the energy grid becomes more important. For this reason, the balancing energy market has been introduced into the European energy market. The first phase automatically stabilises the frequency within a few seconds. The second phase kicks in if the first phase fails to stabilise the frequency. This is also automatic and lasts from a few seconds to 15 minutes. The third phase follows if the second phase was unsuccessful and lasts up to 60 minutes.

Financially, this market is an interesting area for private storage operators. The energy that is retained and used for the first phase of control is subsidised. In addition, energy supplied for the second and third phases will be paid at market value. However, this does not have a negative impact as the prices for balancing energy are above normal market prices. In addition, energy that is stored during over-production is usually cheap, whereas energy that is withdrawn from a storage unit due to lack of production usually results in higher prices (EHA 2024).

3.3.5 Value creation for municipalities:

Another advantage of building and implementing storage solutions in combination with renewable power plants is the local value chain. Local construction companies will be contracted to provide the infrastructure and facilities, and planning institutions will be contracted to develop new plans. Newly created storage and power plants will create more jobs, add value to the area and increase the attractiveness of a community. Further municipalities will profit from taxes being paid by storage operators (Hildebrand u. a. 2023).

Further links for additional information:

- roland_berger_energy_storage_final.pdf
- Battery Charts - (rwth-aachen.de)

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