TenneT
Taking power further

Energy
from sea to land

Our task:
facilitating a sustainable energy supply

Far-reaching.

TenneT's twelve completed grid connections in the German North Sea already transport more than 7,000 MW of renewable energy from sea to land: sustainable energy supply for around 9 million households.

By law.

TenneT is obliged to connect offshore wind farms in the German and Dutch North Sea to the power grid.

Sustainable.

TenneT has set its sights on clear targets: By 2030, TenneT will have installed around 30 GW transmission capacity.

TenneT is Europe's largest and first ever cross-border transmission system operator. The company is responsible for the operation, maintenance and expansion of the extra-high voltage grid in large parts of Germany and in the Netherlands.

As the transmission system operator in the coastal German states of Schleswig-Holstein and Lower Saxony, TenneT has been under obligation to connect wind farms in the North Sea to the extra-high voltage grid on the German mainland since 2006. And in 2016, the Dutch government appointed TenneT as the offshore grid operator in the Netherlands.

The energy transition in Germany

The energy transition is the largest future project ever seen in Germany. In the future, in Germany more electricity is to be generated from renewable energies in order to be able to do without electricity from nuclear energy in the medium term and electricity from coal-fired power plants in the long term. Wind energy generated far away at sea is one of the main pillars in the energy transition. The German federal government has set specific objectives to meet this target: by 2020, offshore wind farms with a capacity of 6.5 gigawatts (GW) are to be connected to the grid. By 2030, a total of 20 GW should be available. This corresponds to the energy output of about 20 large power plants. TenneT is ensuring the infrastructure required is in place. Pioneering work has been conducted by TenneT in the world's first offshore grid connections using direct current (DC) technology. Already in 2019 TenneT had met and even significantly exceeded the German government's expansion targets of 6.5 GW for 2020 for sustainable North Sea wind power. The projects for connecting offshore wind farms realised to date already transport more than seven GW of offshore wind energy to land. By 2027, TenneT will have completed four more of these grid connections in the North Sea, which will lead to a total of more than 10 GW of transmission capacity.

Offshore energy in the Netherlands

The Netherlands is also pushing ahead with the expansion of offshore wind energy in the North Sea. In the 2030 Roadmap for offshore wind energy, the government states that 10.6 GW of offshore wind farms will be built and connected to land by 2030. This is 40% of the current electricity consumption of the Netherlands. TenneT thus makes an important contribution to achieving the objectives of the Paris Climate Agreement.

Offshore projects in Germany

Guarantees for a secure supply

TenneT has been successfully building and operating connections for offshore wind farms in Germany since 2006. This includes the world's first 200-kilometre direct current connection completed in 2010 between an offshore wind farm and the extra-high voltage grid: BorWin1. TenneT has already put twelve offshore grid connections into operation. Four more projects will be completed by 2027, thereby increasing the overall capacity of TenneT's offshore projects to over ten GW.

alpha ventus
AC · 66 km · 62 MW · Hagermarsch
in operation since 2009

BorWin1
DC · 200 km · 400 MW · Diele
in operation since 2010

BorWin2
DC · 200 km · 800 MW · Diele
in operation since 2015

BorWin3
DC · 160 km · 900 MW · Emden/Ost
in operation since 2019

BorWin5
DC · 230 km · 900 MW · Garrel/Ost
Commissioning 2025

DolWin1
DC · 165 km · 800 MW · Dörpen/West
in operation since 2015

DolWin2
DC · 135 km · 916 MW · Dörpen/West
in operation since 2016

DolWin3
DC · 160 km · 900 MW · Dörpen/West
in operation since 2018

DolWin5
DC · 130 km · 900 MW · Emden/Ost
Commissioning 2024

DolWin6
DC · 90 km · 900 MW · Emden/Ost
Commissioning 2023

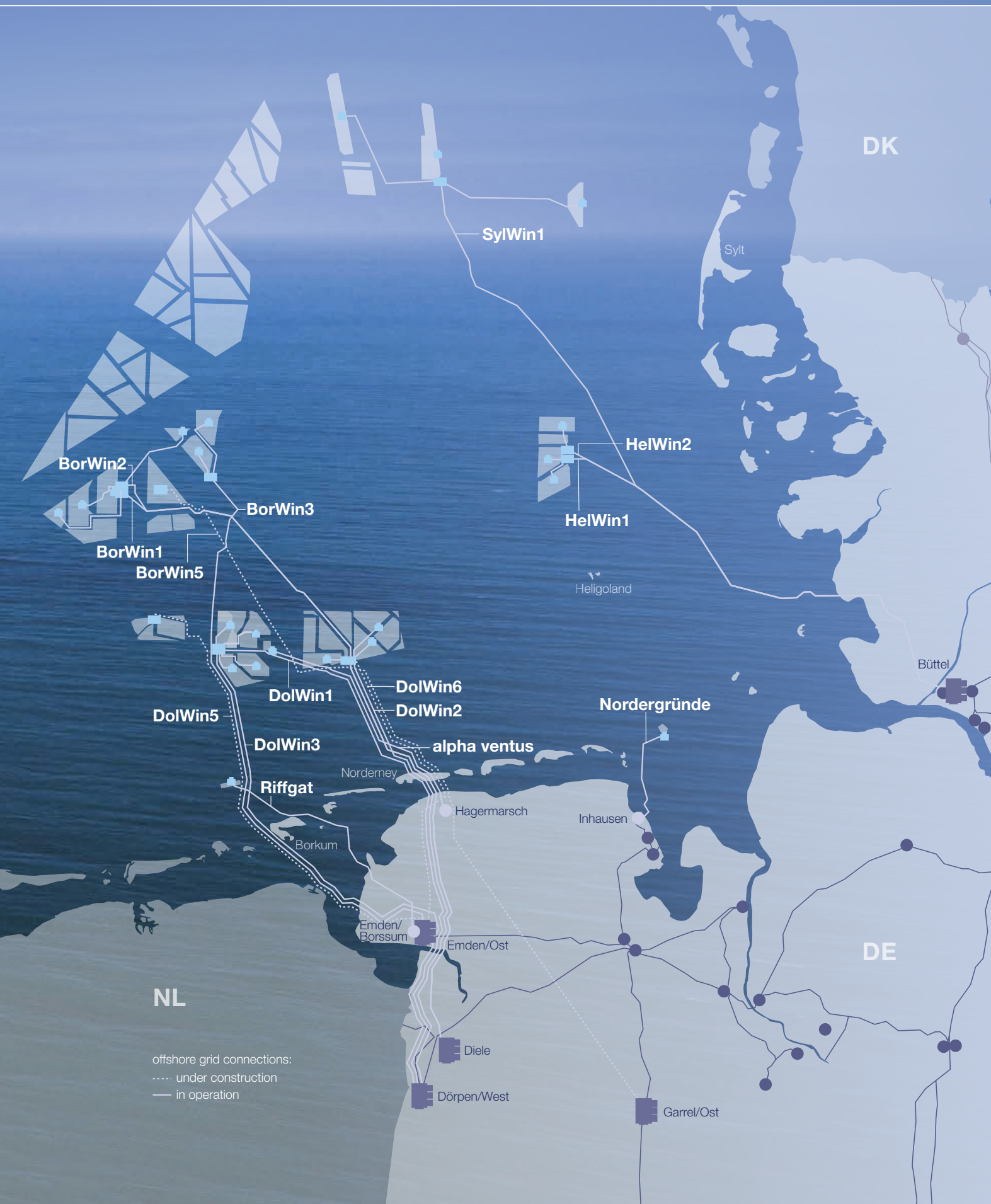
HelWin1
DC · 130 km · 576 MW · Büttel
in operation since 2015

HelWin2
DC · 130 km · 690 MW · Büttel
in operation since 2015

Nordergründe
AC · 32 km · 111 MW · Inhausen
in operation since 2017

Riffgat
AC · 80 km · 113 MW · Emden/Borssum
in operation since 2014

SylWin1
DC · 205 km · 864 MW · Büttel
in operation since 2015


DK
SylWin1
Sylt
HelWin2
HelWin1
BorWin2
BorWin3
BorWin1
BorWin5
Heligoland
Büttel
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DolWin6
DolWin2
DolWin5
DolWin3
alpha ventus
Nordergründe
Norderney
Riffgat
Hagermarsch
Inhausen
Borkum
Emden/
Borssum
Emden/Ost
DE
NL
Diele
Dörpen/West
Garrel/Ost
offshore grid connections:
under construction
in operation

Our technology: cables and converters

Connecting offshore wind farms to land requires the utmost in technical expertise, since energy generated at sea must be fed into the transmission grid and transported to consumers. Smaller wind farms located close to the coast are being linked directly to the mainland via three-phase electric power cables. North Sea wind farms located at distances far greater than 100 kilometres from the coast, by contrast, are connected via direct current cables. The power passes through several stations on its journey to the mainland.

For short stretches: three-phase electric power

This three-phase electric power features an alternating current (AC) and is intended for larger-scale electrical output. Three-phase electric power technology is primarily used for connecting wind farms close to the coast, since it is the most economically and technically efficient method for transporting wind energy across short routes. The power reaches the land directly via a sea and underground cable to the closest grid connection point – a substation. Here, the electricity is transformed to the voltage level of the extra-high voltage grid (380 or 220 kilovolts), where it is directly fed into TenneT's transmission grid.

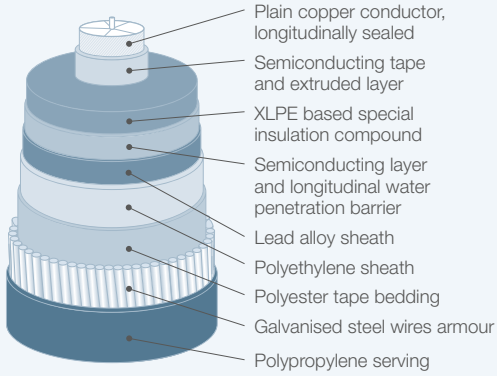
For long stretches: direct current with converter

High voltage direct current transmission (HVDC) is used for offshore wind farms located far out at sea. The advantage: considerably higher volumes of energy can be transferred compared to three-phase electric power. And the losses incurred are also lower (depending on distance). Offshore wind farms in the German North Sea are thus predominantly connected using HVDC technology via sea and underground cables. Each grid connection system consists of one pair of cables. The voltage and electricity transmission (three-phase electric power/direct current) must both be adjusted prior to feeding into the extra-high voltage grid. The process takes place in two converter stations.

In the projects realised to date, the electricity generated at sea was collected in the wind farm's own substation and fed from there to the converter platform via a 155 kV three-phase cable. In future, the wind farms will be directly connected to the converter platform at sea – using 66-kV three-phase AC cables. This means, firstly, that the wind farm's own substations are no longer required. Secondly, the 155 kV three-phase current cable for connecting the offshore converter platform from TenneT with the substations of the connected wind farms is no longer required. After the electricity generated at sea has reached the offshore converter platform, the voltage is increased to the converter working voltage of 320 kV by the use of power transformers. The three-phase electric power is converted into direct current (±320 kV) within the converter stations and subsequent smoothing also takes place here. This is key in regulating the direct current system. The two direct current cables (one plus and one minus pole) lead from the platform's direct current section down to the sea bed, where they are routed towards the mainland – the "landing point". This point marks the transition from sea to land. Once it reaches this point, the power is transported by underground cable to the onshore converter station, reconverted into three-phase electric power, transformed to the correct voltage and fed into TenneT's 380-kV grid within the linked substation.

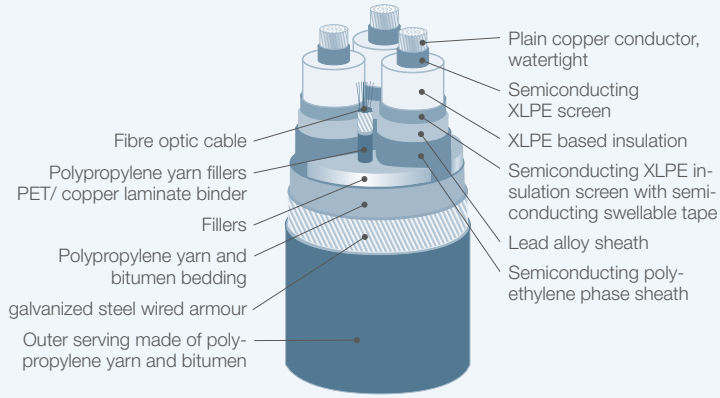
DC Subsea Cable Structure

Cable diameter approx. 13 cm / Weight approx, 45 kg/m
Cable cross section 1.250 mm²
(Diameter copper core approx. 4 cm)



AC Subsea Cable Structure

Cable diameter approx. 22 cm / Weight approx, 59 kg/m
Cable cross section 240 mm²
(Diameter copper core [3 x] approx. 1,86 cm)

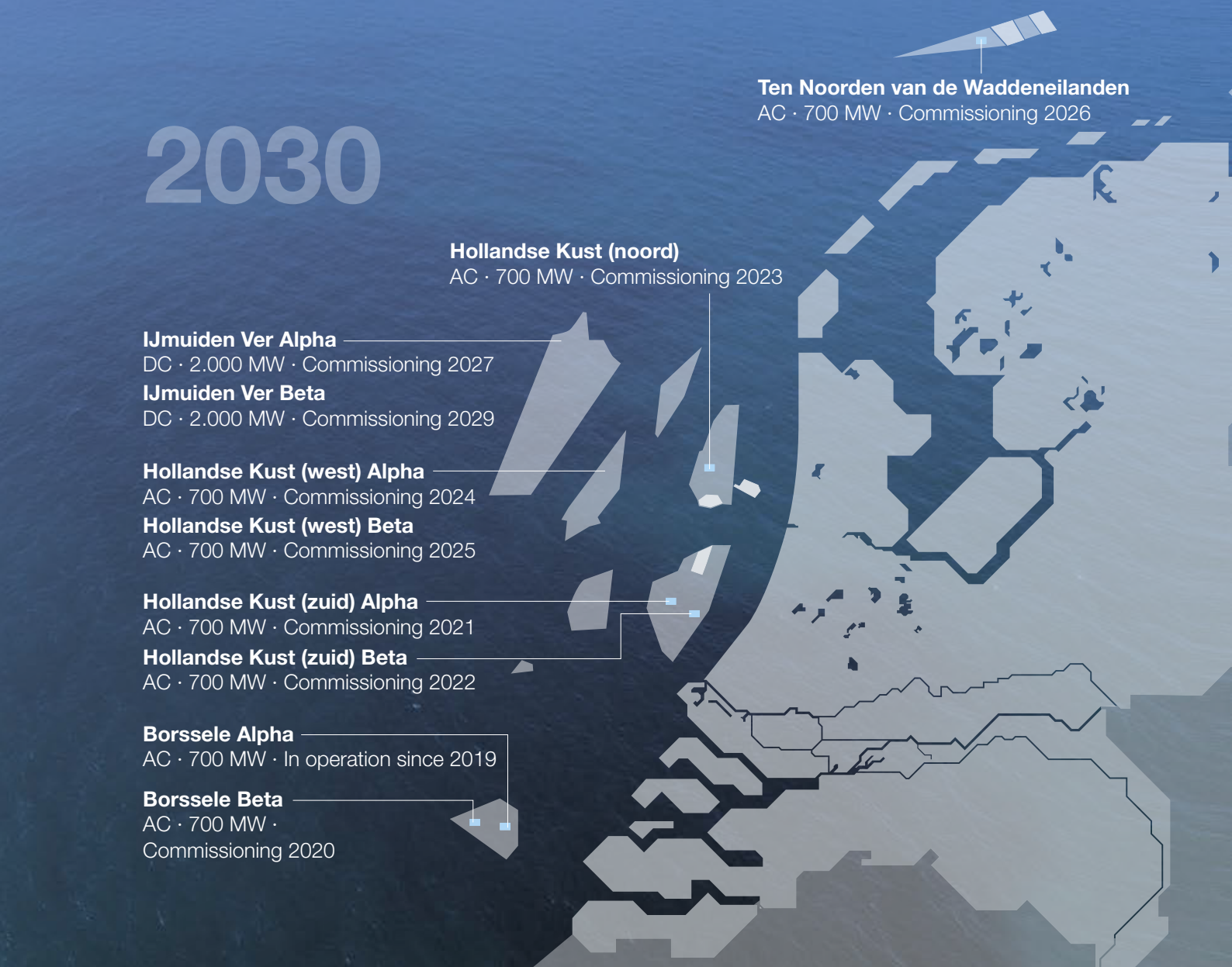


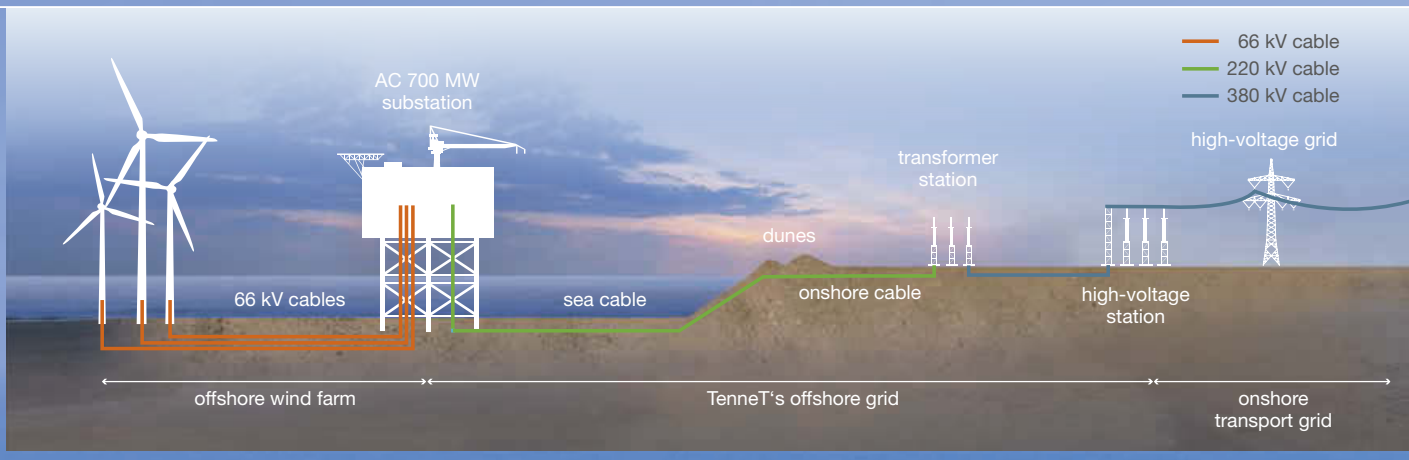
Our offshore projects in the Netherlands

Since 2016, TenneT has also been responsible for connecting offshore wind energy farms in the Netherlands. Prior to TenneT's appointment as transmission system operator at sea, all offshore grid connections were built by the offshore wind farm developers themselves.

In addition to the 3.5 GW laid down in the 'Roadmap for offshore wind energy' (2015), TenneT will connect another 6.1 GW of offshore wind energy to the Dutch high voltage grid according to the 'Roadmap for offshore wind energy 2030' (2019). TenneT will establish eight standard alternating current connections, each with a capacity of 700 megawatts (MW), up to and including 2026. Wind farms will be built further away from the coast in the IJmuiden Ver wind energy region from 2027. Given the large capacity (2 GW per connection), and to limit the loss of energy during transport, TenneT is carrying out this connection as a direct current connection.

2030





The platform is one of the main parts of the offshore grid. Energy generated in wind farms is transported to an offshore platform and then, via the two 220 kV AC cables, to an onshore high-voltage station. The size of the platform is optimised at 700 MW.

> "Standardisation helps to reduce the costs of offshore wind power and reduces the impact on the environment."

Standardisation in technology

In TenneT's view, the best way to connect wind farm areas located relatively close to the Dutch coast to the grid is to use alternating current technology. The energy produced in these areas can be transmitted via a standard TenneT transformer platform that is connected to an onshore high-voltage station located near the coast via 220 kV AC cables buried in the seabed.

This standardised connection system with a capacity of 700 MW each is used by TenneT for the wind energy areas of Borssele (2 x 700 MW), Hollandse Kust (zuid) (2 x 700 MW), Hollandse Kust (noord) (700 MW), Hollandse Kust (west) (2 x 700 MW), and the area Ten Noorden van de Waddeneilanden (700 MW).

The efficient connection of the wind energy areas further away from the North Sea, such as IJmuiden Ver, partly requires other techniques. Given the large capacity (2 GW per connection), and to limit the loss of energy during transport, TenneT is carrying out this connection as a direct current connection with 525 kV cables.

A guiding principle is to develop the connections for these areas at the lowest possible societal costs, with the least disruption to the environment.

The challenge and responsibility

Innovative.

TenneT focuses on future-oriented applications in practice and is testing the use of robots on offshore platforms.

Thoughtful.

Due to innovative and complex technology TenneT defies the harsh conditions of the North Sea.

Competent.

TenneT invests into security trainings for its employees on a regular basis to ensure that daily operations run smoothly.

TenneT is navigating a challenging environment in realising these projects. For work at sea, on tidal flats and on land TenneT needs to satisfy strict requirements. Driving the piles into the ground for converter platform installations, for instance, requires adequate sound insulation measures to protect wildlife. Additionally, difficult weather conditions need to be dealt with: temperature, wind and waves pose particular challenges to TenneT. Cables, for example, may only be laid in temperatures of at least five degrees Celsius. Some activities can only be carried out up to a certain wave height. As for operations in the Wadden Sea, there is a work timeframe of just a few months a year for reasons of natural and coastal protection. Old munition in the North Sea has also caused issues. During and after the Second World War it was disposed into the sea and poses a safety risk for people and nature alike today. By clearing old munitions along cable routes, TenneT makes a key contribution to safety in the North Sea.

Stakeholders & service

TenneT considers it important to incorporate all stakeholders in the planning and approval processes, including all the relevant associations, municipalities and NGOs. All stakeholders should be able to raise their concerns at various points in time during the process. TenneT will also be able to offer a new information service using the platforms in the Netherlands. Sensors providing maritime information on wind speed, waves, ship movements and bird flight directions will be installed. These actions are of considerable importance to various state organisations and scientific institutions.

Crossing technical limits

New methods of increasing utilisation are being tested for the first time in the Netherlands. Since wind at sea does not blow consistently, the power generated varies resulting in a varying level of utilisation of the cables transporting the power. Both of the cables – each capable of transporting 350 MW to land from the Dutch platform – will be able to temporarily transmit more than 350 MW if the cable temperature doesn‘t exceed the legal limits. This means that, under certain circumstances, an additional temporary capacity of a further 30MW can be facilitated. This technical solution will enable offshore wind farm developers to install an additional 30 MW of wind turbine output.

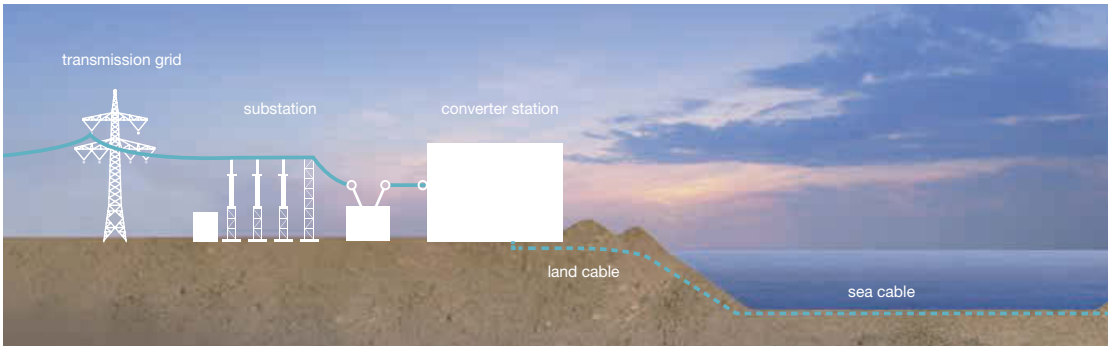
To protect dykes, dunes and the Wadden Sea, TenneT carries out horizontal directional drillings. First, protective conduits are pulled into the borehole. In a second step, the high voltage cables are being pulled into the conduit.

During the cable pull-in the cables are positioned on cable roller tracks.

Our commitment in Europe

As the first cross-border European transmission system operator, TenneT works in conjunction with transmission system operators in other countries to link together Europe's power grids. Using cross-country connections, so called "interconnectors", we are forming a European connection grid, in which electricity can be transferred across borders more simply, efficiently and affordably. To do so, TenneT is operating and building high-performance offshore interconnectors through the North Sea together with partners in Europe. This represents a crucial contribution towards developing an integrated and sustainable electricity market in Northwestern Europe.

Our interconnectors at a glance



BritNed

BritNed has been facilitating the exchange of power between the Netherlands and Great Britain since 2011. The 260-kilometer-long HVDC transmission line has a transmission capacity of 1 GW. The interconnector passes through the North Sea between the English Isle of Grain and Dutch harbour Maasvlakte. BritNed Ltd. is a joint venture between TenneT and the British energy supplier, the National Grid.

COBRAcable

700 MW output, 325 kilometres in length: This is benchmark data from COBRAcable, the HVDC transmission line that directly links together the power markets of the Netherlands and Denmark. TenneT realised this project in cooperation with the Danish grid operator Energienet.dk. COBRAcable has been in operation since 2019 and contributes to integrating more electricity from renewable energy sources, especially wind energy in Denmark, into the European electricity market. Furthermore the cable connection has been designed in a such a way that it will be possible to connect an offshore wind farm at a later stage.

NordLink

NordLink is the first direct power link between Germany and Norway. This 623-kilometre-long HVDC transmission line facilitates the exchange of 1.4 GW of renewable energy – wind power from Germany and hydropower from Norway. NordLink is a key building block in the energy transition and one of the most significant projects in the European energy sector.

NorNed

This 580-kilometre-long HVDC transmission line passes through the North Sea from Feda in Norway to Eemshaven in the north of the Netherlands as a subsea cable. NorNed has been in operation since 2008. It has a capacity of 700 MW. Currently the longest subsea cable line in the world, this link between Norway and the Netherlands makes a considerable contribution towards strengthening the security of supply in the two countries.

Our interconnectors:
- secure a sustainable and efficient energy supply that is fit for the future
- facilitate the integration of renewable energies across national boundaries
- ensure more competition on the energy market
- promote the importing and exporting of energy

Our vision

Sustainable Energy Supply – Today and in the Future

Good ideas and forward-looking innovations drive TenneT anew every day. Because they make a significant contribution to meeting the challenges of the energy transition now and in the future. This is why TenneT participates in pilot projects and research programmes on a whole range of topics for a sustainable and future-proof energy supply.

Green electricity becomes green gas

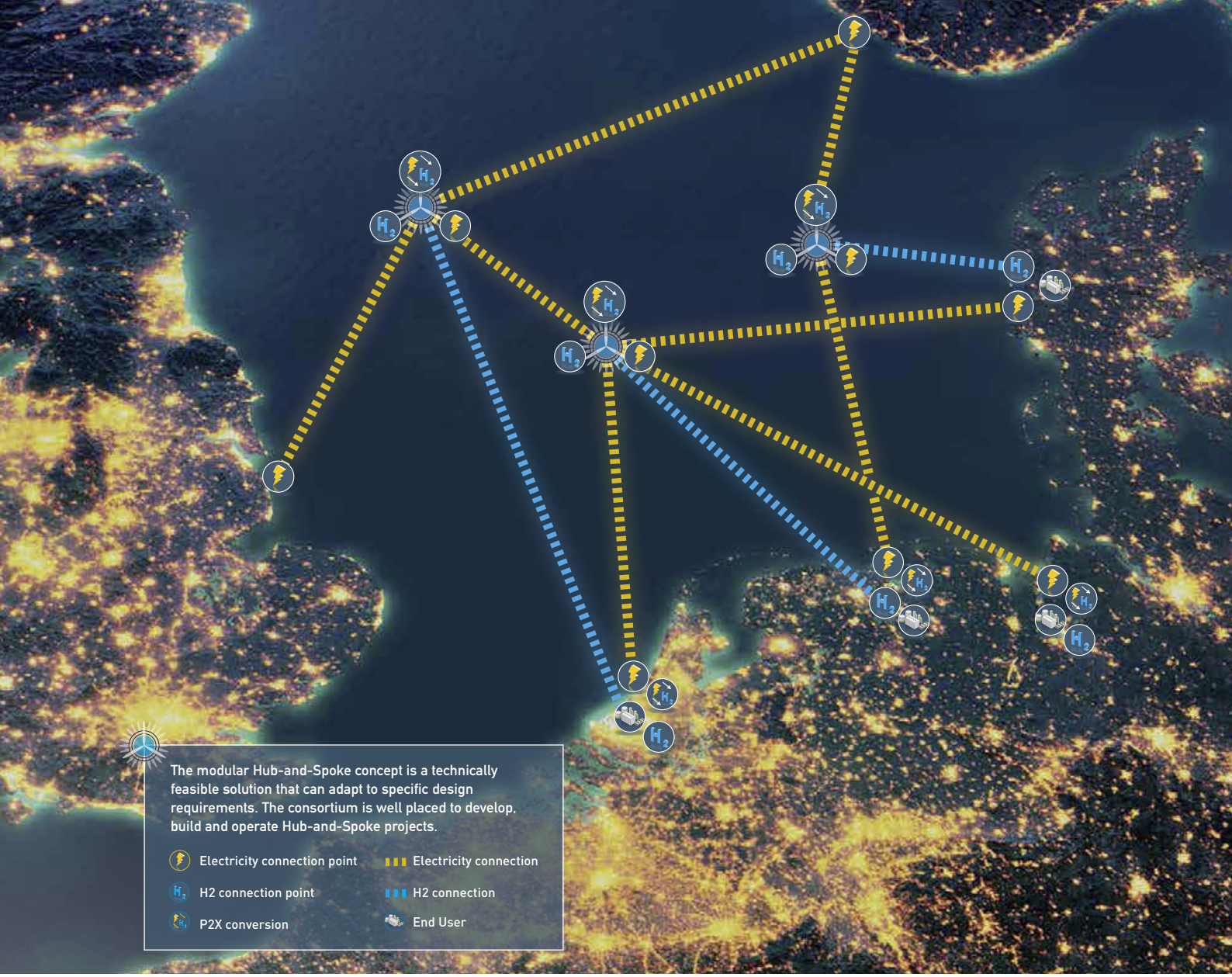
How can renewable electricity be transported and stored as green gas? TenneT collects answers to these questions together with gas network operators and various research institutions in the pilot project „ELEMENT EINS“.

The project focuses on the following question: How can surplus electricity, e.g. clean wind energy from the North Sea, be used in other sectors? Until today there is no technically and economically convincing solution to store surplus electricity. TenneT is well aware that, in addition to a suitable power grid infrastructure, efficient storage technologies and alternative transport solutions are also needed to successfully master the energy transition. In the future, electricity and gas will have to complement each other so that the energy system remains reliable. Power-to-Gas technology offers considerable potential for this. Together with the gas transmission system operators involved, TenneT is therefore planning to build a 100 MW power-to-gas pilot plant. At a site where mainly wind energy from the North Sea is collected, the plant will be connected to the grid step by step from 2022 and convert green electricity into green gas in order to open up new storage potential for renewable electricity. The partners are focusing on the far-reaching coupling of the energy, transport and industry sectors. This means that the electricity converted into green gas can not only be transported from the North Sea to the Ruhr area via existing gas pipelines, but can also be made available for mobility via hydrogen filling stations. By storing it in caverns, the green gas can also be used in industry.

New cable generation: plastic-insulated 525 kV

TenneT is preparing the use of a new generation of cables: plastic-insulated cables for the voltage level of 525 kilovolts. They make offshore grid connections even more economical and ecological. The higher voltage level means that considerably more power can be transmitted than with the 320 kV HVDC cable system currently still used in the industry. On the one hand, this reduces energy costs (LCOE = social electricity production costs). On the other hand, the spatial and ecological effects are reduced, since the higher voltage level means that fewer cables are required to transmit high outputs of two GW and more.

TenneT and the other German transmission system operators have carried out prequalification tests to prove that this type of cable is technically ready for the market – on land and at sea. In the offshore sector, the new cable generation will be used for the first time as part of the TenneT project IJmuiden Ver, the world‘s first 2-gigawatt offshore grid connection. Onshore, the new 525 kV cables will be used for SuedLink and SuedOstLink.



North Sea Wind Power Hub

Cover Central Europe‘s electricity consumption with clean wind energy alone? What may sound like science fiction is TenneT‘s vision for a large direct current distribution network in the North Sea. TenneT has developed the idea of North Sea Wind Power Hubs, which, in combination with interconnectors, will connect up to 180 GW of offshore wind energy to the transmission grids of the North Sea countries by 2045.

After an intensive evaluation phase, the international consortium (consisting of TenneT, Energinet, Gasunie and Port of Rotterdam) presented the first results of feasibility studies, examined scenarios and discussions with political decision-makers, leading offshore wind farm developers and non-governmental organisations in summer 2019. The main result: the proposed Hub-and-Spoke concept is technically feasible. The relevant wind power capacities in the North Sea range from 70 to 150 GW by the year 2040 and up to 180 GW in 2045, respectively, and are to be expanded according to a modular, step-by-step approach and later combined with power-to-gas plants. A first Hub-and-Spoke project with a capacity of 10 to 15 GW could go into operation in the 2030s.

Glossary

Connecting offshore wind farms to the power grid is technically challenging and very complex. This complexity results in many technical terms that may sometimes be difficult for laypersons to understand.

We explain the most important concepts in this glossary.

Cable joints

Cable joints are connecting pieces with which individual cable sections are connected together. Many more casing collars are used on land than offshore, because underground cables can only be laid in sections of about 750 to 1,000 metres. This is necessary because longer cable sections cannot be transported on public roads for weight reasons. Offshore, cables can sometimes be laid in a single piece or with significantly fewer joints than on land, because no transport restrictions apply there. Special cable laying ships can sometimes transport as well as lay the entire cable length in a single pass.

Construction schedule restriction

Regulations that restrict the construction schedule in the interests of protecting the coastal region, natural areas and local species. For example: Because construction is only permitted in the Wadden Sea National Park outside of the breeding season of birds, the time window for construction here is only a few weeks, typically from mid-July to the end of August. As of September, the ban on construction begins again for reasons of coastal protection.

Converter

A converter converts three-phase electric power into direct current and vice versa. Depending on the direction of transmission, converters operate as rectifiers (three-phase electric power to direct current) or inverters (direct current to three-phase electric power).
Offshore, the electricity produced in the wind farms is converted from three-phase electric power to direct current on the converter platform.
Onshore, the direct current coming from the sea is converted back into three-phase electric power in the converter station.

Converter platform

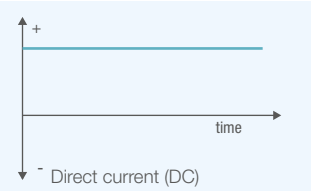
Offshore structure that converts the electricity produced in the offshore wind farms from three-phase electric power to direct current. The offshore converter platform is connected to the onshore converter station via a subsea and land cable. The converter platform itself is a component of the HVDC transmission line.

Converter station

Onshore structure that converts the direct current coming from offshore back into three-phase electric power. The onshore converter station is also part of the HVDC transmission line.

Direct current

Direct current is electrical current that does not change in strength or direction. Internationally, this is commonly referred to with the English abbreviation ‘DC’.

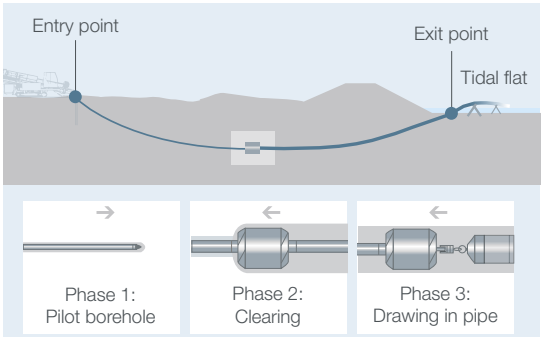


Direct current (DC)

Extra-high voltage

The voltage range of 220 kV and higher; the transmission grids often referred to as ‘electricity highways’ receive the power produced in large power plants or generated from renewable sources and transport it at an extra-high voltage of 380 or 220 kilovolts (kV) over large distances to the main points of consumption.

Horizontal boreholes/Horizontal directional drilling (HDD)
Horizontal directional drilling (HDD) is a drilling technology for creating horizontal boreholes. This allows cables for electricity to be run underground without the need to excavate trenches. A special machine bores out an underground channel into which one or more empty protective conduits are inserted. Power cables can later be pulled through these pipes. The method is especially well suited for environmentally sensitive areas, such as in the area of the Wadden Sea, or for crossing dyke and dunes, since excavation work can be kept to a minimum. It is also possible to cross under flowing water, roads and railways with this technique. The boreholes can be over a thousand metres long and can be steered precisely with centimetre accuracy.



Schematic representation of the phases of horizontal drilling

HVDC/High voltage direct current transmission
High voltage direct current transmission (HVDC) is a method by which large quantities of electricity can be transported over very long distances at very high voltages (100 to 1,000 kV). The highest possible voltages are selected in order to minimize the electrical losses during transmission of electrical energy over long distances.

Interconnector
High voltage connection between two countries which allows the exchange of electricity.

Land cable
Term for a power line that is run underground.

Landfall
This refers to the point where the subsea cable first reaches shore. It marks the transition from sea to land. From here, the electricity generated at sea is transported to the onshore converter station via underground cable.

Low voltage
Voltage range up to 1 kV; low-voltage grids are responsible for the fine distribution of electricity. Private households, smaller industrial operations and commercial and administrative buildings obtain electricity in this way.
Low voltage corresponds to the ‘power from the socket’.

Offshore
The adjective offshore refers to the area of water near the coast.

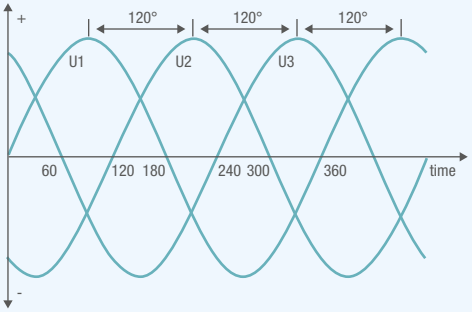
Offshore wind farm (OWF)
This term applies to wind farms for which the foundations of the wind turbines rest in the ocean. Offshore wind farms achieve significantly higher wind yields than wind farms on land.

Three-phase electric power
Three-phase electric power is a form of alternating current that is usved for the transmission of large quantities of energy. Single-phase alternating current is used in homes and for lower power


Horizontal boreholes: The actual cables are pulled through the plastic pipes later.

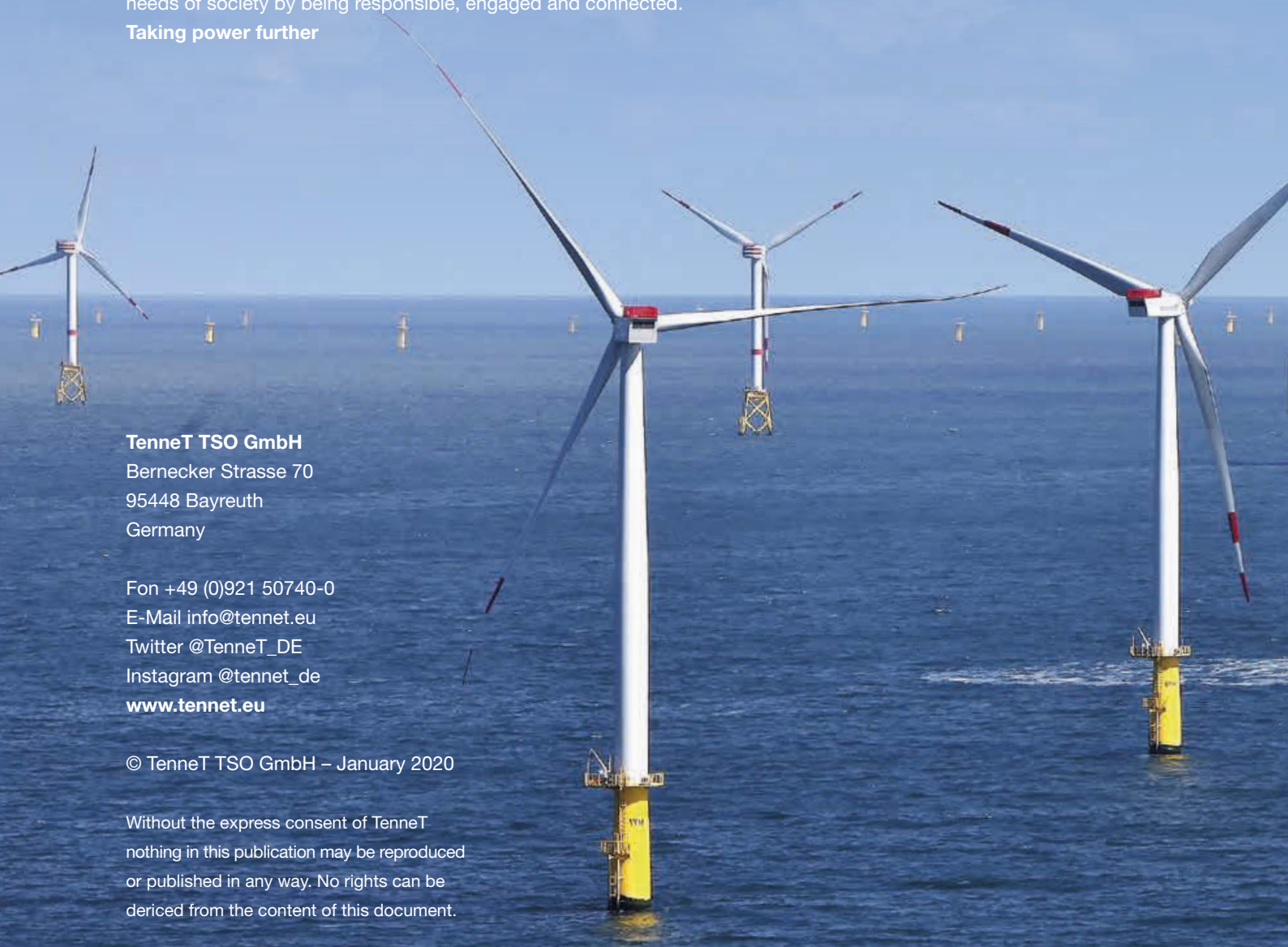

Büttel converter station

applications. In contrast to direct current, this type of power alternates periodically with regular changes of direction. The three phases of these alternating currents – in other words the rise and fall of the sine wave upon every turn of the generator axis by 360 degrees – are each offset to each other by 120 degrees. This produces a three-phase alternating current with sine waves that overlap evenly. The frequency of the oscillation, i.e. the number of oscillations per second, is 50 Hz in the synchronous grid of continental Europe. Internationally, three-phase electric power is frequently referred to as ‘alternating current’ (AC). In the case of high and extra-high voltage lines, TenneT speaks of three-phase electric power.



Three-phase electric power (AC)

TenneT is a leading European electricity transmission system operator (TSO) with its main activities in the Netherlands and Germany. With over 23,000 kilometres of high-voltage connections we ensure a secure supply of electricity to 41 million end-users. TenneT is one of Europe's major investors in national and cross-border grid connections on land and at sea, bringing together the Northwest European energy markets and accelerating the energy transition. We make every effort to meet the needs of society by being responsible, engaged and connected.
Taking power further



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