LEBENSADERN

THE AMPRION MAGAZINE | VOL. 01

Responsibility for a strong grid

AMPRION – A BRIEF PROFILE

With 11,000 kilometres of extra-high-voltage grid, Amprion GmbH is a major transmission system operator in Germany and Europe. As an innovative service provider, Amprion offers both its customers in industry and its network partners maximum security of supply. Our workforce of around 1,300 people works hard to ensure that we do so.

~64 GW

The total installed generation capacity in the Amprion grid area.

79,200 KM²

The area covered by the Amprion grid, extending from Lower Saxony to the Alps.

11,000 KM

of power lines in the Amprion transmission system.

~29 M

People supplied with electricity from the Amprion grid.

161

Substations connecting the Amprion grid to the regional distribution systems and our industrial customers.

The energy transition is one of the great innovative projects of our times. We want it to succeed.

Electricity is the lifeblood of our modern society. It enhances quality of life and makes businesses competitive. As a transmission system operator Amprion is responsible for ensuring that sufficient energy is delivered to the power point. Thus our power lines form the metaphorical lifelines of our economy. They reliably transmit power for 29 million people over a territory extending from Lower Saxony to the Alps.

This helps us to see very clearly what challenges are posed by the energy transition: by 2050 renewable energy is set to generate at least 80 per cent of Germany's electricity. The transmission network will have to transport ever greater, strongly fluctuating volumes of weather-dependent power. To do so we will have to expand the grid, including across national borders, and that in turn will require us to integrate new, innovative technologies into the power system.

Not only will the energy transition fundamentally transform the economy, it will also change our everyday relationship with energy. We want this process to succeed, and are making our own contribution to ensuring a future-proof, secure and efficient energy supply for Germany and Europe. You can read about how we do that in this magazine, which we shall be putting out under a new title from now on: Lebensadern, or lifelines.

I hope you have a lot of pleasure reading it.

THOMAS WIEDE

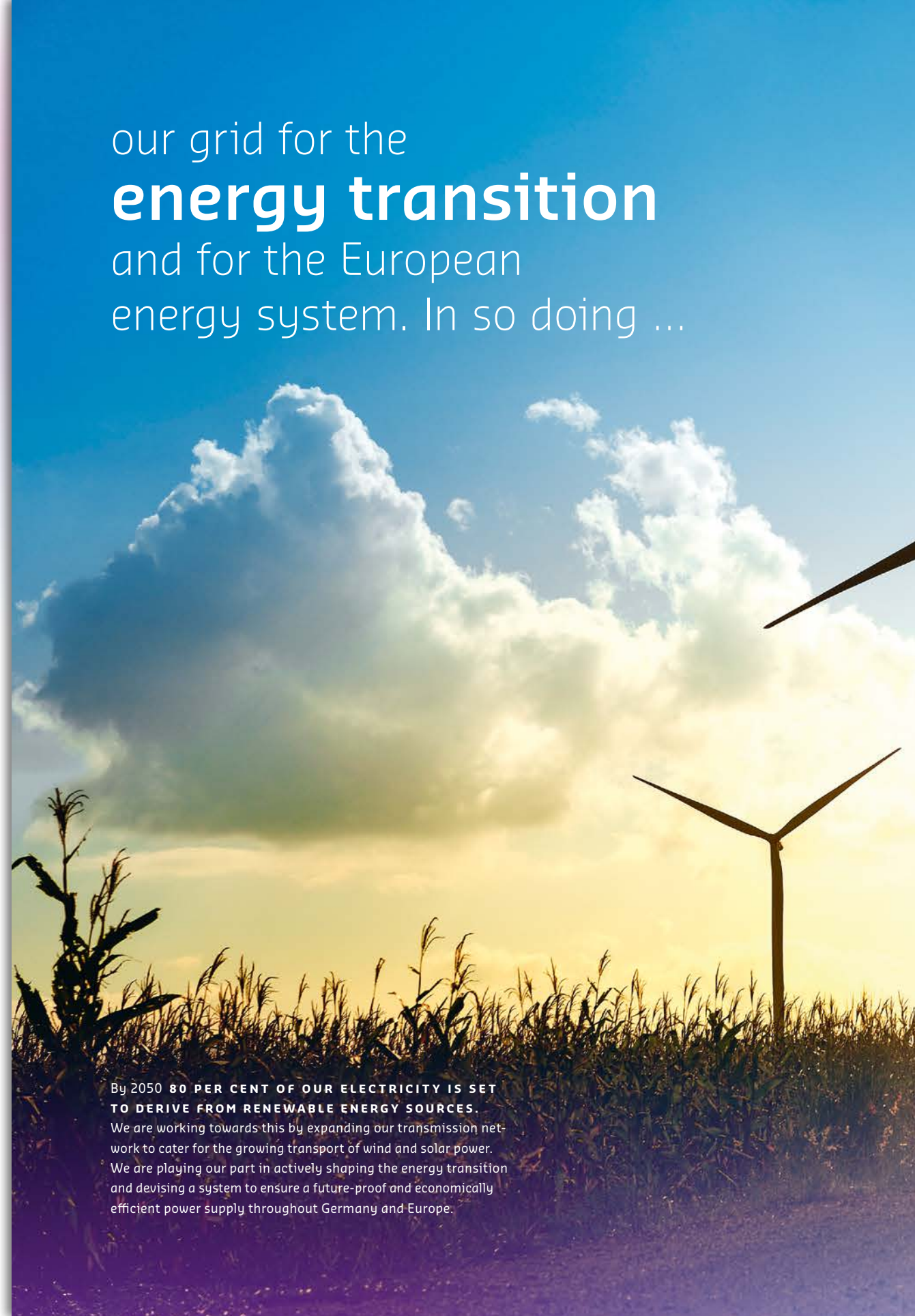
Head of Corporate Communications and Digital Media at Amprion


Our power lines are
the lifelines of our
economy because
they safeguard the ...

DILLINGER'S HEAVY PLATE can be found in bridges, pipelines, offshore wind installations and heavy machinery. It is rolled from steel manufactured at temperatures of around 1,700 degrees Celsius. As an energy-intensive enterprise, Dillinger procures its electricity directly from our transmission network. Just one way in which we contribute to safeguarding jobs in Saarland and beyond.

quality of life of 29 million people. From Lower Saxony to the Alps, we are reinforcing …

POWER IS LIFE. More than that, power is quality of life. Smartphones and mobile communications networks only function if they have a secure and reliable power supply. We lay the foundations for this through our transmission network, which transports large quantities of electricity over long distances to the places where people live and work.



our grid for the **energy transition** and for the European energy system. In so doing …

By 2050 **80 PER CENT OF OUR ELECTRICITY IS SET TO DERIVE FROM RENEWABLE ENERGY SOURCES.** We are working towards this by expanding our transmission network to cater for the growing transport of wind and solar power. We are playing our part in actively shaping the energy transition and devising a system to ensure a future-proof and economically efficient power supply throughout Germany and Europe.

CONTENTS

We link up industrial centres and generation facilities. Over our **11,000-KILOMETRE-LONG GRID** we transport electricity for 29 million people. Our remit for this comes from the legislators. We are aware of our responsibility and endeavour to live up to it round the clock, 365 days a year. Our workforce of around 1,300 people works hard to ensure that we do so.


our responsibility
to deliver a strong grid is
both a legal requirement and
a self-imposed duty.

28

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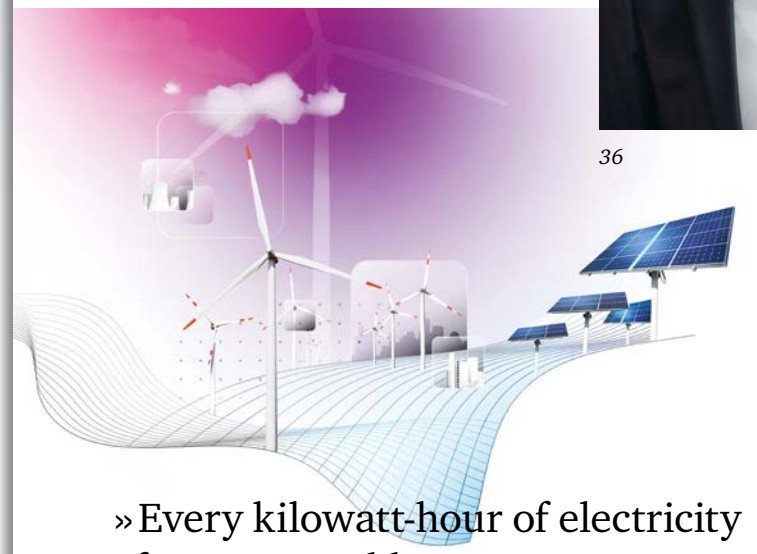

»Every kilowatt-hour of electricity from renewable energy sources helps protect the climate.«

GERALD KAENDLER

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LEBENSADERN

Responsibility for a strong grid

You can find all the contributions in the magazine plus other intriguing insights online at amprion.net/ar2017

STRONG GRID, STRONG RELATIONSHIPS

A stable power grid lays the foundation for our energy supply. Responsibility for the extra-high-voltage grid in Germany rests with Amprion and three other transmission system operators. Their remit is to operate a safe, efficient grid and to expand it as and when needed, under the supervision of the Federal Network Agency (Bundesnetzagentur). In so doing the operators are independent of the generation and sales arms, providing the grid in their control areas as neutral platforms for the electricity market. The transmission system operators' customers are energy producers, distribution system operators and industry. For the power they consume they pay network charges which are controlled by the Federal Network Agency.

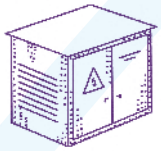
Prescribes climate protection goals and presses ahead with the development of the European internal electricity market.

EUROPEAN PARTNERS

Together with other European transmission system operators and associations, Amprion is further expanding the power grid in Europe.

OTHER TRANSMISSION NETWORK OPERATORS

Like Amprion, 50Hertz, TenneT and TransnetBW are responsible for the extra-high-voltage grid in their control areas and work together in the interconnected network.



DISTRIBUTION SYSTEM OPERATORS

Distribute electricity from the transmission network to municipal utilities and regional enterprises. Some of them also feed electricity into the transmission network.

LEGISLATORS AND THE FEDERAL GOVERNMENT

Have subjected transmission system operators to a legal requirement to expand networks according to need and to operate them safely.

FEDERAL NETWORK AGENCY

Supervises the grid operators, regulates network charges and approves grid expansion requirements.

ELECTRICITY EXCHANGES AND ENERGY TRADERS

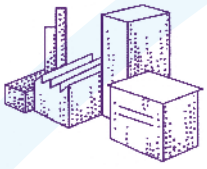
Due to its central location the Amprion grid forms a hub of the energy trading market. Amprion works closely with all market participants throughout Germany and Europe.

STATE LICENSING AUTHORITIES

Approve grid expansion projects at state level, after first reviewing objections raised by citizens, public authorities and environmental associations.

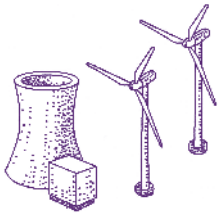
CITIZENS, AUTHORITIES AND ENVIRONMENTAL ASSOCIATIONS

Are involved by Amprion in grid expansion plans, expressing their opinions to the state licensing authorities and the Federal Network Agency.



INDUSTRIAL CUSTOMERS

Companies in the aluminium, steel and chemical industries purchase large quantities of electricity directly from the extra-high-voltage grid.



ENERGY PRODUCERS

Sell power to the electricity exchanges and use the transmission network.

FOCUS

ENERGY WORLD IN TRANSFORMATION

The energy transition is one of the great innovative projects of our times. Together with its many partners Amprion is driving the process forward. The goal is to make the energy of the future safe, sustainable and economically efficient. But the challenges are great. Next we take a look at the energy world, past and future.

Text: Volker Göttsche Illustration: Marie Luise Emmermann

PHASE

01

ENERGY TRANSITION 1990–2013: DYNAMIC EXPANSION OF RENEWABLE ENERGY. START OF THE RESTRUCTURING OF CONVENTIONAL ENERGY PRODUCTION. PLANNING OF GRID EXPANSION.

The road to the energy transition was paved with protest: since the 1970s an ever-growing environmental movement has stridently demanded change: away from coal, crude oil and nuclear energy and towards renewable energy. With visible results. In 1987 the first German wind farm was connected to the grid in Schleswig-Holstein. Shortly afterwards the political world took its first steps towards the new energy world. The Electricity Feed-in Act (Stromeinspeisegesetz) of 1990 required suppliers to give preference to green electricity produced by small-scale providers at prescribed feed-in tariffs.

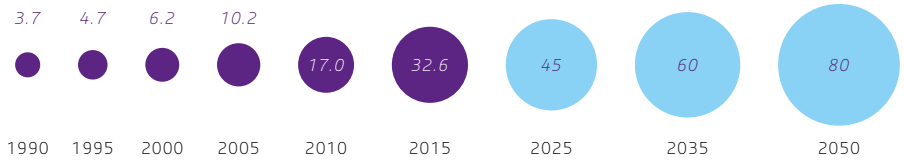
This created the foundations for the rapid expansion of green power generation: by 1999 the installed capacity produced by wind turbine generators had increased more than 70-fold to 4.3 gigawatts. Further legal underpinning came in 2000 in the form of the Renewable Energy Sources Act, which prescribed the progressive replacement of fossil energy sources by renewables. Attractive feed-in tariffs and growing environmental awareness fuelled the boom. By 2010 the share of energy produced by wind, sun, water and biomass had risen to 24 per cent. “It was back then that the first studies for the energy system of the future came out”, says Gerald Kaendler, head of Asset Management at Amprion. “However, nobody imagined that the actual expansion of renewable energy would exceed all the forecasts.” The following year a further structural change was initiated: after the Fukushima disaster the federal government decided to decree the shutdown of nuclear reactors, with the oldest generators being removed from the grid immediately. The remaining nuclear power stations will go off line by the end of 2022. “We immediately realised”, recalls Kaendler, “that it would be impossible to develop the new generation landscape without a stronger and more flexible grid, so we got down to work without delay.”

Germany became an energy transition country. Then in 2014 the climate protection goals approved by the European Union lent further backing for the German approach: in order to limit global warming to two degrees Celsius, by 2050 greenhouse gas emissions were to be reduced by at least 80 per cent as compared with 1990. Thus the transformation of the energy system to low-emission, sustainable generation became a pan-European project.

But how did the German energy system respond to the transition? Increasingly power was no longer being produced where it was consumed but where the wind was blowing or the sun shining. “Generation remote from the load”, the experts call it. However, this is not what the power grid was designed for. Accordingly it would have to undergo wide-ranging renovation and expansion in order, for instance, to convey wind power from the north to the centres of consumption in the west and south. In 2009 and 2013 the legislators therefore gave the green light for major grid expansion projects, to be implemented by the transmission system operators over an average timespan for planning, approval and construction of up to ten years, and even longer for the largest projects. On top of this, although there was widespread public approval of the energy transition, the associated measures by no means always met with acceptance. “We have learnt that grid expansion can only succeed through intensive dialogue with local people”, says Kaendler, “But for that we need time.” As a result, renewable energy grew faster than the infrastructure for its transport. And that in turn led to ever more frequent stresses and bottlenecks in the grid.

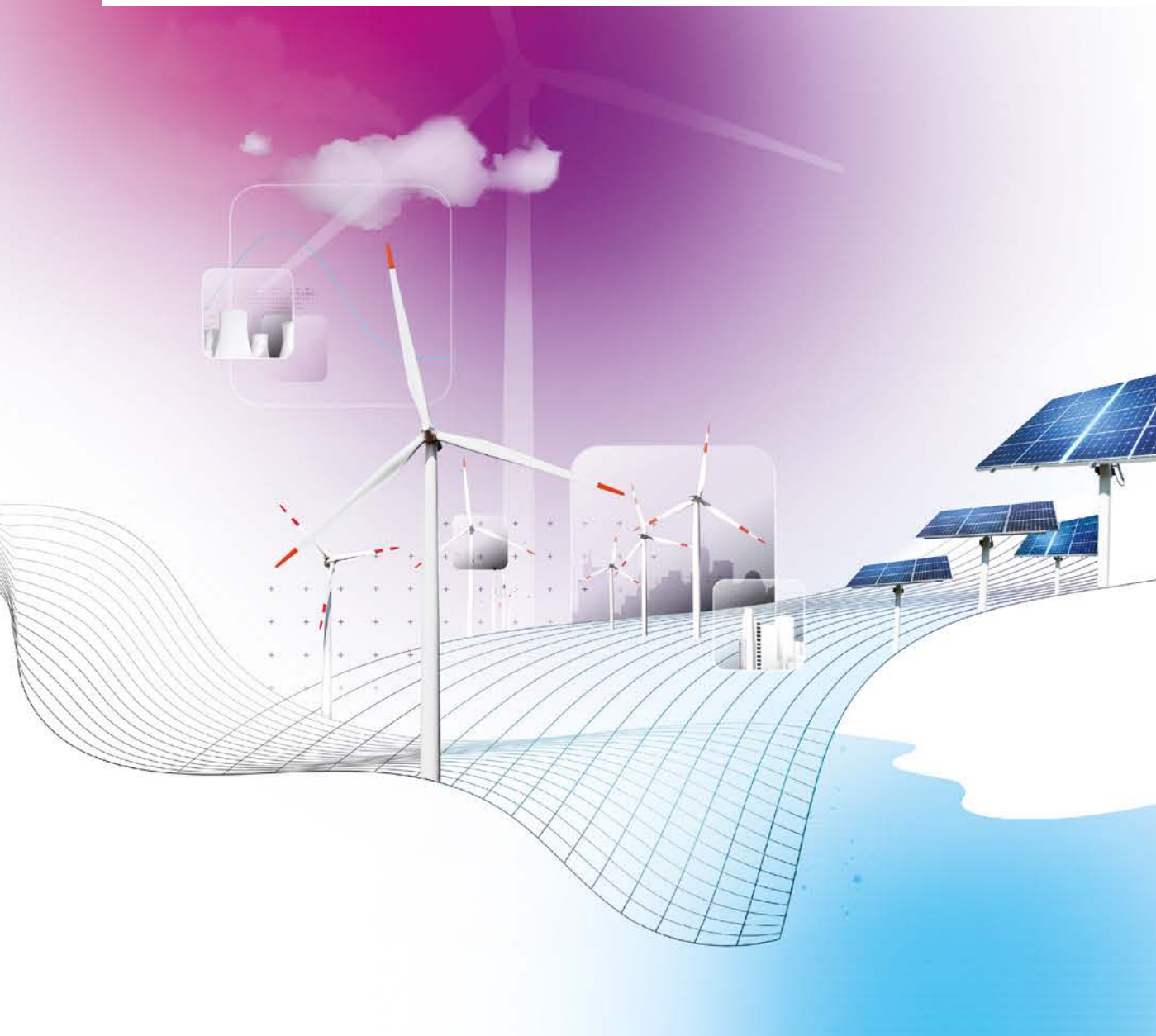
RENEWABLE ENERGY ON THE ADVANCE

Proportion of all generated energy in per cent



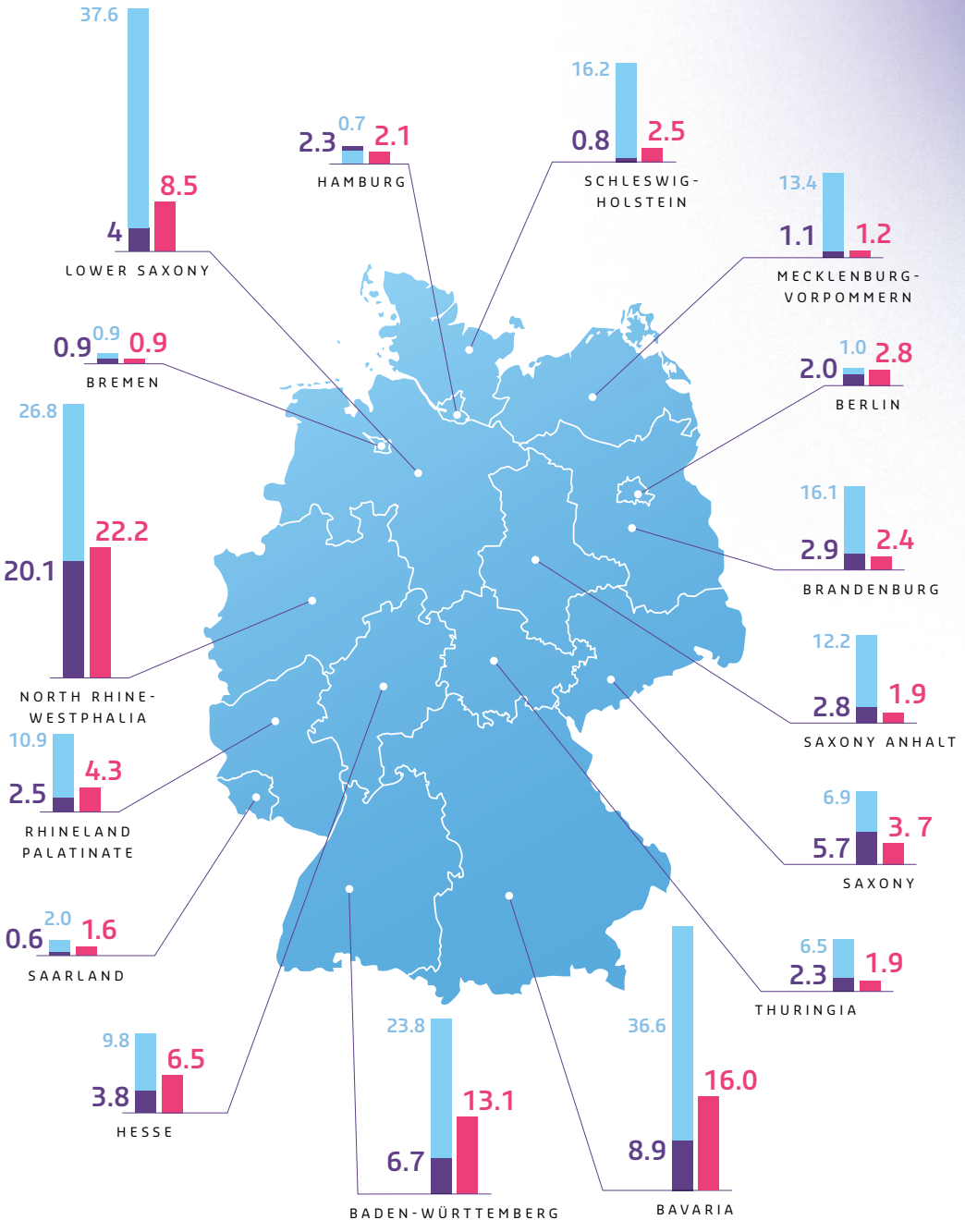
Actual figures

Target figures laid down in the 2017 amended version of the Renewable Energy Sources Act (EEG 2017)



THE 2030 POWER LANDSCAPE

In future many of Germany's federal states will not have enough reliably available capacity to cover their electricity consumption needs if the wind and sun do not deliver any energy. Only by using the grid will it be possible to import energy to make good shortfalls or, in the event of a surplus, export energy.



Installed capacity from conventional power generation in gigawatts (GW)

Installed capacity from renewable power generation in gigawatts (GW)

Maximum power usage per federal state in gigawatts (GW)

Source: Network Development Plan 2030, Scenario B

PHASE

02

ENERGY TRANSITION 2013–2025: GRIDS UNDER STRESS. EXPANSION PROGRESS. PLANNING CROSS-SECTORAL ELECTRICITY USAGE. NUCLEAR SHUTDOWN THE GUIDING PRINCIPLE.

»These days there are a number of hours each year when we are running our grid at its technical limits.«

JOACHIM VANZETTA, AMPRION SYSTEM OPERATION AND CONTROL MANAGER

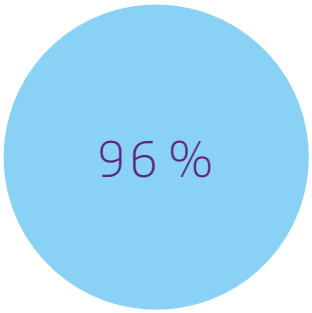
Too much stress is unhealthy. What holds true for people also applies to a power grid. This stress is generated by ever greater, sharply fluctuating, weather-dependent volumes of electricity which need to be transported elsewhere. Some days wind and solar power inundate the regional networks, and the transmission networks have to convey the electricity to the regions with the heaviest consumption. Other days the renewables produce hardly any electricity, and then gas- and coal-fired power stations must spring into action. However, more and more plants are leaving the grid because many of them cannot operate economically in competition with subsidised wind and solar power. As a result the reliably available capacity which is so vital for security of supply is diminishing. The transmission networks are under pressure. They are transporting electricity from other parts of the country as well as from other European countries.

As a result, particularly in the winter months many lines are operating close to capacity, and can offer minimal reserve capacity should others break down. A stable grid, though, is the cornerstone of a secure energy supply. “Power lines are the lifelines of the German economy, and as a transmission system operator we are responsible for them”, says Dr Hans-Jürgen Brick, Commercial Director of Amprion.

How stress management operates on the grid may be observed in Brauweiler near Cologne, where the legislators have given Amprion System Operation and Control Centre the tools needed to respond to bottlenecks in the grid. One of these is known as redispatch: Amprion’s control engineers can perform unscheduled power station ramp downs or generation increases as and when system security demands. However, even these options are eventually exhausted, and they cost a great deal of money: power station operators are compensated if their facilities are ramped down unexpectedly, as well as being paid if required to mobilise their reserves at short notice. As a result, in 2017 transmission system operators made more than a billion euros in payments in order to prevent bottlenecks. More than 100 million euros

EXTREME GRID SITUATIONS

The contribution made by renewables towards meeting the power demand in Germany



of Germany's entire electricity consumption was covered by renewable energy sources at 2 p.m. on 7 June 2017.

The proportion of consumption covered by renewable energy sources at 5 p.m. on 8 January 2017. The remaining 99.5 % was supplied by conventional power stations.

of this was attributable to the Amprion grid. These costs are met by electricity consumers.

And the number of critical situations is mounting. "These days there are a number of hours each year when we are running our grid at its technical limits, and this is a growing trend", notes Joachim Vanzetta, Amprion's System Operation and Control Manager. Accordingly it is all the more important for grid expansion to gather pace. Amprion will further increase the efficiency of its grid to ensure that it can cater for and transport significantly larger quantities of electricity fed in from renewable energy sources. Alongside the reinforcement of important existing alternating current (AC) power lines and the installation of new ones, this process will also involve the completion of vital direct current (DC) projects: A-North connects Emden with the Rhineland; Ultranet is running from there to Phillipsburg. The same applies to the expansion of the cross-border interconnectors which will further strengthen the links between the Amprion grid and the grids in neighbouring countries. One of these interconnectors is ALEGrO. In 2020 the first German-Belgian power line will commence operation. This also represents an innovative solution in another respect, as it features a DC underground cable whereby the flows of current to and from Belgium can be precisely controlled. The technology for this is known as an extra-high-voltage direct current transmission cable. It will help make the grids in Belgium, the Netherlands, Luxembourg and Germany even safer.

Fluctuations on the grid are large because ever more smaller "power stations" are producing sun-and-wind-dependent electricity. "We need to know exactly how the weather, electricity feed-in and consumption patterns are likely to change over time", says Vanzetta. "Only then can we maintain the stability of the power system. That is why efforts began some time ago to make our grid ever more intelligent." In 2019 Amprion will reach a further milestone in the digitalisation field, when the new central control station in Brauweiler comes on line. Aided by cutting-edge technology, the grid control system will process vast volumes of data on the operation and capacity utilisation of overhead power lines, underground cables and substations, as well as data such as weather forecasts and power station schedules. The new control system will collate and evaluate all of this information vir-

tually in real time, and notify control engineers of places where bottlenecks might occur, both on the Amprion grid itself and far beyond. Vanzetta and his colleagues also have the adjacent domestic and international transmission networks in their sights: the entire "observability area," in fact. This is because congestions there could also have an impact on the Amprion grid. In parallel the company is also working to set up new data flows between energy producers, consumers and distribution system operators. These will become indispensable to maintain equilibrium on the power system of the future.

However, all that will not be enough in the long term: when there is a lot of wind and sun, more renewable energy is frequently produced than can be transported at that moment, and to date there is no prospect of electrical storage facilities large enough to accommodate these surpluses. Because of this, "the energy transition is more than just a power transition", notes Professor Manfred Fischedick, Vice President of the Wuppertal Institute. He regards Germany as standing on the threshold of incipient systemic restructuring which will embrace not just the power sector but also sectors such as transport, residential accommodation and industry, and argues that the surplus electricity from renewable energy sources will be used there, in order to radically reduce carbon dioxide emissions. Kaendler shares his vision: "Alongside grid expansion, the intelligent coupling of sectors such as electricity, gas, heat and mobility will be a further step towards designing a future-proof energy system. Together with our partners we have already begun working on this."

PHASE

03

ENERGY TRANSITION 2025–2050: EXPANSION OF CROSS-SECTORAL USE OF ENERGY AND ELECTROMOBILITY. ONWARD MARCH OF DIGITALISATION. ACHIEVEMENT OF EU CLIMATE GOALS.

The energy world of the future will be based chiefly on electricity generated from renewable energy sources. The vision is one of companies that not only use energy to operate installations but also convert it into hydrogen, synthetic gas, fuels and chemicals. That way it can either be used for industrial production or stored. Private individuals will charge their cars with energy from renewable sources. “The entire economy will use green electricity”, forecasts Kaendler. “Because every kilowatt-hour of electricity from renewable energy sources helps protect the climate.”

However, every new “power station” using renewable sources, every installation converting electricity into synthetic gas, every new electric car, further increases the challenges facing the power grid. “The processes will get ever more complex”, predicts Vanzetta. “Power generation and consumption by millions of actors will have to be coordinated”. He expects the pace of digitalisation to increase, and to do so across national borders. New information and communication technologies would then help to further improve the coordination of flows of electricity within the European internal market, thereby strengthening cross-border collaboration.

On top of this come new questions to which Kaendler, Vanzetta and their colleagues are devising answers: how will we continue to guarantee data security? How can the grid be kept stable as the proportion of fluctuating renewable energy grows to 60 per cent and beyond? How can grids based on renewable energy be brought back on line after widespread breakdowns?

As yet grids and system operation and control processes are not ready to meet all these future challenges. However, research is already under way at Amprion and its partners. Thinking ahead and seeking economically sensible solutions: that is how Amprion views this task. Unlike in 1990, it is founded on a broad societal consensus – and there is a plan for the future. “Thanks to the EU climate protection goals our direction of travel has been mapped out until 2050”, Gerald Kaendler points out. Nevertheless, this much is clear: to make the third phase of the energy transition a success, we will have to put in place cross-sectoral, macroeconomic solutions. As Kaendler puts it, “restructuring our energy system is and will remain a community task, and at Amprion we will be providing important impetus.”

RENEWABLES ON THE MARCH

Generation capacities in Germany (in gigawatts)

	Nuclear power	Sun	Wind
2015	11	39	45
2030	0	66	74
2035	0	75	81

Source: Scenario Framework 2017 – 2030, Scenario B

IF

Network expansion is progressing, but it is still falling behind the expansion of renewable energy. Dr Hans-Jürgen Brick, Commercial Director of Amprion, wants to change that.

Illustration: Xenia Fink


TH
EN

IF Germany wants to obtain at least 80 per cent of its electricity from renewable energy by 2050 ...

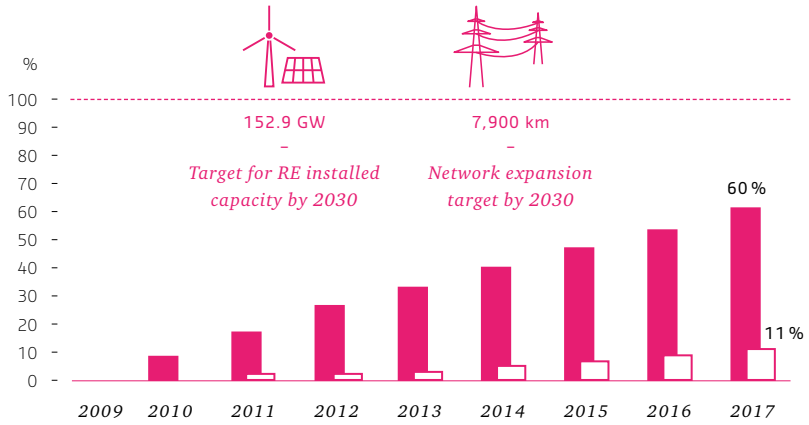
THEN we will have to prepare our grid for it right now, full speed ahead. For that reason Amprion alone will be investing almost seven billion euros over the next few years into the expansion of existing power lines and building new ones. However, we are not progressing as quickly as planned. This is not only down to new legislative requirements. All those involved in the generations-long energy transition project have experienced a steep learning curve. Network expansion must accelerate and be better intermeshed with the growth of renewable energy generation. That will enable us to reduce the grid bottlenecks which are getting ever more frequent.

IF there were fewer grid bottlenecks ...

THEN the risk of major disruption would diminish. Costs would also be reduced. Whenever we ramp down power stations or wind farms off schedule in order to keep the power grid stable, or have to ramp up the output of other facilities, it costs a lot of money. And in the end electricity consumers have to pay, and that means all of us.

RENEWABLE ENERGY IS GROWING FASTER THAN THE TRANSMISSION NETWORK

By the end of 2017 60 per cent of the renewable energy generation capacity scheduled for 2030 had already been installed. However, only 11 per cent of the grid expansion planned to cater for it had been implemented.



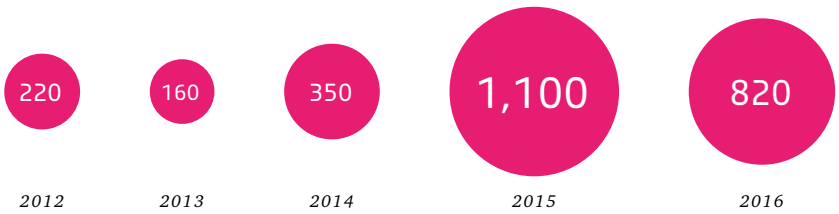
■ *Installed capacity from renewable energy sources in per cent*

□ *Implemented grid expansion in per cent*

Source: Federal Network Agency, Fraunhofer ISE, NEP 2030 Confirmation

COSTS FOR REDISPATCH, NETWORK RESERVE AND FEED-IN MANAGEMENT

in EUR millions



Source: Federal Network Agency

IF you could turbocharge the rate of the grid expansion …

THEN for one thing we would make a start with the licensing process. There is considerable scope there for cutting away red tape, for example by simplifying and accelerating the process. We could also do with adding some support from politicians to our tool kit. For instance, we would take the opportunity to use our projects to generate greater added value for the infrastructure of the region, to the benefit of private individuals and local communities alike.

IF you could explain the ins and outs to the general public …

THEN I would make it clear that we are undertaking grid expansion with people and for people. As far as possible we want to implement our projects with the consent of local people. However, we do need to make swift progress. We have an obligation to the 29 million people and thousands of businesses in our grid area who are all dependent on a secure and affordable power supply.

IF you talk to politicians responsible for energy …

THEN I sense that they are waiting for constructive proposals on how to control the cost of the energy transition. By accelerating the grid expansion process we could save billions of euros.

WESEL – DOETINCHEM

GO WEST!

In the energy sphere Europe is growing ever closer together. A visit to the work on the Wesel–Doetinchem route, where Amprion is building a new 57-kilometre power bridge between Germany and the Netherlands.

Text: Alexandra Brandt Photos: Marcus Pietrek

Novel design: between Millingen substation and the Dutch border Amprion is trialling a new type of pylon.

AMPRION – NETHERLANDS

The new power line from Wesel to Doetinchem is scheduled to increase the number of interconnectors to four from the end of 2018. Amprion is in charge of three of them.

AMPRION – BELGIUM

ALEGrO, the first power bridge between Germany and Belgium, is set to commence operations in 2020. Preliminary planning for a second connection is now under way.

AMPRION – LUXEMBOURG

Two cross-border power lines link the Amprion grid with Luxembourg. The supply capacity of the interconnector from Heisdorf to Niederstedem is scheduled to be increased in future.

AMPRION – FRANCE

Today there are already two cross-border power lines between the Amprion control area and France. The existing link from Vigy to Uchtelfangen is scheduled for future reinforcement.

AMPRION – SWITZERLAND

Three interconnectors currently link the Amprion grid with Switzerland. The power line from Beznau to Tiengen is planned for future expansion.

AMPRION – AUSTRIA

Currently three power lines cross the border between the Amprion control area and Austria. The interconnectors between Bürs and Vöhringen and between western Tyrol and Leupolz are scheduled for future reinforcement.

Securely fastened:
60 anchor bolts fasten the pylon shaft to the concrete foundations.

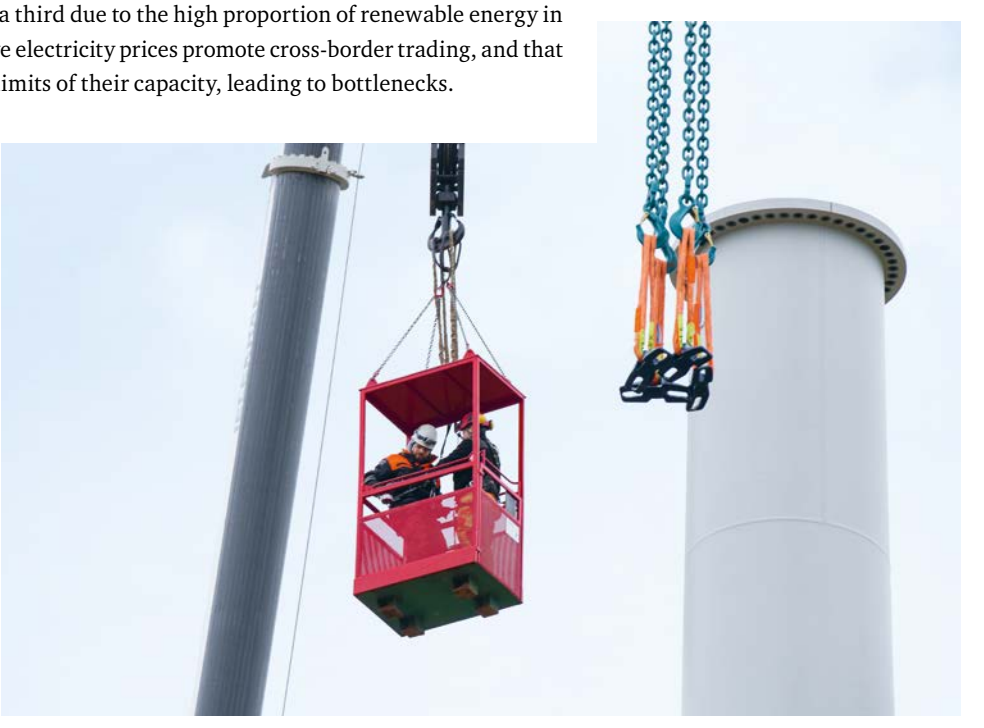
The 35-metre long tubes hang vertically from a crane. The operator manoeuvres them over the circle of anchor bolts on a concrete base and lowers the tubes carefully onto them. The tubes in question are the shafts for a new type of pylon which Amprion is erecting in Isselburg close to the Dutch border: the solid panel pylon. Once erected, they are about 60 metres tall and feature three curved cross-arms. During the project Amprion aims to gain technical and commercial experience in the erection and operation of these new pylons. In addition, the company wants to test whether the new design gains greater acceptance among the general public. “Through projects like these we extend our line construction tool kit, helping us implement every project in the optimum way”, says Dr Christoph Gehlen, Amprion’s head of power line construction.

A total of 22 solid panel pylons are being deployed along the seven-kilometre section leading up to the national border. The pylons form a visually harmonious match with the design of the Dutch Wintrack pylons which convey the power lines onward to Doetinchem in the province of Gelderland. Thanks to this cross-border connection the German and Dutch transmission network will grow even closer together. And that yields many benefits, as Martin Finkelmann, Head of Long-term Grid Planning at Amprion, explains: “The more closely we link up different grids at supra-regional level, the more secure the power supply becomes”.

»Electricity exports from Germany to its neighbouring countries rose by almost 90 % between 2011 and 2017.«

MARTIN FINKELMANN, HEAD OF LONG-TERM GRID PLANNING AT AMPRION

Today the Amprion grid is already connected with the transmission networks in the Netherlands, Luxembourg, France, Switzerland and Austria. Experts call these European power bridges interconnectors. Not only do they make national grids more secure, they also offer a platform for a Europe-wide electricity market. “Electricity exports from Germany to its neighbouring countries rose by almost 90 % between 2011 and 2017, whereas imports almost halved”, says Finkelmann. “In parallel with this the market price of electricity has fallen by a third due to the high proportion of renewable energy in Germany.” Attractive electricity prices promote cross-border trading, and that pushes grids to the limits of their capacity, leading to bottlenecks.



Major construction site: the individual components of the solid panel pylons reach 35 metres in length, and some weigh over 50 tonnes. (See above photo)

Aiming high: installing the pylon head is an aerial affair. (See left-hand photo)

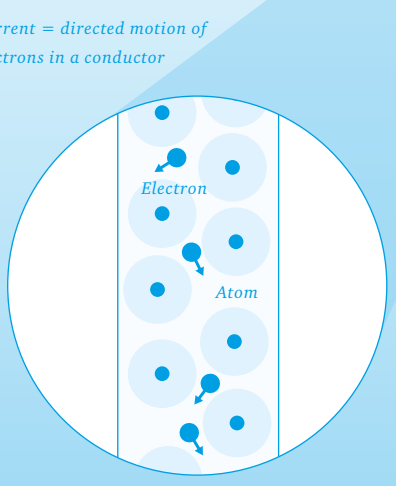
The planned power line between Wesel and Doetinchem should provide relief here. It will significantly increase the transmission capacity between the grids in Germany and the Netherlands. The three existing interconnectors can transport around three gigawatts – enough to cover the needs of around three million people as and when necessary. The new power line is expected to increase the potential transfer capacity by a further 1.5 gigawatts. To ensure that the power flows freely in future, teamwork will be needed. On the German side Amprion is constructing a power line some 30 kilometres long – seven kilometres using the solid panel pylons, with lattice steel pylons over the remainder of the route. The Dutch transmission system operator TenneT is responsible for the construction and operation of the adjoining part of the route. “In a joint feasibility study we showed that the power flows can be distributed significantly better with four interconnectors. That means we are increasing system security in both countries,” explains Martin Finkelmann. The new power bridge is scheduled to come on line in 2018, and when one enquires why it is needed in Germany or the Netherlands, the phrase “energy transition” springs to people’s lips on both sides of the border.

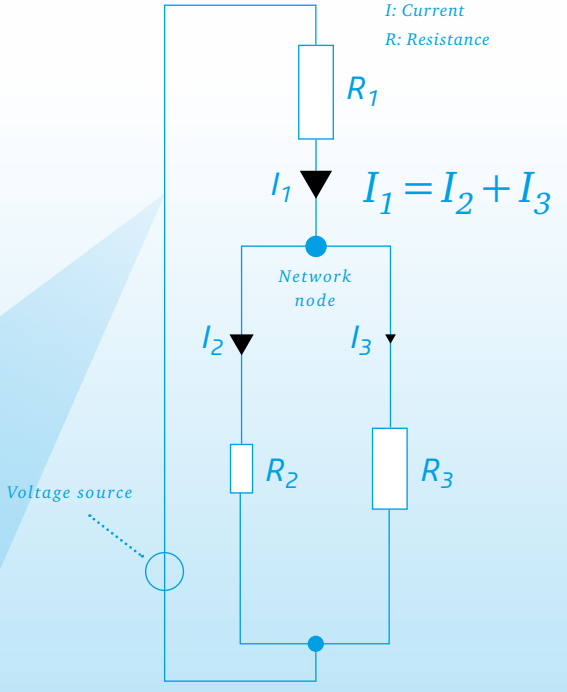
ALWAYS IN FLUX

The discoveries about electrical circuits of researcher Gustav Robert Kirchhoff shape grid planning to this day.

WHAT ARE CURRENT AND RESISTANCE?

Do you recall the physics lesson when you learnt about current, voltage and resistance? Current is the directed motion of electrical charge carriers, namely electrons, through a conductor. Voltage is the driving force behind this motion. When electrons pass through a conductor they bump into the atoms of the conductor material. In the process part of the electrical energy is converted into heat. This impeding of the current's flow is known as resistance. Its strength depends among other things on the material of which the conductor is made and its length: the shorter the conductor the less the electrons are impeded and the smaller the amount of electrical energy lost as heat.

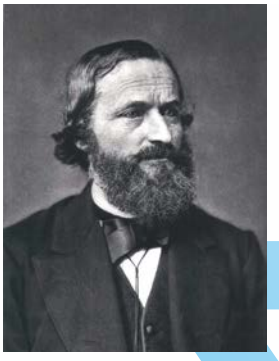




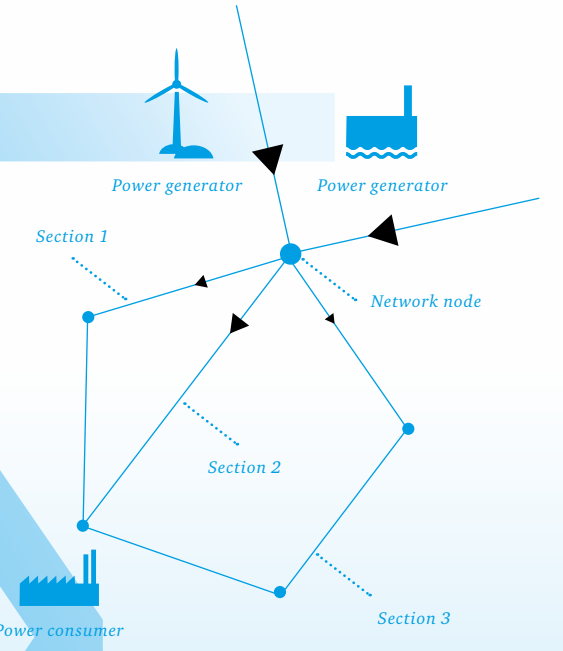
$$\frac{I_2}{I_3} = \frac{R_3}{R_2}$$

HOW DOES CURRENT BEHAVE AT A NETWORK NODE?

One of the pioneers of electrical theory was Gustav Robert Kirchhoff. In 1845 he proposed a law governing the behaviour of current at a junction in a direct current network. Experts refer to this as a parallel circuit (see above graphic), at which the current I_1 divides into sub-currents, here called I_2 and I_3. This occurs in inverse proportion to the resistance of the respective conductors, here termed R_2 and R_3. This means that wherever the resistance is lower (R_2) more current (I_2) flows.



Pioneer of electrical theory:
Gustav Robert Kirchhoff
(1824 – 1887)



Direct current: electrical current whose direction does not change over time.

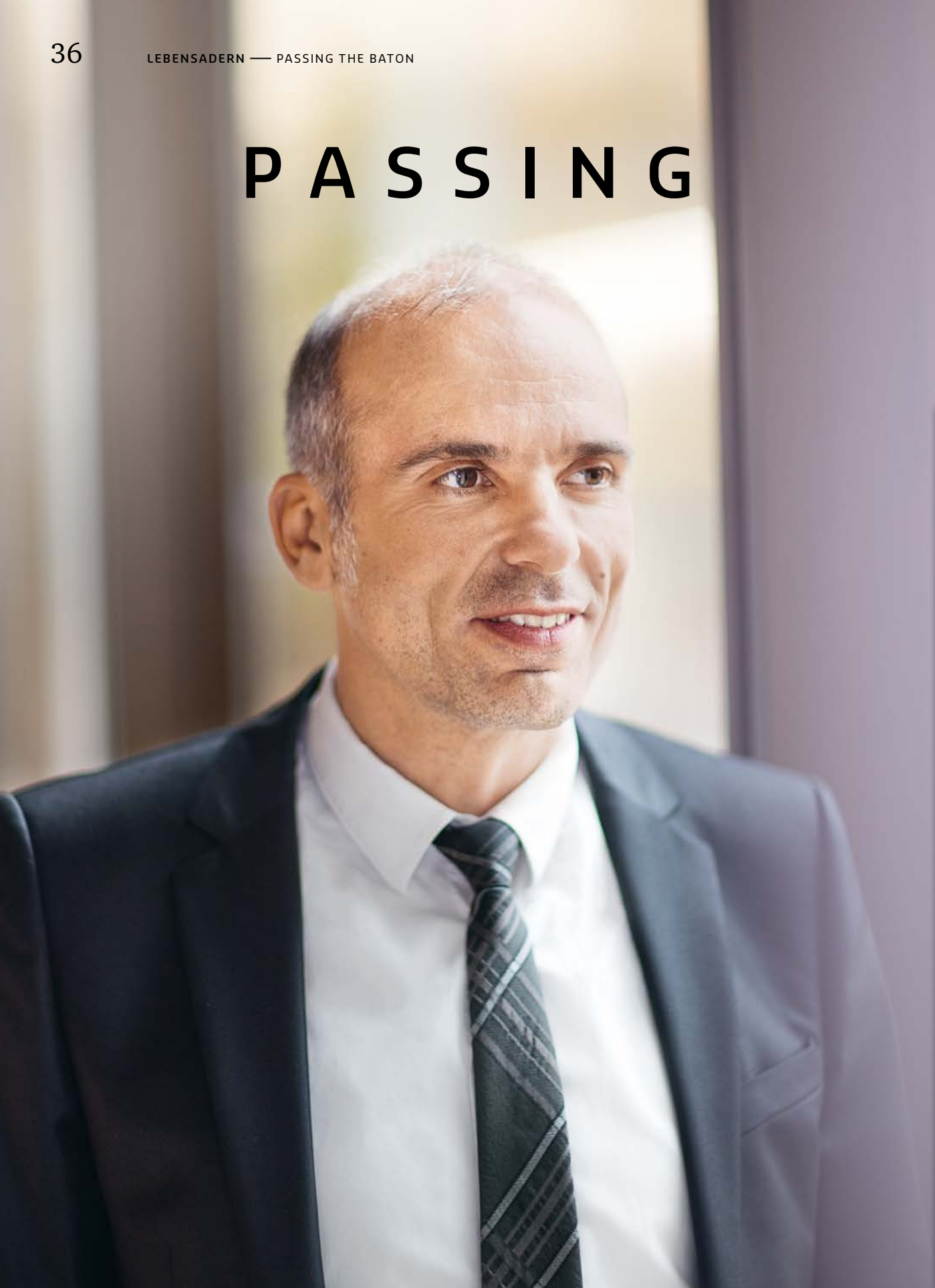
Alternating current: current which changes its direction (polarity) at regular intervals. Takes the form of a sinus curve.

HOW DOES CURRENT FLOW IN A MESHED POWER GRID?

To put it simply, the current in the grid follows the line of least resistance. It divides at network nodes in accordance with the respective resistances of the subsequent sections. Kirchhoff's Law allows these current flows to be calculated. The interconnected grids in Germany and Europe operate on alternating current. Rather than resistance these are subject to impedance, from the Latin for "inhibit" or "impede".). However, here too Kirchhoff's Law applies, provided the elements in the circuit may be described as concentrated components. The current splits in accordance with the impedance relationships of parallel sections of the network. In our example (see above graphic), most of the current flows through section 2.

To this day these physical laws govern the operation and expansion of the transmission network.

PASSING



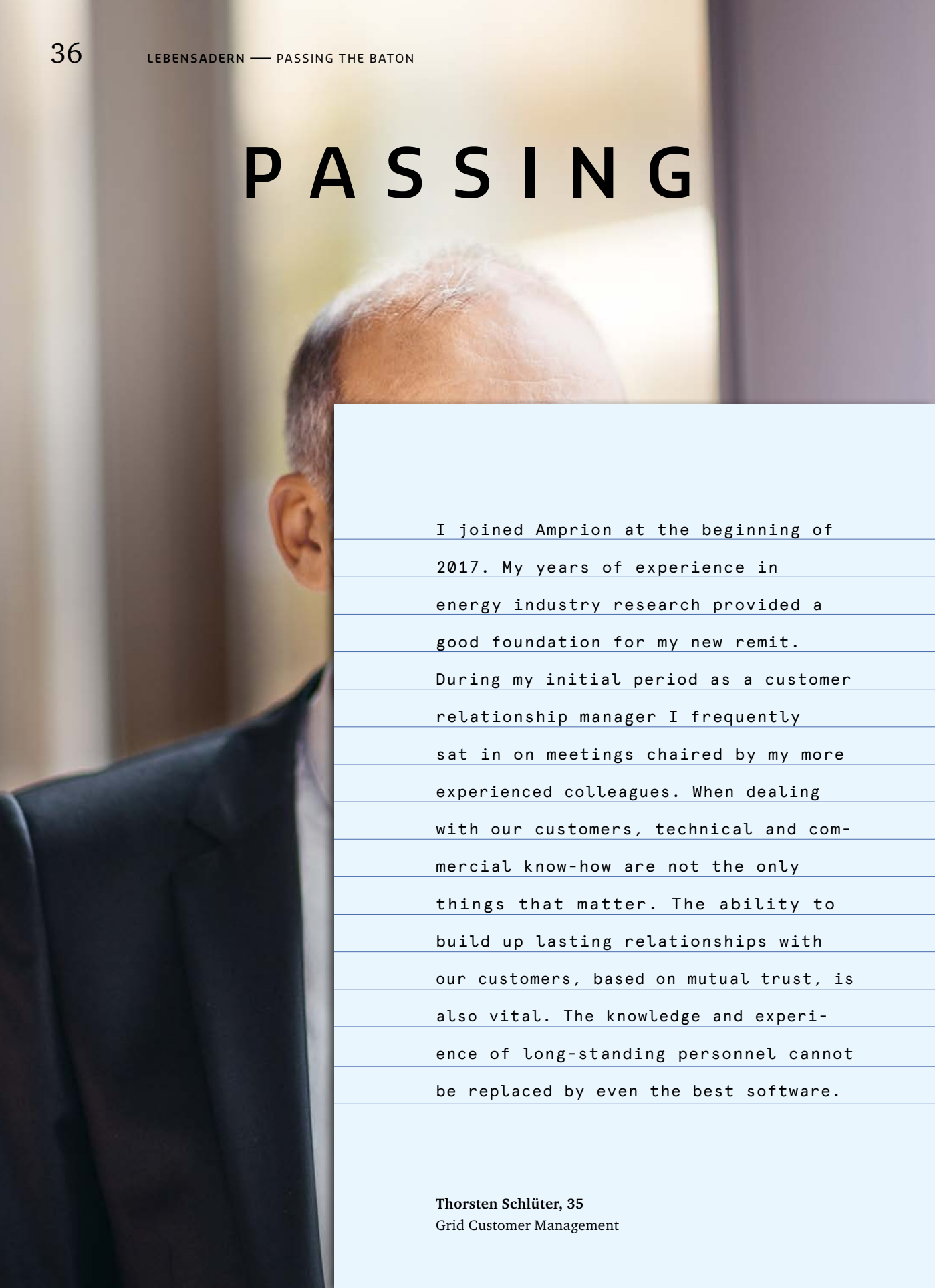
THE BATON

Amprion depends on the know-how of its personnel. Experts therefore pass on their accumulated experience and knowledge to younger colleagues – a process not limited to technical questions.

During the energy transition the tasks of a grid customer manager have steadily increased in number and above all become more diverse. We expect new personnel to have the ability to focus separately on each individual customer. Against this backdrop we often have to come up with new solutions for any given project, and that is when the experience of long-standing employees and the ideas of new personnel complement each other ideally. Thorsten Schlüter ensures that the whole process runs smoothly. He has already begun supporting customers to take the strain off the team.

Thomas Christian Küpper, 50
Head of Grid Customer Management

PASSING

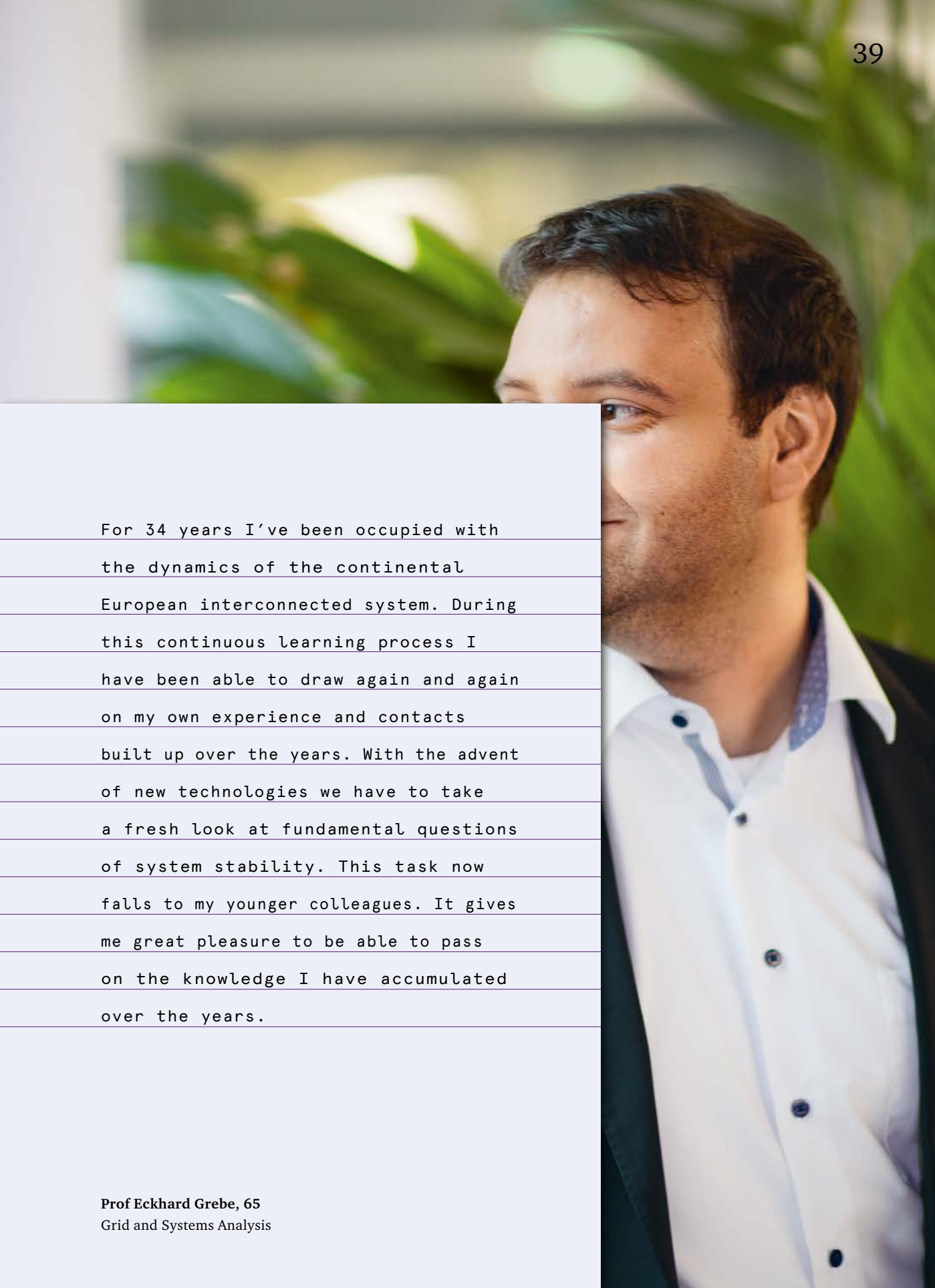


I joined Amprion at the beginning of 2017. My years of experience in energy industry research provided a good foundation for my new remit. During my initial period as a customer relationship manager I frequently sat in on meetings chaired by my more experienced colleagues. When dealing with our customers, technical and commercial know-how are not the only things that matter. The ability to build up lasting relationships with our customers, based on mutual trust, is also vital. The knowledge and experience of long-standing personnel cannot be replaced by even the best software.

Thorsten Schlüter, 35
Grid Customer Management

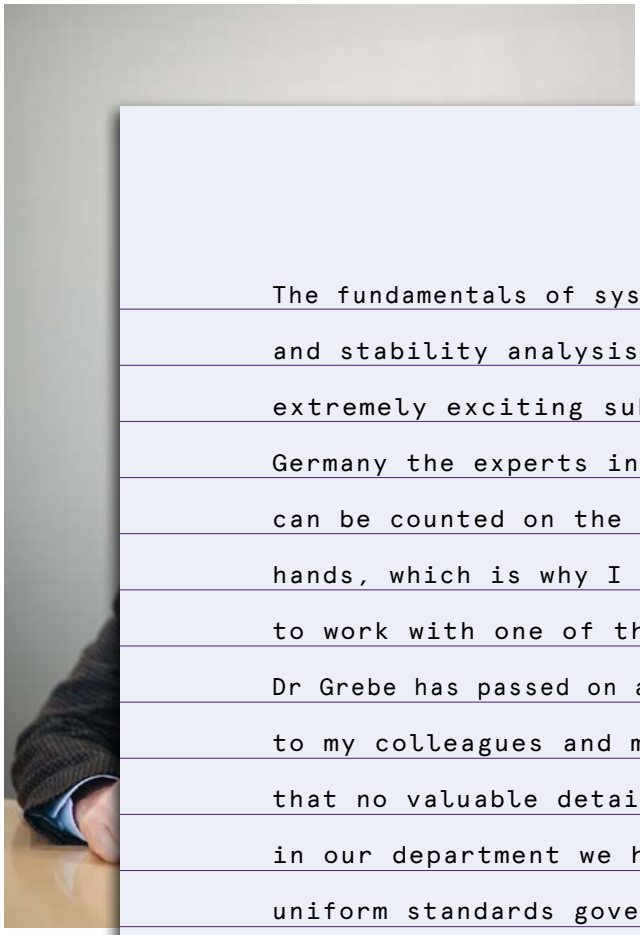
THE BATON

Amprion depends on the know-how of its personnel. Experts therefore pass on their accumulated experience and knowledge to younger colleagues – a process not limited to technical questions.



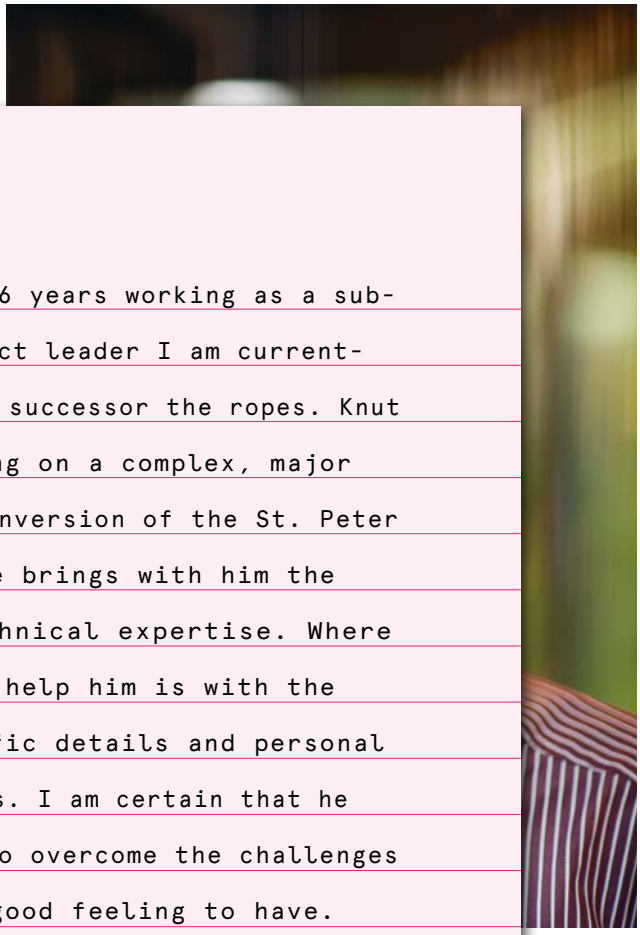
For 34 years I've been occupied with the dynamics of the continental European interconnected system. During this continuous learning process I have been able to draw again and again on my own experience and contacts built up over the years. With the advent of new technologies we have to take a fresh look at fundamental questions of system stability. This task now falls to my younger colleagues. It gives me great pleasure to be able to pass on the knowledge I have accumulated over the years.

Prof Eckhard Grebe, 65
Grid and Systems Analysis



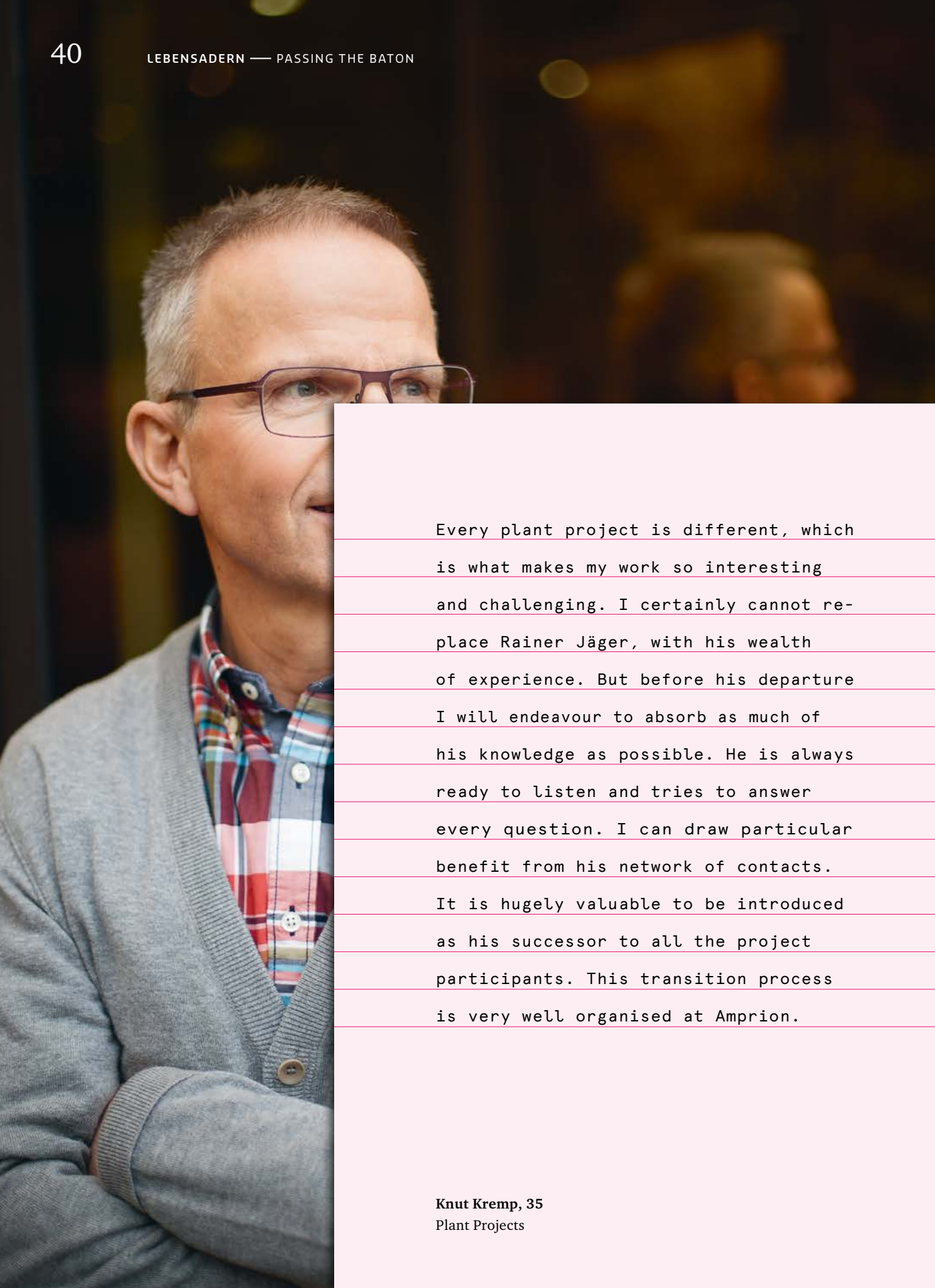
The fundamentals of systems engineering and stability analysis make for an extremely exciting subject area. In Germany the experts in this field can be counted on the fingers of two hands, which is why I was so keen to work with one of them at Amprion. Dr Grebe has passed on a great deal to my colleagues and me. To ensure that no valuable details get lost, in our department we have laid down uniform standards governing know-ledge transfer, and in-house experts support us in their implementation.

Dr Tobias Hennig, 30
Long-term Grid Planning



After almost 36 years working as a sub-stations project leader I am current-ly teaching my successor the ropes. Knut Kremp is taking on a complex, major task in the conversion of the St. Peter substation. He brings with him the necessary technical expertise. Where I am happy to help him is with the project-specific details and personal recommendations. I am certain that he will be able to overcome the challenges he faces - a good feeling to have.

Rainer Jäger, 59
Plant Projects

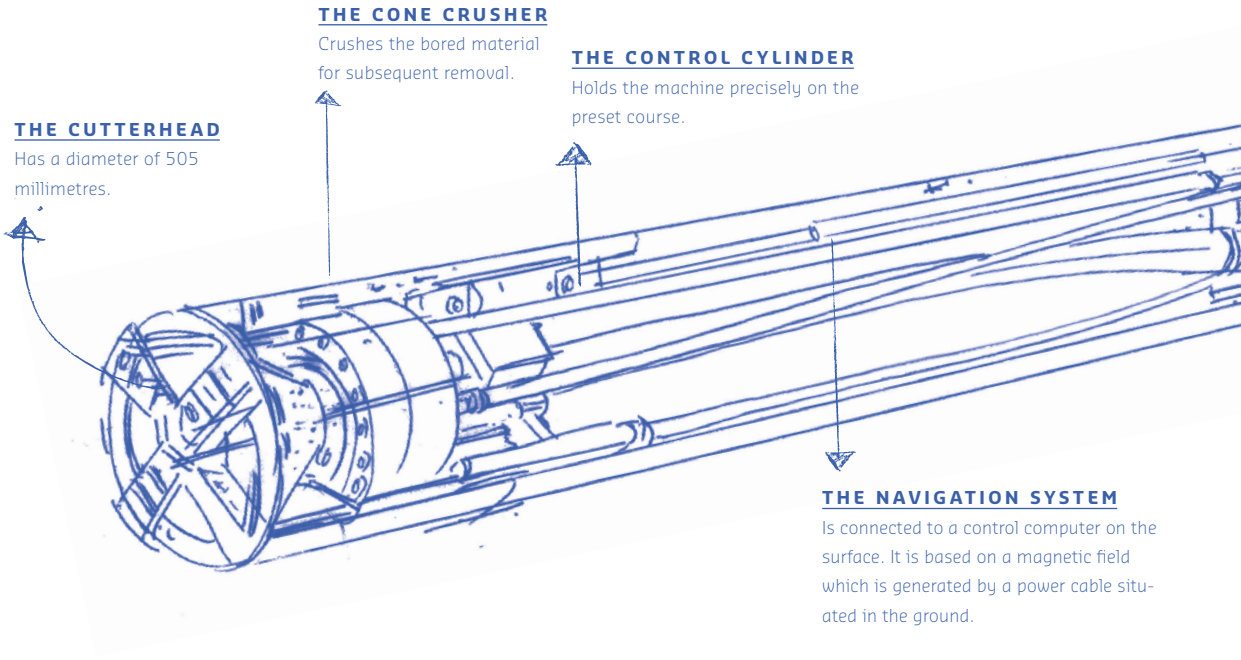


Every plant project is different, which is what makes my work so interesting and challenging. I certainly cannot replace Rainer Jäger, with his wealth of experience. But before his departure I will endeavour to absorb as much of his knowledge as possible. He is always ready to listen and tries to answer every question. I can draw particular benefit from his network of contacts. It is hugely valuable to be introduced as his successor to all the project participants. This transition process is very well organised at Amprion.

Knut Kremp, 35
Plant Projects

BORING THROUGH INSTEAD OF BURROWING DOWN

Precisely laying up to 1,000 metres of underground cable without having to dig a continuous trench: that is the aim of the innovative E-Power Pipe® tunnel boring technique which Amprion has developed together with boring specialists Herrenknecht and RWTH Aachen University, funded by the Federal Ministry for Economic Affairs and Energy.



25
REVOLUTIONS PER MINUTE

Approx. 1,000 m
TUNNELLING LENGTH

+/- 5 cm
DEVIATION FROM THE IDEAL LINE

1,000 m

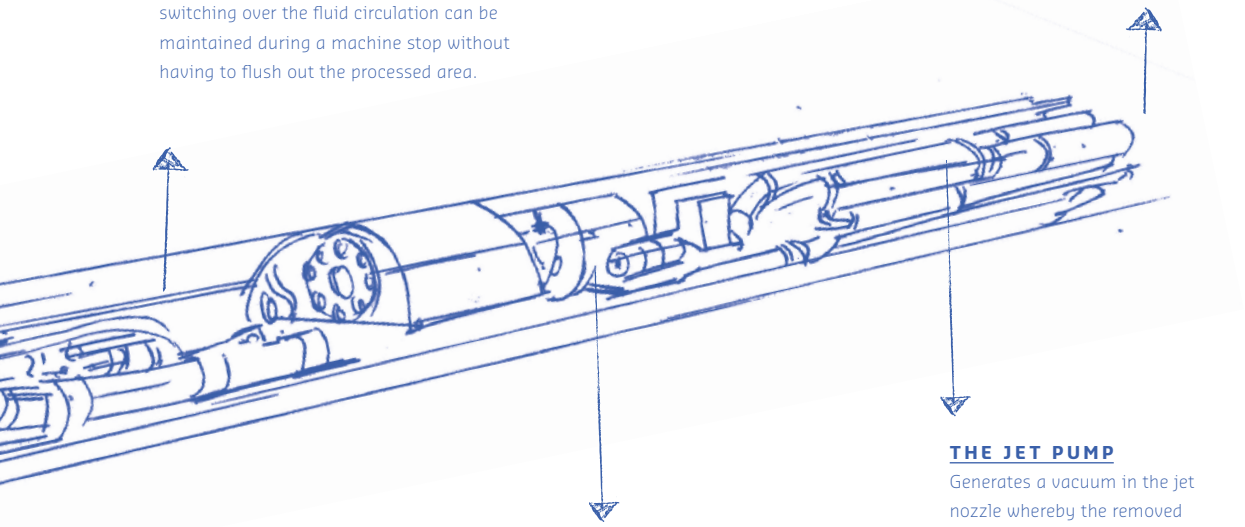
CABLE LENGTH

THE JACKING PIPES

Are successively inserted into the launch shaft, thus forming a closed pipe string. They simultaneously provide the power supply for the machine and allow the removal of the soil via hydraulic circulation.

THE BYPASS

Is part of the supply and slurry circuits. By switching over the fluid circulation can be maintained during a machine stop without having to flush out the processed area.



THE JET PUMP

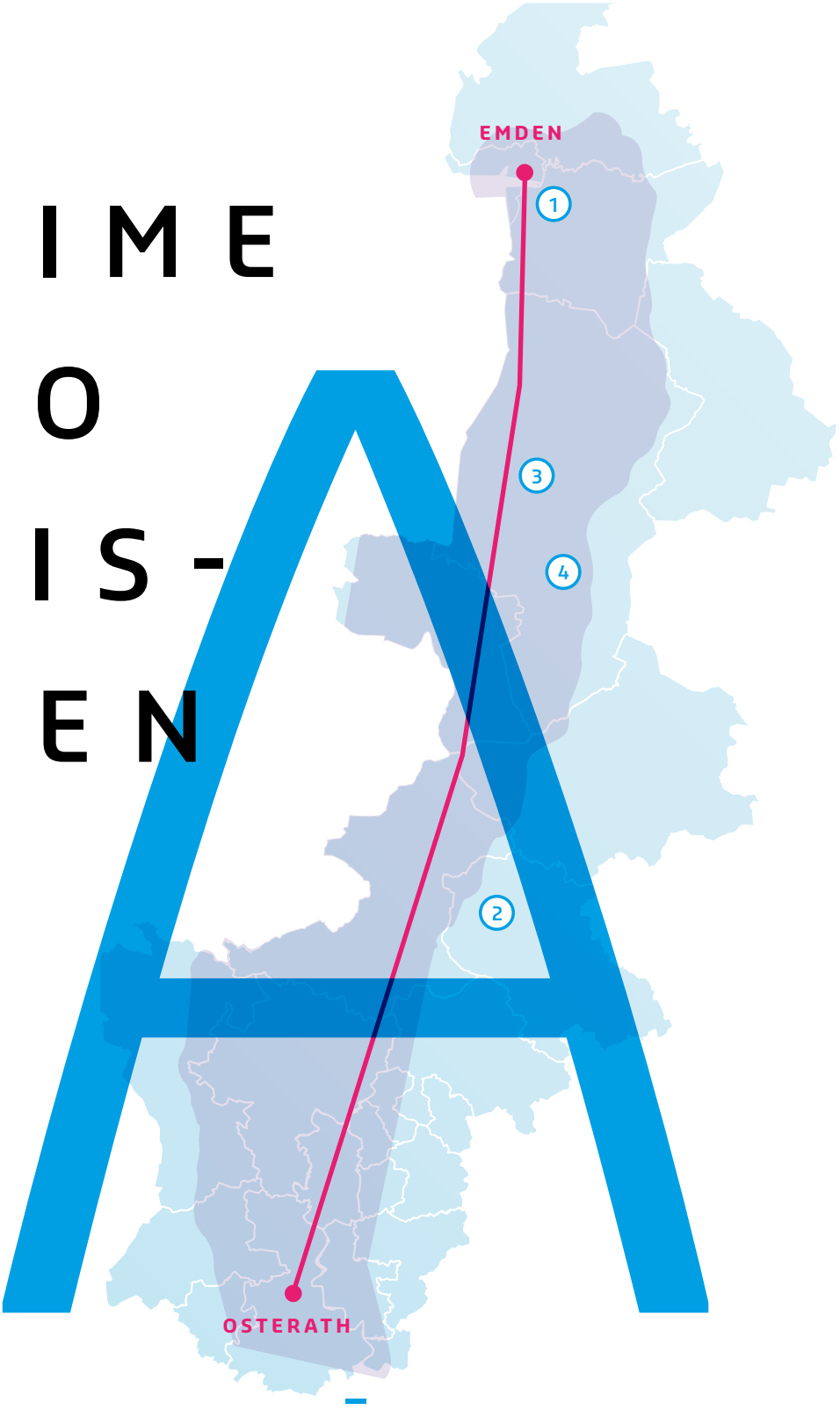
Generates a vacuum in the jet nozzle whereby the removed soil and the slurry can be flushed out through the suction pipe.

THE HYDRAULIC UNIT

Provides up to 22 kW for the propulsion of the cutter head.

Successful pilot project: in spring 2017 Amprion and Herrenknecht tested the new technique under real conditions for the first time in the town of Borken in North Rhine-Westphalia. Three parallel, 300-metre-long borings with a depth of 2.5 metres were made. Under the local conditions, best performances of up to 126 metres of tunnelling per day on the pilot boring demonstrated the effectiveness of this tunnelling technique. "Using E-Power Pipe® we hope to gain benefits during the execution of future cable-laying projects, for example when we have to tunnel beneath roads, railway lines or areas with delicate surfaces", notes Dr Jan Bruggmann, head of Amprion's Cable Technology and Construction Department. However, further tests will be needed. Only after gathering sufficient experience will Amprion add this new technique to its tool kit.

TIME TO LIS-TEN



NORTH

In the search for the best route for the A-North wind power connection Amprion is involving local people at an early stage. What concerns the region's residents, farmers and local politicians?

»How does Amprion decide where a converter should be built?«

1 **HERMANN WESTERMANN,** FARMER, EMDEN

A-North Project Team: Our search for a location for the northern converter takes the Emden East grid connection point as its launch-pad. The legislators have ordained that this substation is where A-North must be connected with the existing transmission network. We are required by law to look for a suitable site within a ten-kilometre radius of that point. In doing so we initially applied the exclusion principle, whereby environmental protection areas and heavily populated areas are ruled out as potential locations for the converter. Other sites were unsuitable for technical or construction-related reasons. Thereafter we conducted a comparative assessment of the remaining locations. Among the criteria applied here are residential environment protection, that is the visibility of the facility or its distance from residential areas, as well as traffic links. In addition it must be possible to connect the location both to our DC underground cable and to the line linking it with the substation at the Emden East grid connection point. Once we have found what we regard as the most suitable location, we shall apply for permission from the Trade Supervisory Office in Emden to build the converter.

» Many people prefer underground cables to overhead power lines for DC transmission. In the event of underground cable breakdowns, can an adequate energy supply and prompt repair be guaranteed? «

② **INGRID ARNDT-BRAUER** (SPD), MEMBER OF THE GERMAN PARLIAMENT, BORKEN CONSTITUENCY

A-North Project Team: When we design an underground cable installation, we give special attention to ensuring that we will be able to transmit electricity at all times, securely and without breakdowns. That is why we are laying A-North as two separate systems, each with a capacity of one gigawatt. This would meet the needs of around two million people in total. When one system needs repairing we can take the faulty cable off line while the intact cable continues to transmit electricity. Thus our two systems are flexible in design. Moreover, we can disconnect faulty components so that the underground cable installation can continue operating with a reduced capacity. In addition, to permit swift repairs no buildings may be constructed within a 24-metre-wide protective strip around the cable installation. This ensures that the cable is accessible at all times.

»What opportunities do the general public have to get involved in the route planning?«

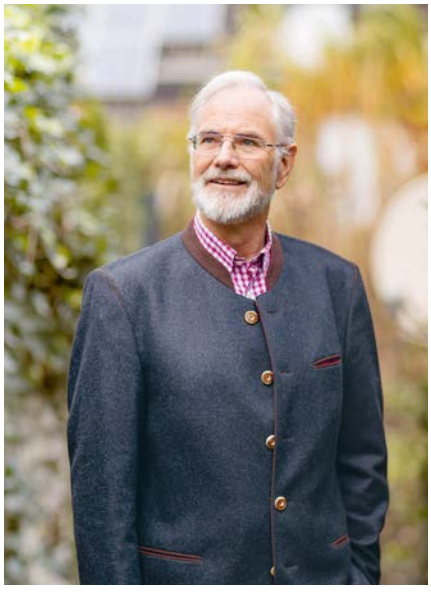
3 **MANFRED WELLEN,** MAYOR OF WIETMARSCHEN MUNICIPALITY

A-North Project Team: As with every project, we want to plan A-North as transparently, comprehensibly and consensually as possible. To be able to take on board plenty of input from the region we began the dialogue at an early stage – with town and parish councils, agricultural and environmental associations and the general public. The process was launched with the presentation of possible route corridors in summer 2017. People likely to be affected were able to make suggestions by email, post, on our online participation platform or at public events. We have scrutinised these in depth and, wherever possible, incorporated them into our planning. As a result we have made further adjustments to our corridor variants at numerous locations. We shall now submit these proposals to the Federal Planning for Transmission Systems, as the formal approval process is known, and which also offers ample opportunities to participate. Every resident is entitled to voice an opinion there. The same applies to the subsequent planning approval procedure, in advance of which we shall be presenting detailed planning, again at an early stage, to a wider public.

»Why can't major power lines like A-North always be put alongside motorways?«

4 **DR HANS-PETER BÖHM,** RESIDENT, RHEDE

A-North Project Team: When planning a new power link the legislators have imposed the bundling requirement, which states that, wherever possible, a new route must follow the course of existing infrastructure. This includes existing electricity lines, gas and oil pipelines and motorways, major roads and railway lines. The aim is to preserve open countryside and minimise any new disruption. However, such bundling can only come about if no technical or area planning considerations stand in the way. In principle, then, we could lay A-North alongside the motorway. There is a rule that no structures may be built above ground within 40 metres of a motorway, but as A-North will be an underground cable this would be no problem. Experience from previous projects has shown us, though, that the areas next to motorways are littered with obstacles to construction work such as entry and exit roads or rest areas. On top of this come industrial/commercial areas and the woodland which often grows up very close to motorways. All of this means that very little room is left there for our cable installations.



WE ARE ALL EARS!

10 ears are pricked,

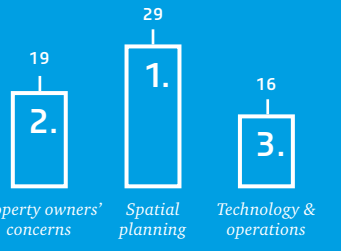
so that that no questions remain unanswered at an Amprion information market. The ears belong to the average of five experts who attend these dialogue events. They come from Amprion's grid planning, project planning, project communication and legal departments. In addition, representatives of the licensing authorities are often also present.

» Without dialogue, no consensus. We listen, find out and explain. That's how we make our project planning transparent and comprehensible. «

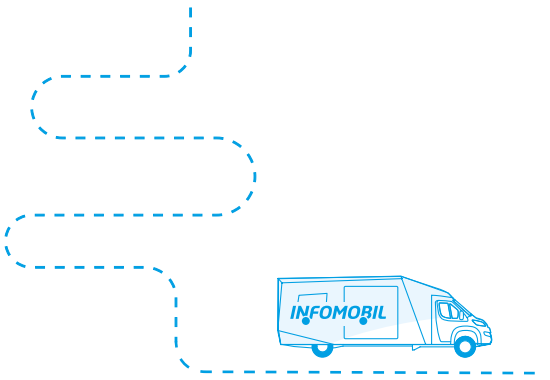
JONAS KNOOP, A-NORTH PROJECT SPOKESMAN

TOP 3

What concerns people about A-North



At an early public consultation at the start of 2017 Amprion surveyed more than 90 representatives of district or town councils and the associations. They gave us some valuable suggestions for the project planning and communication processes.



3,816 km

THE DISTANCE ON THE CLOCK OF THE NEW AMPRION INFOMOBILE AFTER JUST FIVE MONTHS – DESPITE SPENDING MOST OF THAT TIME PARKED IN MARKETPLACES OR OUTSIDE TOWN AND VILLAGE HALLS. THAT IS BECAUSE IT SPENDS MOST OF ITS TIME IN RURAL AREAS TO SPREAD INFORMATION THERE ABOUT THE GRID EXPANSION.

You ask, we answer

Anyone wanting to find out online about Amprion and our grid expansion projects, or ask questions about them, has plenty of options:

At www.direktzu.de/amprion Amprion experts answer selected questions about the company, grid expansion and individual projects. Users decide which questions get answered: contributions receiving the most votes are passed on to the experts to be answered.

The www.amprion.net website mainly offers information about the company and what it does. Under the heading "Dialogue" you can find the contact details of project spokespersons. They are available to answer questions about expansion plans.

The www.a-nord.net website provides information on the A-North project, as well as details of upcoming events and the minutes of past dialogue events. The contact form can be used to ask questions.

519

citizens' information markets and other dialogue events

about the grid expansion were organised by Amprion in 2017. The programme included around 100 events for the A-North project alone. At the events Amprion presented possible route corridors for the planned DC link from the North Sea to the Rhineland. Another focal point was dialogue events on the Ultranet project in the south of North Rhine-Westphalia, Rhineland Palatinate and Baden-Wurttemberg. For the first time, in places where there was no suitable space for a citizens' information market Amprion used its own Infomobile.


GERALD KAENDLER (50)


MARCEL KURTH (29)


ANDRÉ HOFFRICHTER (29)


JANEK MASSMANN (28)

LATERAL THINKERS WITH THEIR FEET ON THE GROUND

Amprion actively seeks contacts with young scientists to find solutions for the energy world of tomorrow. With this in mind Gerald Kaendler, Head of Asset Management, went to Aachen.

Interviewer: Volker Göttsche Photos: Matthias Haslauer

In a seminar room at RWTH Aachen University's Institute for High Voltage Technology Gerald Kaendler meets the postgraduate students André Hoffrichter, Janek Massmann and Marcel Kurth. All three have studied electrical engineering, are working at the institute while pursuing their postgraduate studies and lead research teams: Hoffrichter researches stationary network analysis and system evaluation, and Massmann system stability. Kurth heads the grid planning and grid operation team. None of them need worry about their professional futures, as the RWTH is regarded as one of the country's finest technical universities.

BACK AT UNI, MR KAENDLER. A GOOD FEELING?

GERALD KAENDLER: Yes, it certainly takes me back. I myself studied at RWTH Aachen University. In those days the energy world was still tranquil and inward-looking. Today we are preoccupied as transmission system operators with the energy transition and all the challenges that it throws up. This always entails a risk of becoming to some extent blinkered in our thinking, underestimating developments and only developing solutions along familiar pathways. Science, on the other hand, can think more freely and laterally.

MR HOFFRICHTER, YOU GRADUATED IN ELECTRICAL ENGINEERING AND ARE CURRENTLY WORKING ON YOUR DOCTORATE. ARE YOU A LATERAL THINKER?

ANDRÉ HOFFRICHTER: A lateral thinker with his feet on the ground, I'd say. Here at the Institute for High Voltage Technology we take a whole lot on board thanks to the research contracts we receive. On top of that, in recent years we have created on our computers a digital representation of the energy world on which we can simulate developments and play through the consequences of decisions. That sometimes involves some crazy things. But on the other hand we need feedback from practical applications: what can actually be used? What really preoccupies the energy industry? Where can we provide concrete help?

WHAT QUESTIONS RELATING TO THE ENERGY TRANSITION MOST CONCERN YOU, MR KAENDLER?

KAENDLER: In 2030 will we be able to provide households and business in Germany and Europe with a secure supply of energy at all times? In other words, will the lights stay on if our electricity is generated predominantly from renewable energy? With their sharp fluctuations and the changes to the conventional fleet of power stations, renewables are taking the power grid

close to its limits ever more often. Particularly in winter we are struggling. More and more frequently, in order to circumvent bottlenecks in the transmission network we have to make unscheduled generation cutbacks in some places while ramping generation up in others. The cost of this to the economy runs into the billions. Our goal must be to reduce the cost to the economy and thus relieve the burden on electricity consumers.

MARCEL KURTH: I take the view that for a stable grid we need not only grid expansion but also more flexibility in the energy system. More components and technologies with which we can respond to sudden, sharp changes in energy generation. One example of this for me is "power-to-gas" technology. This involves converting green electricity into synthetic gas whenever more is produced than can be used at that time. Industry can then process this raw material, or power stations can use it to generate energy. The demand for such solutions is extremely high.

» For a stable grid we need not only grid expansion but also more flexibility in the energy system. «

MARCEL KURTH
POSTGRADUATE STUDENT, RWTH AACHEN

HOFFRICHTER: This is a trend I can also see. At the end of the day we will have a power system with many more highly diverse components and actors than the current one. A system make-up, comparable with an orchestra, composed of renewable energy, conventional power stations, storage facilities, cross-sectoral technologies and many electricity-driven plants and appliances.

KURTH: This system will also include electrical heating. We are currently working on a project looking into whether night storage heaters can help us make electricity consumption more flexible. For example, consumers could charge up the electrical heating when the wind is blowing strongly and correspondingly large amounts of wind-generated electricity are available. We therefore talk about "wind heating".

KAENDLER: An intriguing example. Would electricity consumers accept this and charge up their heating systems on a weather-dependent basis?

KURTH: That's a tricky question. A similar one confronts us in the sphere of electromobility. Let's assume there are a million electric cars on the road. We would prefer to charge them at night, even though we might not want to set off until noon the following day. However, this simultaneous charging places an enormous strain on the grid. It would be preferable for the charging to be spread over time, based on when I actually want to use my electric car. So I'd have to register that in advance, and in return I'd get a cheaper rate. It would be interesting to conduct a study into consumer willingness.

JANEK MASSMANN: That is perhaps also a question of generations. We know no other world than one in which unlimited electricity is available at all times. However, might it not at some point become normal for consumers to adapt to new rules which create flexibility in the system for us?

EVERYBODY IS TALKING ABOUT SAVING ENERGY. BUT WON'T ELECTRICAL HEATING AND ELECTRIC CARS SIGNIFICANTLY INCREASE DEMAND FOR ELECTRICITY?

KURTH: In the long term demand for electricity will rise, in defiance of all the efficiency measures. We will notice that above all in urban areas where the demand for heat and mobility is highest.

MASSMANN: And if that happens, it will also make itself felt on the transmission networks.

KAENDLER: It would mean that we would have to make upward adjustments to our grid expansion planning. And we would also have to be able to plan for transmission network reserves. Currently we are not allowed to engage in this kind of advance planning. Metaphorically speaking, what I'd like to do is build a house with two spare rooms for future children.

HOFFRICHTER: I hope that flexible components such as wind heating will make a contribution to bringing the timing of electricity generation and consumption into step.

MASSMANN: For that we'll need models, though, and also in future new control strategies. The system on which we work today comes from a different world entirely.

KURTH: Maybe then we'll have to realign the relationship between electricity consumption and generation. As an electricity consumer, I would then receive a set daily amount of electricity with which to operate my household appliances. A control unit would then decide in real time where this electricity comes from: directly from a wind turbine, from the car battery or from a power station driven by synthetic gas.

KAENDLER: Given such a scenario, does an electricity market, functioning the way it currently does, even make sense? Or would we have to come up with new ways of doing things here too?

MASSMANN: The fundamental task of the market is to efficiently coordinate power generation and consumption. That makes sense in a system in which conventional energy sources with differing variable costs are in competition with each other. Once we have a situation where there is almost nothing other than subsidised renewable energy in the system, this market becomes superfluous in any case. In such a system it would make more sense not to pay generation facilities according to the amount of energy they deliver but for generally making power available to the system. When flexible consumers such as power-to-gas plants or wind heating procure electricity, the process would be controlled by the system.

HOFFRICHTER: It would be very useful to scientifically research what added value such a new system could offer.

» Given such a scenario, does the current electricity market even make sense? «

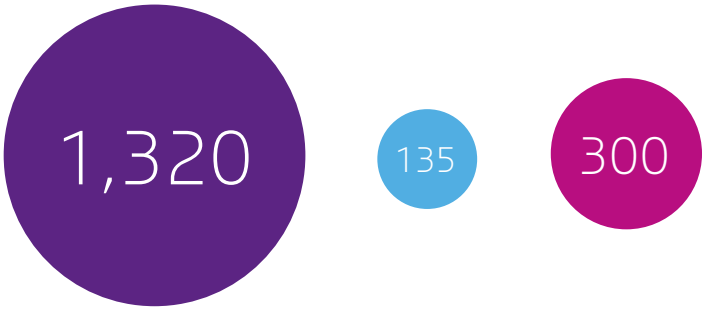
GERALD KAENDLER
HEAD OF ASSET MANAGEMENT AMPRION

LESS MARKET, MORE CONTROL AND NEW REGULATIONS FOR CONSUMERS: IS THAT WHAT AWAITS US IN THE ENERGY WORLD OF TOMORROW?

KAENDLER: The energy system is changing with incredible dynamism. I am convinced that we will meet the challenges we face. However, both as scientists and as transmission system operators we must not shy away from our duty to voice unpleasant truths if we identify them. After all, who other than experts can do that? And we would be well advised to be prepared for anything. Let's take the market model, for instance: all our planning is based on current market price effects. But how far will this model take us in the energy world of tomorrow? Or let us assume for the sake of argument that electricity demand really does increase. What would that mean for our grid expansion planning? All these are questions I'll be asking myself after our discussion. We will all have to think laterally, I guess.

NETWORK EXPANSION AT AMPRION

Amprion is making its transmission network fit for the future. The expansion is based on the Energy Grid Expansion Act (EnLAG) and the Federal Requirement Plan Act (BBPlG).



Awaiting or undergoing approval | *Under construction* | *Completed*

In km

In 2017 many of our projects moved from the preparation stage to the official approval process. In addition, during the year we received approval for a total of 57 kilometres of line, the majority of which are now under construction.

519

Citizens' information markets and other grid expansion dialogue events organised by Amprion in 2017.

€ 702 MILLION

Invested by Amprion in 2017 on the modernisation and expansion of our grid.

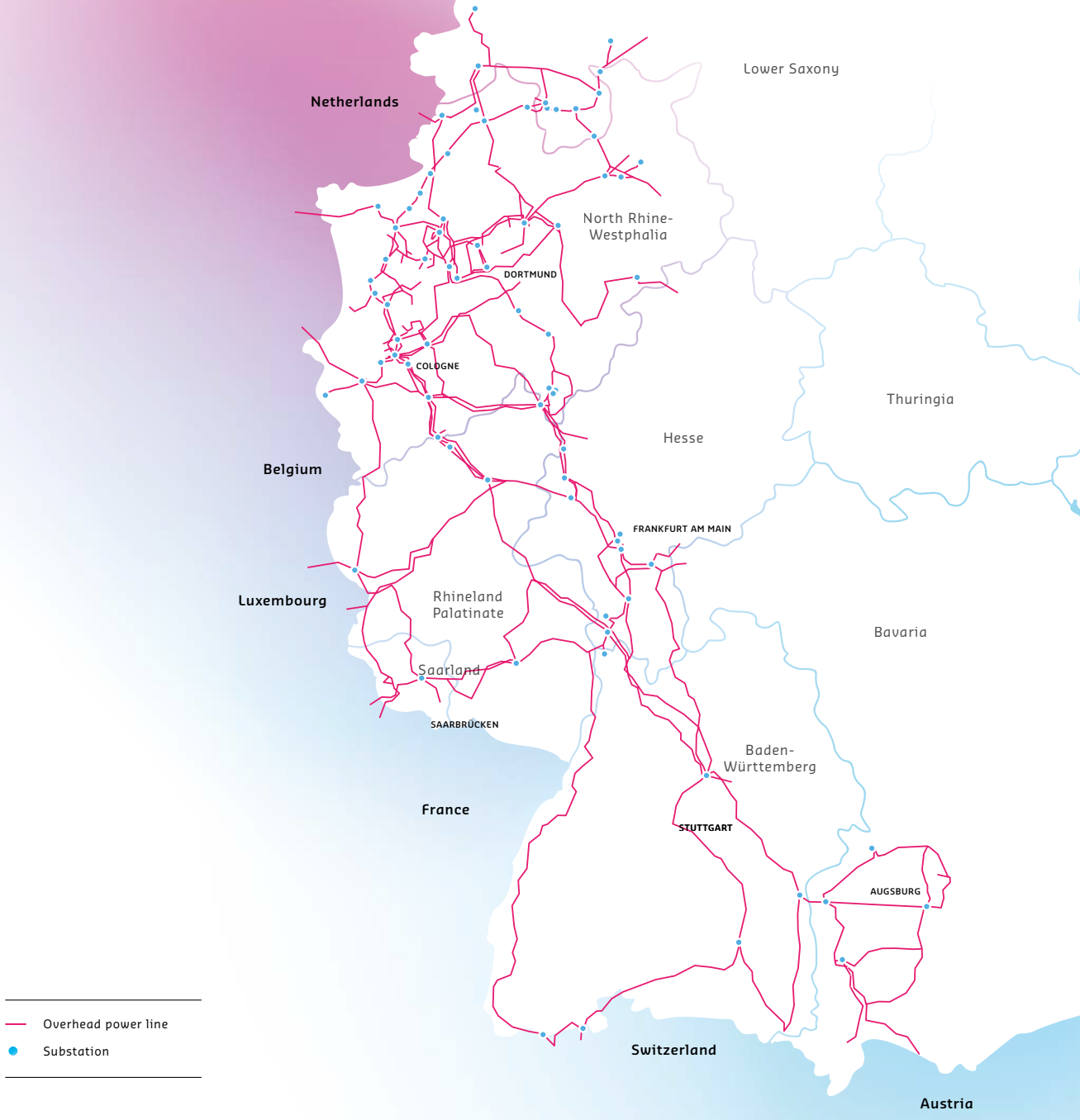
110

The average number of Amprion construction sites running in parallel.

2,000 KM

Power lines which Amprion intends to build or upgrade by 2027, investing some 6.8 billion euros in the process.

THE AMPRION GRID



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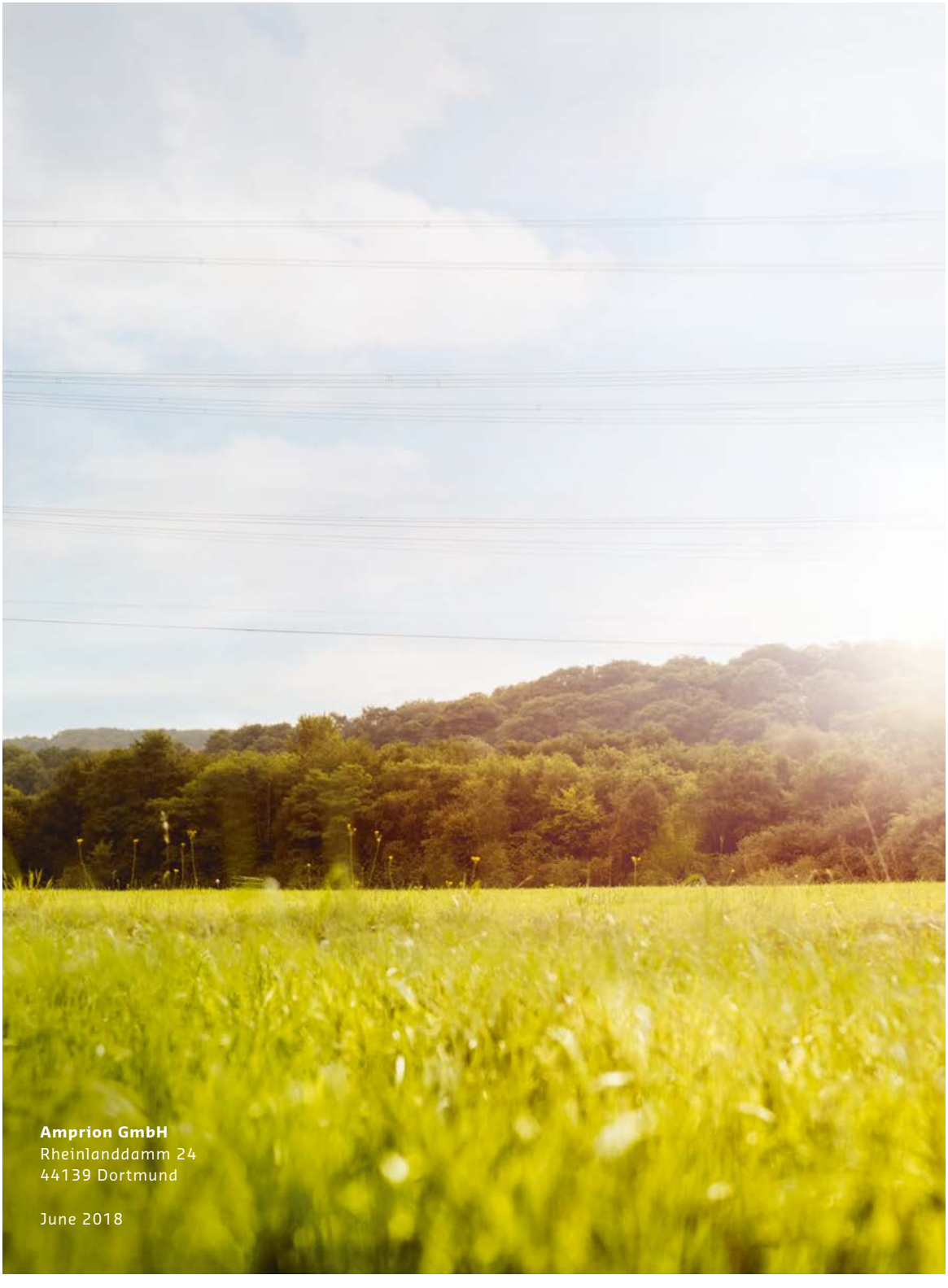
NOTE

This is a translation of the German version. In cases of uncertainty or conflict, the German version shall prevail.



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