FINAL REPORT
OF THE CONSORTIUM
MEDIUM 1/2

2021

# enera

PROJECT MAGAZINE

Connecting energy.

SINTEG
SMART ENERGY SHOWCASES

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enera

# Foreword

The “Smart Energy Showcase – Digital Agenda for the Energy Transition” (SINTEG) funding programme is ahead of its time. The results have shown that we have the technical ability to integrate a high percentage of solar and wind power into our electricity grids and to thus guarantee secure system operations. Soft- and hardware solutions have been developed that enable renewable energy generators and electricity consumers to contribute to network stability. SINTEG has also confirmed that digitisation is a key to the success of the energy transition.

Over the past four years, experts in five model regions across the entire federal territory have developed and tested methods to ensure the energy system of the future is economic, sustainable and reliable in terms of supply. In the course of this, they were able to transfer numerous concepts and ideas from the field of digital economy to the energy industry. These specialists have proved that smart grids can guarantee a stable and secure system using digital technology, even if, at times, 100% of the electricity fed into the grid is generated from renewable energy. The project has resulted in the development of innovative blueprints for future grid operations and new business models.

I am particularly pleased to see that SINTEG has united teams of researchers from every region of Germany, creating a network and a shared trust in new solutions. After all, new findings often only arise in the course of dialogues. Designing creative solutions and testing them in reality is an important step on the way to the energy transition, to which SINTEG has made a meaningful contribution.

The report at hand provides an overview of the results of the enera showcase. I would like to wish the participants in the model region all the best and hope that you, dear reader, will find the following pages informative and interesting.

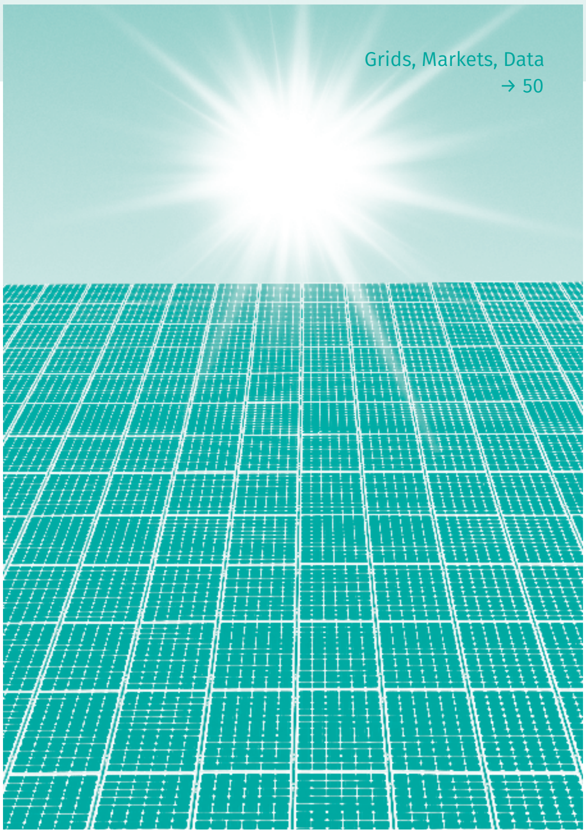
PETER ALTMAIER

Federal Minister for Economic Affairs and Energy

The model region
→ 12

# enera Project Magazine

## Contents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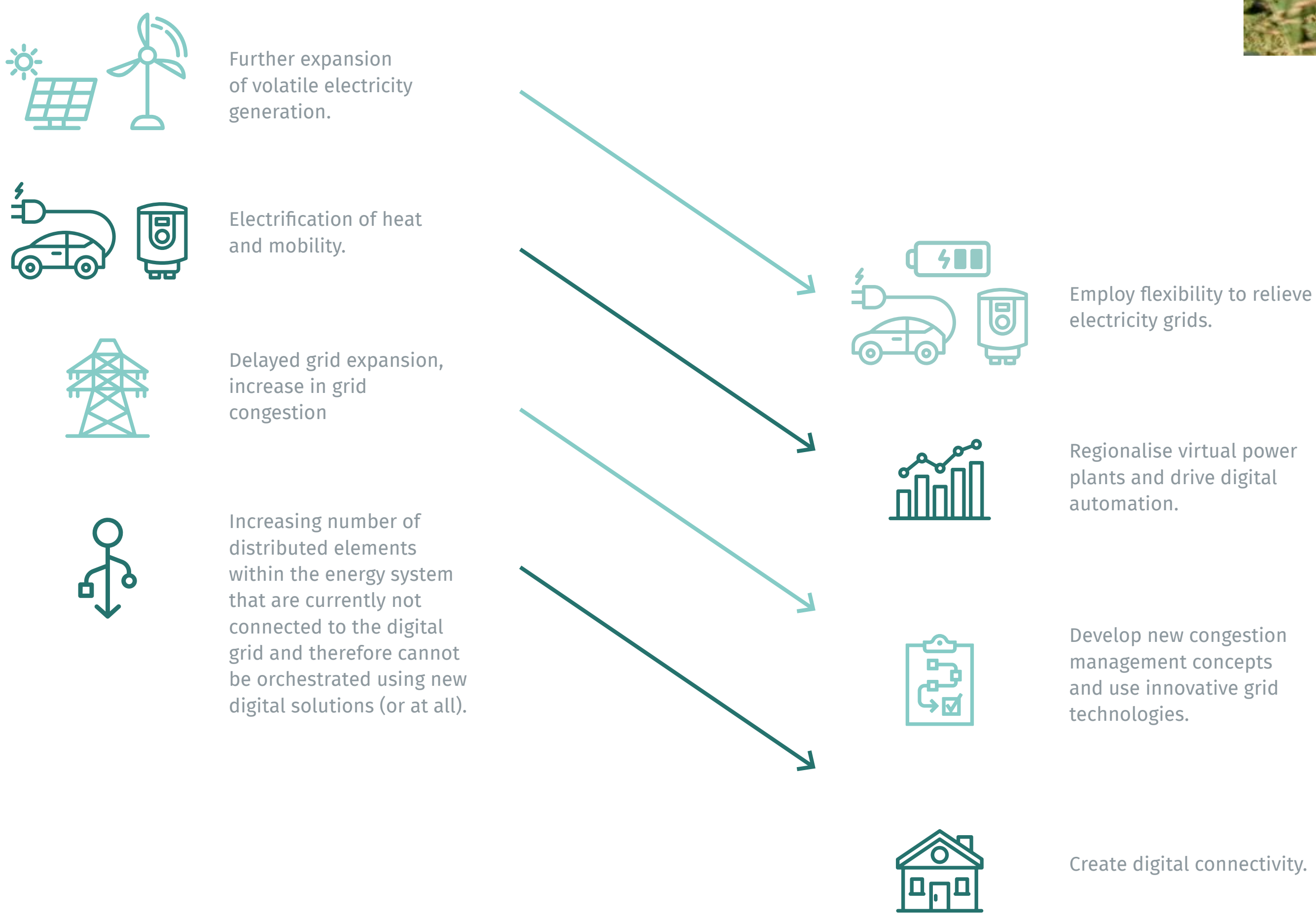
# A regulatory sandbox for a climate friendly, economic and reliable energy supply

## WORK PACKAGES WITHIN ENERA

# enera and the next major step towards the energy transition




CHALLENGES OF THE ENERGY TRANSITION AND SOLUTIONS PURSUED IN ENERA.

31 consortium partners with hundreds of persons involved, a budget of more than €170 million and several hundred steps pooled into 13 work packages – enera is one of the most comprehensive funding projects in Germany. The size and complexity arose from the project assignment: to develop model solutions for a climate friendly, economic and reliable energy supply and test them under real-world conditions.

Over the course of four years, the project teams tested numerous components for the energy system of the future in the enera model region, providing grid operators access to a wider range of smart tools to integrate more renewable energy. Extensive digitisation provided the foundation for new, data-based business models and when the wind and sun generated too much electricity on the grid, a market based on the stock exchange helped resolve bottlenecks.

Due to the increasing percentage of volatile renewable electricity and the delayed expansion of the grids, the latter are increasingly overloaded; generation and loads are not distributed evenly. On the electricity market, the price determines who is awarded the contract for generating electricity but does not determine the location thereof. The integration of more renewable energy into the system calls for innovative congestion management solutions.

Using an EPEX SPOT trading platform, the enera flex market allowed grid operators to procure flexible active power for the exact locations at risk of grid overload. Until recently, the power exchange only traded contracts that could be fulfilled by feeding power into, or increasing consumption at, random locations in Germany. By introducing a local component to energy trading, enera provided a foundation for grid operators to use the markets for their congestion management. enera has shown that the exchange in Paris can also integrate order books for smaller grid areas, for example the area surrounding a substation in East Frisia. The trading platform helps operators find local →

users for electricity that would otherwise have to be curtailed, which allows existing grids to absorb more renewable energy. The fact that preventive, as opposed to curative, congestion management works across all voltage levels from both a technical and procedural perspective is a key finding of this project.

Like many other solutions developed in enera, the flex market is based on exhaustive digitisation and technical flexibilisation within the model region. Communication and measurement technology installed in households, companies and on the grid ensures that both the flow of electricity and grid conditions are transparent and that plants can be controlled. A central IT platform developed for this precise purpose in enera amalgamates a wide range of data from various sources. Combining and correlating this mass data paves the way for completely new products and services: apps are supplied with data on energy consumption in seconds, small-scale flexibility transactions can be reproduced efficiently and complex patterns identified using state-of-the-art data science methods.

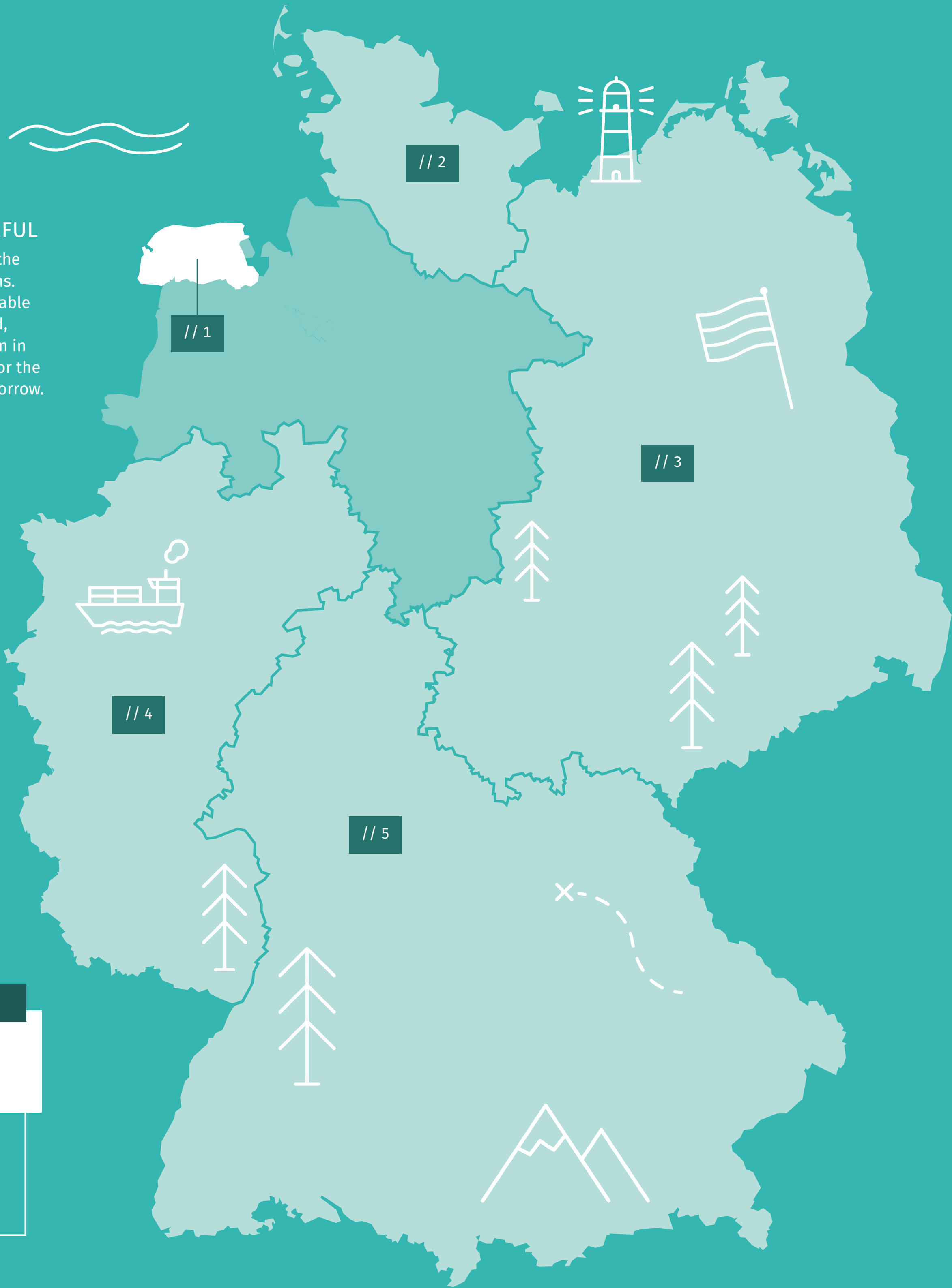
Data are the foundation for innovative business models, many of which have been developed across sectors in cooperation with new economy companies. In the energy sector, digitisation has given rise to an additional value chain that is accompanied by fundamental change; as energy purchasers, end consumers simultaneously generate data.

enera is one of five projects within the "Smart Energy Showcase – Digital Agenda for the Energy Transition" (SINTEG). The funding programme initiated by the Federal Ministry for Economic Affairs and Energy (BMWi) aims to find solutions for an environmentally friendly, efficient and secure energy supply on a renewable basis. To do so, enera has developed a systemic solution that links grids, markets and data. As one of the first pioneers of regulatory sandboxes, enera has demonstrated solutions for the energy transition under practical conditions in the model region. In cooperation with players in the region, the consortium partners have created a transparent, digital energy system with smart networks.

The first part of this final report provides an overview of the enera project, introducing the model region and the partner consortium as well as enera's assignment, conditions and solutions, supplemented by recommended courses of action. The second part of this report provides insight into the individual work packages. A separate, third part contains detailed information on solution elements developed over the course of the project. //

## SMALL YET POWERFUL

enera is the smallest of the five SINTEG model regions. It generates more renewable energy than is consumed, making it the ideal region in which to test solutions for the electricity supply of tomorrow.




### // MODEL REGION 1

enera

Emden
Aurich county
Frisia county
Wittmund county

### // MODEL REGION 2

NEW 4.0
Norddeutsche EnergieWende

Schleswig-Holstein
Hamburg

### // MODEL REGION 3

WINDNODE

Mecklenburg-Vorpommern
Berlin
Brandenburg
Saxony-Anhalt
Saxony
Thuringia

### // MODEL REGION 4

DESIGNETZ
VERBUNDEN MIT KREATIVER ENERGIE

North Rhine-Westphalia
Rhineland-Palatinate
Saarland

### // MODEL REGION 5

C sells

Bavaria
Baden-Württemberg
Hesse

# 2017

At the **Dangast barcamp,**, energy experts, specialists and model region residents set their own agenda.

// WP 11, P. 128

The **enera qualification centre** launches

// WP 10, P. 90

The **e-Now nowcasting tool** uses short-term forecasts on renewable energy feeds to forecast critical grid situations

// WP 06, P. 106

**The first enera Road Trip** – touring the model region on cargo bikes

// WP 11, P. 128

With the **Brainwave format,** the project has developed an innovative mechanism for data-based potential analyses

// WP 09, P. 122

The **enera Data Lab** launches, employing **data science methods** in an energy context for enera partners for the first time

// WP 09, P. 122

# 2018

EPEX SPOT and EWE conclude an agreement to develop an **intraday flexibility platform**

// WP 07, P. 112

**Algotrading solution for grid operators** in flexibility markets tested for use on the enera flex market for the first time

//

The **large-scale hybrid storage system in Varel** joins the enera flexibility pool

// WP 05, P. 102

The enera **Netflex tool** is put into operation to forecast bottlenecks on the low-voltage grid

// WP 03, P. 82

Three start-ups are selected to cooperate with enera at the **PitchX event** in Bremen

// WP 09, P. 122

**An electric gas compressor** operated by Open Grid Europe in Manslagt joins the enera flexibility market

// WP 05, P. 102

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

WP = WORK PACKAGE

# 2019

The **SDSP** is now the data hub for the enera verification, flex registry and consumption visualisation apps

// WP 02, P. 78

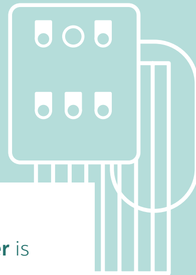
In **penetration tests**, the team simulates hacker attacks to check the robustness of regulated distribution transformers

// WP 12, P. 94

**The protection requirements analysis** for enera use cases is concluded and incorporated into the **information security management system**

// WP 12, P. 94

# 2020



The **210th regulated distribution transformer** is installed in Remels

// WP 04, P. 86

The three grid operators (EWE NETZ, Avacon, TenneT) co-operate to have **24 megawatts of flexibility** supplied (on the generation and load sides)

// WP 06, P. 106

**Analysis of the impact of a broad roll-out** of the enera flex market on the nation-wide German electricity market and transmission grid

// WP 13, P. 142

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

**First SAM** is installed and the first user receives the enera app to visualise consumption data

// WP 01, P. 74

**The flex market** goes live

// WP 07, P. 112

**Acquisition of participants** for the SAM field test launches in cinemas, on the radio and in print media as well as at many other meet-ups

// WP 11, P. 128

enera partners present their **position paper** on a framework for the energy industry of the future to the Federal Ministry for Economic Affairs

// AP 08, P. 138

First **real-world bottleneck is resolved** by EWE NETZ at Manslagt substation

// WP 06, P. 106

**The enera Data Labs algorithm** recognises consumption of individual appliances based on SAM data

// WP 09, P. 122

Varel Paper and Cardboard Factory [Papier- und Kartonfabrik Varel] with its **power-to-heat module** (20 megawatts) is the largest individual plant to join the enera flex market

// WP 05, P. 102



The first **wind farm is retrofitted for STATCOM functionality** (expanded ability to set control values for reactive power)

// WP 05, P. 102

**STATCOM container** implemented in Werlte to provide reactive power flexibility to the distribution grid

// WP 05, P. 102

**CDMA 450 MHz infrastructure** tested for smart meters

//

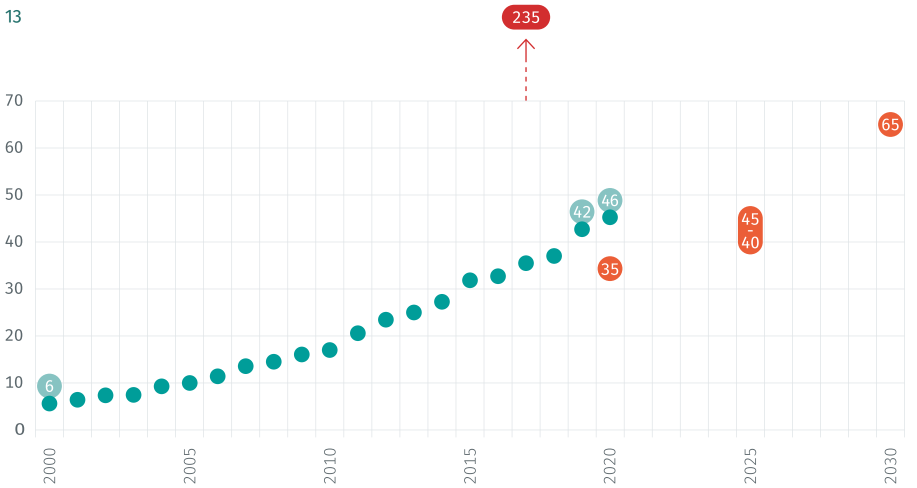
**System studies** are conducted to investigate the impact and transferability of enera approaches to active distribution grid operations

//

**Peak shaving regulator** is put into operation in Wiesmoor for the first time

// WP 03, P. 82

# Coastal energy: the enera model region




Percentage of renewable energy in gross electricity consumption in Germany until 2019

- in Germany until 2019
- in the model region in 2017

Federal Government targets until 2030

// When the project launched, renewable energy accounted for 235% of consumption in the model region.

The enera model region comprises the three counties Aurich, Frisia and Wittmund as well as the independent town of Emden and covers a large part of the East Frisian peninsula. This prominent position on the windy North Sea coast provides the best conditions for the use of renewable energy. The many wind power plants located on the marshes, moors and sandy uplands as well as offshore alone generate more than twice as much electricity as is consumed locally, making this region in the north-west of Germany the ideal place to find solutions for key challenges facing the energy transition: across the nation, the majority of all electricity will soon be generated from renewable sources – today, the model region demonstrates how a temporary excess of electricity can then be smartly integrated into the grid.

## A PIONEER OF THE RENEWABLES EXPANSION

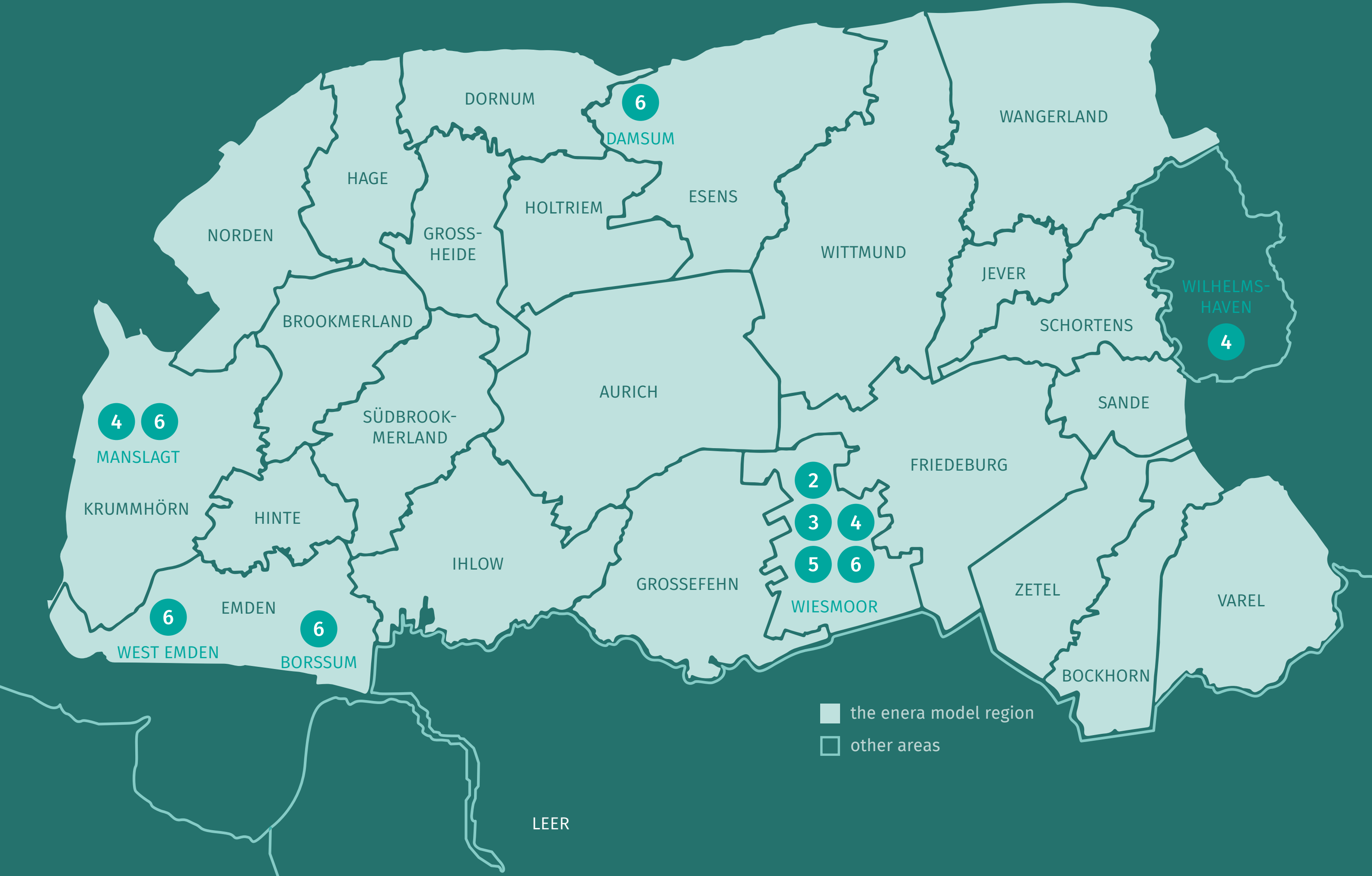
Over the course of three decades, various renewable energy generators have been installed in the model region, including photovoltaic, biogas and wind power plants – resulting in a share of renewable energy in consumption of over 235% even before the project had launched. This makes the model region a large-scale, green power plant and an export region for electricity from renewable sources. The cities are the largest electricity consumers in this predominantly agricultural region; around 390,000 residents live in villages, small towns and six medium-sized cities. Spread across an area of 2,665 square kilometres, the population density in the region is thus roughly a third less than the German average.

## THE POWER GRID IN THE MODEL REGION

The structure of its power grid allows the model region to demonstrate optimised distribution grid operations and the efficient integration of large quantities of renewable energy. At 24 transmission points, the low and medium-voltage grids run by distribution grid operator EWE NETZ feed into the 110 kilovolt grid of upstream grid operator Avacon. This high-voltage grid with its double closed-loop structure is located in the model region. The TenneT transmission grid is connected to the regional distribution grid via three transmission points; the grid also absorbs electricity from the offshore wind farms. In terms of communication, the relevant hubs in the low and medium-voltage grids are connected via a cutting-edge, large-scale glass fibre infrastructure.

The structure of both electricity grid and generation make the enera model region the ideal place to demonstrate the energy supply system of the future. And the energy transition has considerable backing in the region: the enera project is widely supported by municipalities, companies and private individuals. Many people in the region are proud of their contribution to the energy transition, especially when it comes to the numerous plants that use the wind, the sun and biomass to generate electricity, making the north-west a pioneer for a climate-friendly future. //

# Powerful locations






## STATCOM CONTAINERS REGULATE VOLTAGE

In our three-phase electric power grids, we need to regulate both active and reactive power. In enera, a static synchronous compensator (STATCOM) provides reactive power to maintain voltage levels. Weighing roughly 30 tons, the compensator is housed in a container and connected to the medium-voltage grid via a transfer station. The power converter helps the network absorb more renewable energy.

→ For more details, see Work Package 05, p. 102



## WIND FARM SUPPLIES REACTIVE POWER

With STATCOM-compatible wind power plants, the project tested an innovative voltage control technology in the field. Upgrading wind farms with this technology allowed operators to regulate reactive power on the grid even in the event of a low feed. Upgrading wind power plants with full power converters in particular prevents having to expand larger plants to compensate for reactive power.

→ For more details, see Work Package 05, p. 102

THE ENTIRE MODEL REGION

## CONSUMPTION MEASURED IN AROUND 700 HOUSEHOLDS

In order to record the power consumption of households and municipalities to the second, the team installed more than 700 electric meters, together with compatible smart access modules (SAM). During the field test, enera used these devices – the first of which was installed in Varel – to demonstrate the benefits of measuring consumption in real time: the smart linkage of consumption and generation as well as more transparent current flows.

→ For more details, see Work Package 01, p. 74

3

## REGULATED DISTRIBUTION TRANSFOMERS USED THROUGHOUT THE REGION

Regulated distribution transformers independently control voltages on the grid, meaning that photovoltaic plants and heat pumps, for example, can be integrated more effectively into existing grids. To date, these regulated transformers have only been used occasionally. enera equipped an entire substation with the technology, allowingg project members to investigate the influence of several regulated transformers on the stability of the grid.

→ For more details, see Work Package 04, p. 86

4

## VOLTAGE REGULATORS RELIEVE CONTROL CENTRES

In renewable energy generation, weather conditions may lead to grid congestion, often in several places at the same time. To relieve control centres, enera created an automated process that uses voltage regulators to resolve bottlenecks, thus allowing generators to be actuated in a more targeted manner and without delays. This in turn means curtailing less electricity from renewable sources. This innovative technology was tested at the grid laboratory at Jade University of Applied Sciences before being put to use on the public power grid.

→ For more details, see Work Package 03, p. 82

THE ENTIRE MODEL REGION

## MORE TRANSPARENCY ON THE GRID

To date, only a few points on the grid provide grid operators with information on current power grid conditions. To increase transparency, 92 substations in the model region have been retrofitted. The measured data are sent to the control centre and are a prerequisite for smart grid control.

→ For more details, see Work Package 01, p. 74

THE ENTIRE MODEL REGION

## MONITORING MUNICIPAL CONSUMPTION

13 municipalities in the model region took part in enera and monitored their power consumption. This was recorded in real-time at properties including schools and administration buildings and evaluated via a web application, thus helping administrations reduce electricity consumption. Zetel was the first municipality to be awarded the title Municipality of the Energy Transition.

→ For more details, see Work Package 11, p. 128

5

## CONTINUOUSLY VARIABLE WIND FARMS

When grids threaten to overload, the feed from wind power plants could previously only be reduced by 30, 60 or 100 percent. To enable continuously variable adjustments, ten wind farms in three substation areas were equipped with cutting-edge control and measurement technology. The grid control centre was able to curtail the total output of the plants, amounting to 85 megawatts, according to precise needs, thus allowing the use of more renewable energy.

→ For more details, see Work Package 03, p. 82

6

## PEAK SHAVING IN PRACTICE

Distribution grids no longer need to be designed “down to the last kilowatt hour”. Grid operators can now plan expansions in a manner that allows the curtailment of up to three percent of possible energy quantities. Peak shaving allows operators to connect more renewable generators without having to expand the grid, an approach tested for the first time during the enera project.

→ For more details, see Work Package 03, p. 82

# New concepts for the energy transition

// CINEMA AD

DURING THE MAKING OF THE ENERA "CHAMPIONS AT SAVING POWER" CINEMA AD AND THE ENERA FLEX MARKET IMAGE FILM, ENERA EMPLOYEES PLAYED LEADING ROLES.


// TARGET GROUP ANALYSIS

IN ORDER TO UNDERSTAND RESIDENTS IN THE MODEL REGION, THE ENERA TEAM CREATED PROFILES AND PERSONAS BASED ON A WEALTH OF INTERVIEWS.

## // ENERA CAMPAIGNS

UNUSUAL FORMATS SUCH AS THE DANGAST BARCAMP HELPED ENERA RAISE AWARENESS IN THE MODEL REGION AND BEYOND.

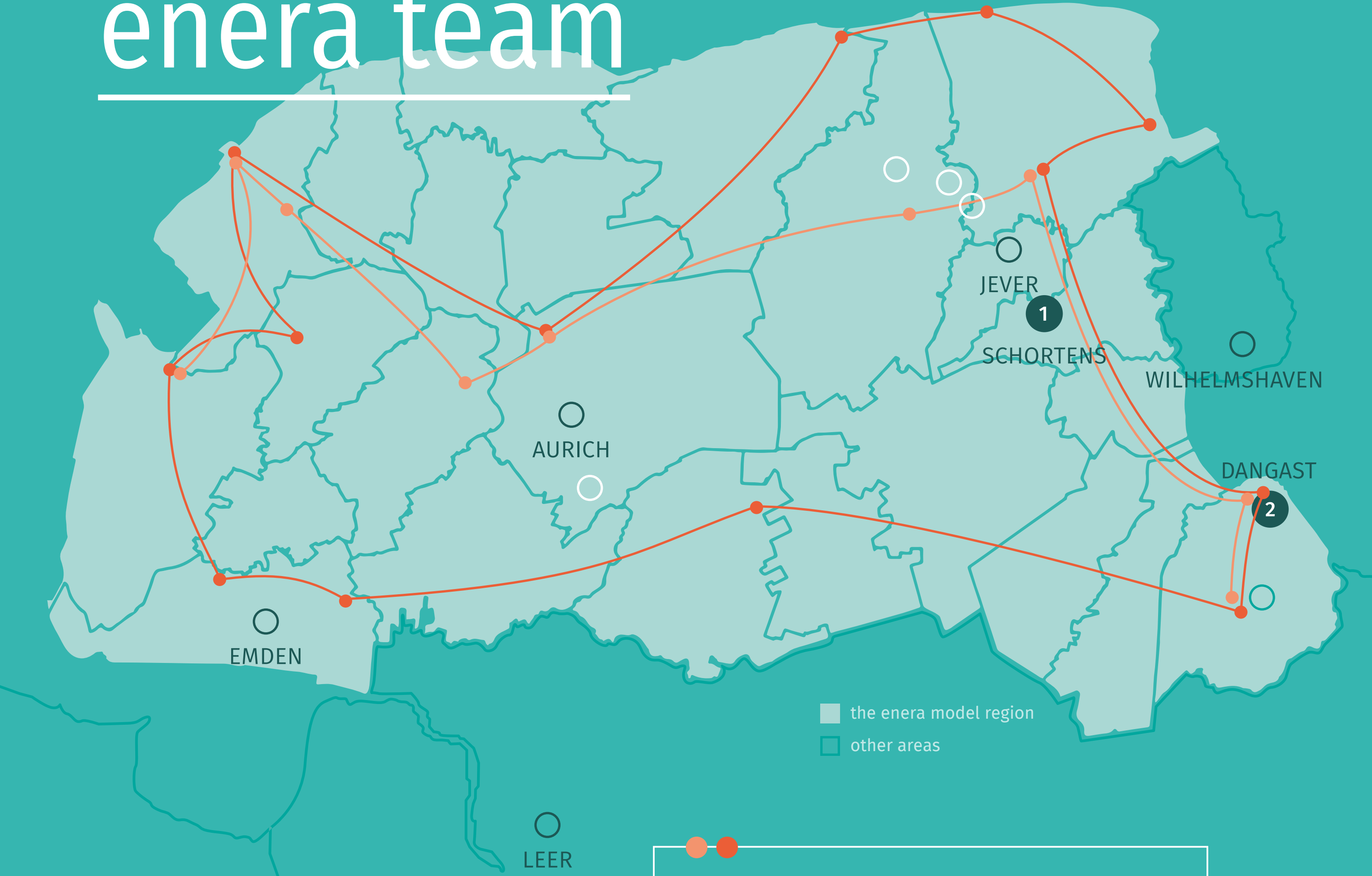


THE ENERA TEAM COMPETED AT THE LEGENDARY DANGAST FLIGHT DAY WITH A SAM CONSTRUCTION THEY HAD DESIGNED THEMSELVES.

## // MUNICIPALITY OF THE ENERGY TRANSITION


ZETEL AND 12 OTHER MUNICIPALITES IN THE MODEL REGION TOOK PART IN THE ENERA FIELD TEST, THUS POSITIONING THEMSELVES AS PIONEERS OF THE ENERGY TRANSITION.

# Activities of the enera team




## PROTOTYPE PARTIES

Mobile robots, illuminated cube and interactive mirrors – at prototype parties, participants developed a host of ideas on how to visualise and regulate a household's flow of energy. Here, potential users in the model region defined the design and characteristics of the objects and applications themselves. The enera team took their objective of getting close to the public literally: some prototype workshops were even held in people's living rooms.

→ For more details, see Work Package 11, p. 128

## THE 2018 & 2019 ROAD TRIPS

When it comes to public participation, communicating as equals is key. That's why project members toured the model region on electrically powered cargo bikes for one week during each of the two enera road trips. In around 600 face-to-face conversations, on social media channels as well as in the press and on the radio, they raised awareness for the project and established contacts. This was particularly successful in semi-public spaces: at neighbourhood events and societies, at sport clubs and Country Women's Associations [Landfrauenvereinigung], all of which aimed to find out more about the needs and interests of people in the model region in connection with the energy transition.

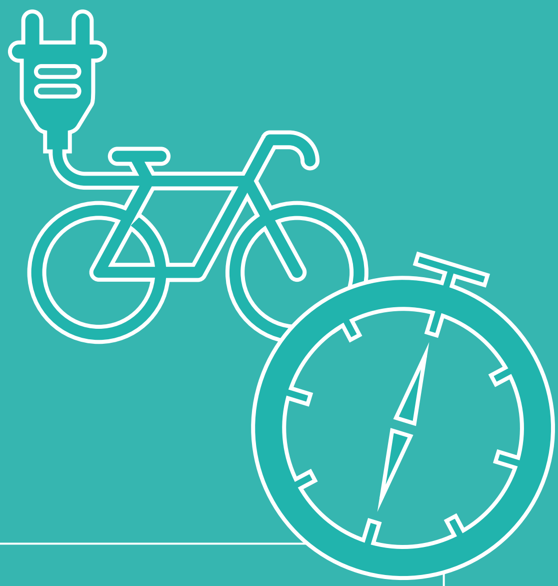
→ For more details, see Work Package 11, p. 128

1

## THE ENERA FRISIAN FESTIVAL

At the enera Frisian Festival in Schortens, visitors were invited to try their hand at games created exclusively for this occasion, such as stacking ***Kluntje*** rock candy and ***bosseln***, the Frisian version of boccia. Even East Frisian social media star Keno Veith dropped by for a game or two. The festival was the result of a media project run by twenty students at Jade University of Applied Sciences and aimed to raise awareness for enera. And this combination of barbecue and Frisian sports was successful, winning support for the enera app and smart consumption data recording methods. The Frisian Festival was followed by many other local events, including energy dialogues and events held in cooperation with trade and business associations.

→ For more details, see Work Package 11, p. 128



## THE ENERA CINEMA ADVERT

Frying eggs over a candle, using a bicycle pump as a hair dryer, ironing a tie with a rolling pin – the project's cinema ad starts by showing some less practical approaches to saving energy. The enera app is then presented as a more relaxing alternative, visualising energy consumption and costs to the second on users' smartphones. Besides this amusing ad, the team organised a range of campaigns that effectively raised public awareness, placing ads in regional newspapers, on billboards and the radio. As a result, in a little over one year around 1,500 people had volunteered to test smart consumption data recording methods. Digital power meters and communication modules were installed in the homes of roughly half of these volunteers, providing the project with a valuable database.

→ www.youtube.com/watch?v=s1WppKp1ZL4

2

## THE 2017, 2018 AND 2019 BARCAMPS

enera aimed to help people in the model region participate actively in the energy system, as opposed to being passive users. The formats used to implement this approach included three barcamps, at which the 200 participants total defined agendas themselves. They negotiated a range of topics, including mobility, renewable energy and the link between life, learning and digitisation. The barcamps were also used to present the first prototypes developed in the workshops.

→ For more details, see Work Package 11, p. 128

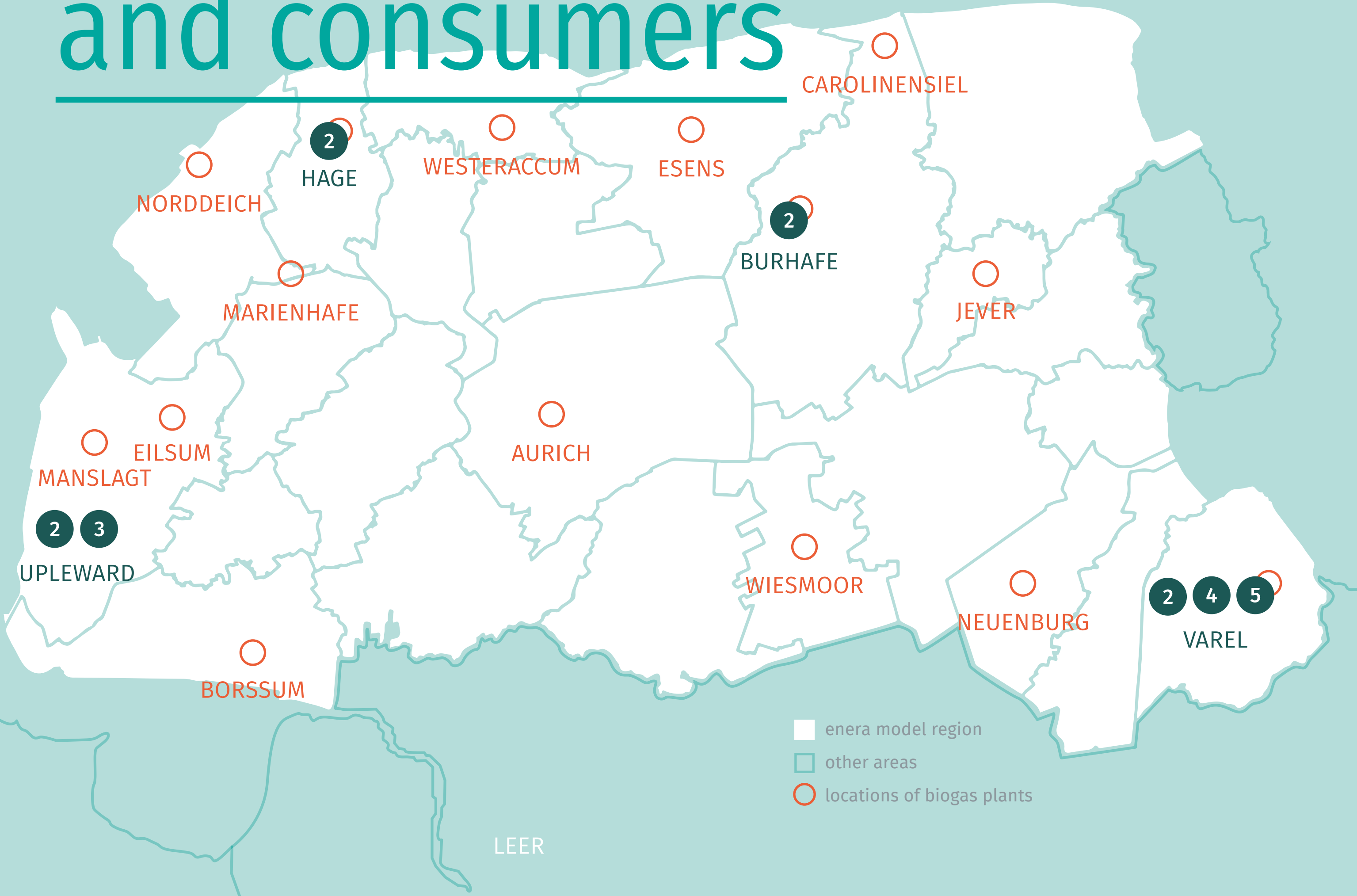
3

## THE ENERA QUALIFICATION CENTRE

From online courses on blockchain technology to a guided virtual reality tour of a substation: a digital platform provided access to around one hundred sessions in a range of formats. With this training offer, enera reacted to the rising need for qualification resulting in particular from the digitisation of the energy sector. The platform allowed enera project partner employees to broaden their knowledge in the fields of smart grids and flexibility, grid planning and design, smart meters and battery storage.

→ For more details, see Work Package 10, p. 90

# Flexible generators and consumers



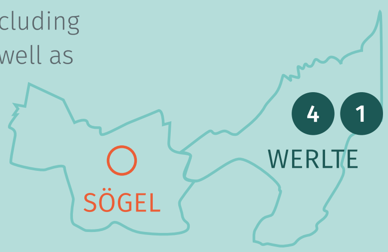

enera has shown how grid congestion can be prevented. On the flex market, which is modeled on the stock exchange, grid operators used forecasts to announce their demand for power adjustments, to which marketers then reacted by offering a lower feed-in or increased consumption.

The **power consumers** integrated into the flex market ranged from heating units with power ratings of merely a few kilowatts to industrial megawatt plants. Small devices in private households, such as heat pumps, night storage systems and heating rods, were pooled and controlled via virtual power plants. Storage systems also came in a variety of sizes, including home storage systems for solar power as well as batteries in the megawatt class.

When it came to **power generators**, many biogas plants participated in the flex market, along with wind and solar power plants. The nominal capacity of these biogas plants amounted to 47 megawatts, half of which was employed in a grid-friendly manner. Biogas plants are particularly flexible, as they can store the generated gas before it is converted into energy in combined heat and power plants. This flexibility, which some plants are already marketing as balancing energy on a national level, helped resolve local grid congestion in the project.

→ For more details, see Work Package 05, p. 102

OLDENBURG



1

### HYDROGEN PRODUCTION RELIEVES THE GRID

The flexibility market makes its debut in Germany: in February, the first trade was completed on a platform provided by European power exchange EPEX SPOT and helped resolve grid congestion caused by a strong input of wind power. To balance generation and consumption, automotive manufacturer Audi started up its power-to-gas plant in Werlte, using local excess wind power to generate climate-neutral hydrogen in a grid-friendly manner.

→ For more details, see Work Package 07, p. 112

2

### THREE GRID OPERATORS COOPERATE TO REQUEST FLEXIBILITY

On 3 April 2020, grid operators Avacon Netz, EWE NETZ and TenneT cooperated to have 24 megawatts of flexible output supplied within one hour. Flexibility is provided in parallel by storage systems, industrial plants and renewable energy generators throughout the entire model region.

→ For more details, see *Spotlight on the flex market*, p. 24

3

### COMPRESSOR USED IN SECTOR COUPLING

An electric compressor was integrated into the flex market as an industrial consumer to transport natural gas. Due to complex operating processes, marketing and control processes were largely automated and carried out by a virtual power plant. The Open Grid Europe compressor has a maximum output of 13 megawatts, which were used to resolve congestion on various voltage levels in the areas of three grid operators – an example of the successful coupling of the gas and power sectors.

→ For more details, see Work Package 05, p. 102

4

### GENERATING STEAM WITH GREEN ELECTRICITY INSTEAD OF GAS

Varel Paper and Cardboard Factory [Papier- und Kartonfabrik Varel] uses a lot of steam, which had previously been generated with gas. A power-to-heat module with a nominal capacity of 20 megawatts now allows the industrial company to switch to electric steam generation when wind power plants in the area generate excess energy. This stabilises the grid and prevents carbon dioxide emissions. As energy consumption fluctuates greatly during the production process, the module’s respective available capacities need to be forecast for the flex market, while control and marketing processes have been automated.

→ For more details, see Work Package 05, p. 102

5

### HYBRID STORAGE SYSTEM STABILISES THE GRID

The hybrid storage system in Varel uses lithium-ion batteries to balance temporary fluctuations in frequency on the grid. The sodium-sulphur batteries are primarily used to store large quantities of energy for longer periods of time and can temporarily store around 22 megawatt hours; they also provide reactive power. This large-scale storage system is particularly versatile when it comes to grid congestion management and can supply and absorb more than 11 megawatts.

→ For more details, see Work Package 05, p. 102

# People in the region support enera

Residents in the region have participated in enera in numerous ways. As an active part of the energy system, they support the energy transition with their personal behaviour.

// BARCAMP PARTICIPANT AND ALLY

## "I consider myself an ambassador for enera."

OLAF HARJES, JEVER

After the first barcamp in Dangast, I considered myself a bit of an ambassador for the project in the region. I am one of the co-founders of a free cargo bike rental service called "Dein Deichrad", which translates to "Your Dyke Bike". Our non-profit organisation began cooperating with the energy transition project at an early stage – which was great. Overall, we launched various initiatives together and raised awareness for digitisation in the energy industry in our region with enera. There were a lot of opportunities: barbecue evenings with project colleagues, talks at economic summits, film projects and the enera Frisian Festival, hosted in cooperation with Jade University of Applied Sciences.


// THE FIRST SAM USER

# “I am proud that the first SAM was installed in my home.”

MARLENA MEINEN, VAREL

I live in the south of Frisia and found out about enera early on. I am rather proud of the fact that my home was the first to be equipped with a modern metering device and enera’s own SAM solution in early 2019. Since then, I have been able to use my enera app to track my energy consumption basically down to the second, which has definitely changed how I use energy and think about sustainability.

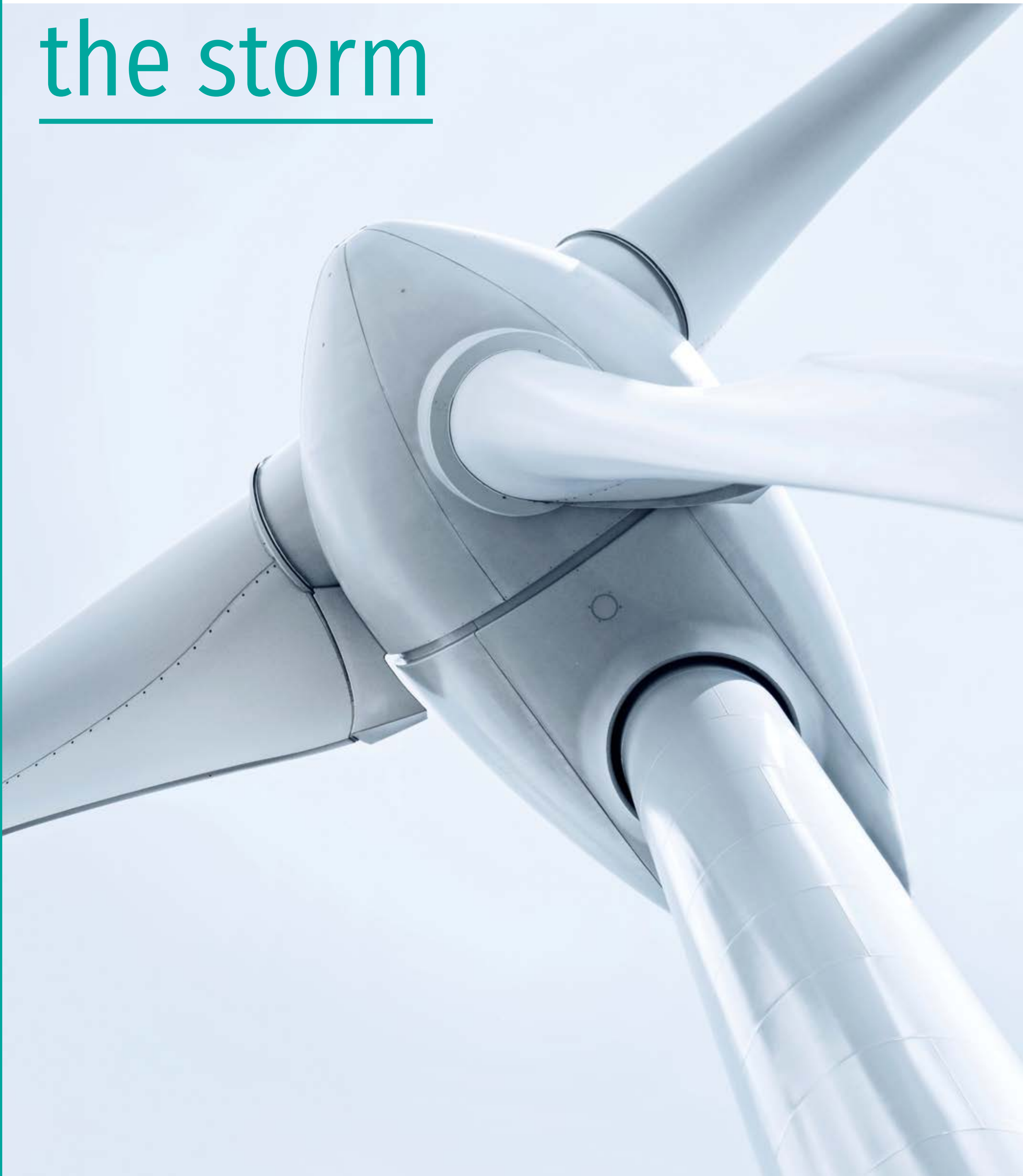
// FLEX MARKET PARTICIPANT

HANS-JÜRGEN ONKES, HAGE

My son talked me into joining the enera project, in the scope of which we tested a hybrid gas heater in my home. Now I am flexible and can use electricity to run my heating system when it’s windy here in the northwest. I think that’s great, as it allows me to contribute to green electricity actually being consumed, instead of simply being destroyed when lines are congested in the south.

# “I think it’s great that I can contribute to the energy transition.”

# How the market helps weather the storm



FURTHER DETAILS

**Flexibility and the market**

→ p. 102, Work Package 05
→ p. 106, Work Package 06
→ p. 112, Work Package 07

With the flex market, enera has shown how we can balance electricity demands and supplies within the energy system of the future, conducting a field test that ran for around one and a half years. On 3 April 2020, particularly high capacities were purchased to relieve local grids: biogas and wind power plants temporarily reduced their input, while an electric gas compressor and a large-scale storage system in Varel, Frisia, absorbed electricity from the grid. Within one hour, grid operators were able to use 24 megawatts of power to stabilise the grid.

On the energy market, flexibility means a deviation from the power input and purchases originally scheduled. In the example above, this deviation from forecasts was a result of the flex market. Grid operators had announced their flexibility needs on the trading platform and marketers had submitted their flexibility offers. The two bids were then matched, thus determining a market-based price for said flexibility. The platform was developed in cooperation with EPEX SPOT, the European power exchange for short-term wholesale electricity trading on 12 national markets.

With the flex market, flexibility – or, to be more precise, the use of plants to stabilise the grid – became a wholesale product for the first time. Before launching the trading field test, the project team first developed market rules, certified plants for participation in the market and defined local virtual order books in which participants can submit binding bids. The team also ensured that the system could handle deliveries, documentation and accounting automatically. In practical tests, the interactions between grid operators across all voltage levels, marketers and the various technologies proved successful.

## HOW DOES THE NEW TRADING PLATFORM WORK?

Once a transmission or distribution grid operator has identified potential congestion – caused, for example, by a storm front feeding too much wind power into the grid – they can enter their demands and the amounts they are willing to pay into the order book on the enera flex market; all with the aim of reducing a specific capacity in a previously defined area of the market for a specific period of time. Marketers then react to this demand in the order book by submitting bids to reduce input or increase consumption. As soon as supply and demand are matched, a commercial transaction is concluded, thus preventing the imminent congestion. →

EPEX SPOT

The European power exchange EPEX SPOT SE and its affiliates operate physical short-term electricity markets in Central Western Europe, the United Kingdom and Denmark, Finland, Norway and Sweden. As part of the EEX Group, a group of companies serving international commodity markets, EPEX SPOT is committed to the creation of a pan-European power market. Over 300 members trade electricity across 12 countries on EPEX SPOT. 49% of its equity is held by HGRT, a holding of transmission grid operators. For more information, please visit www.epexspot.com

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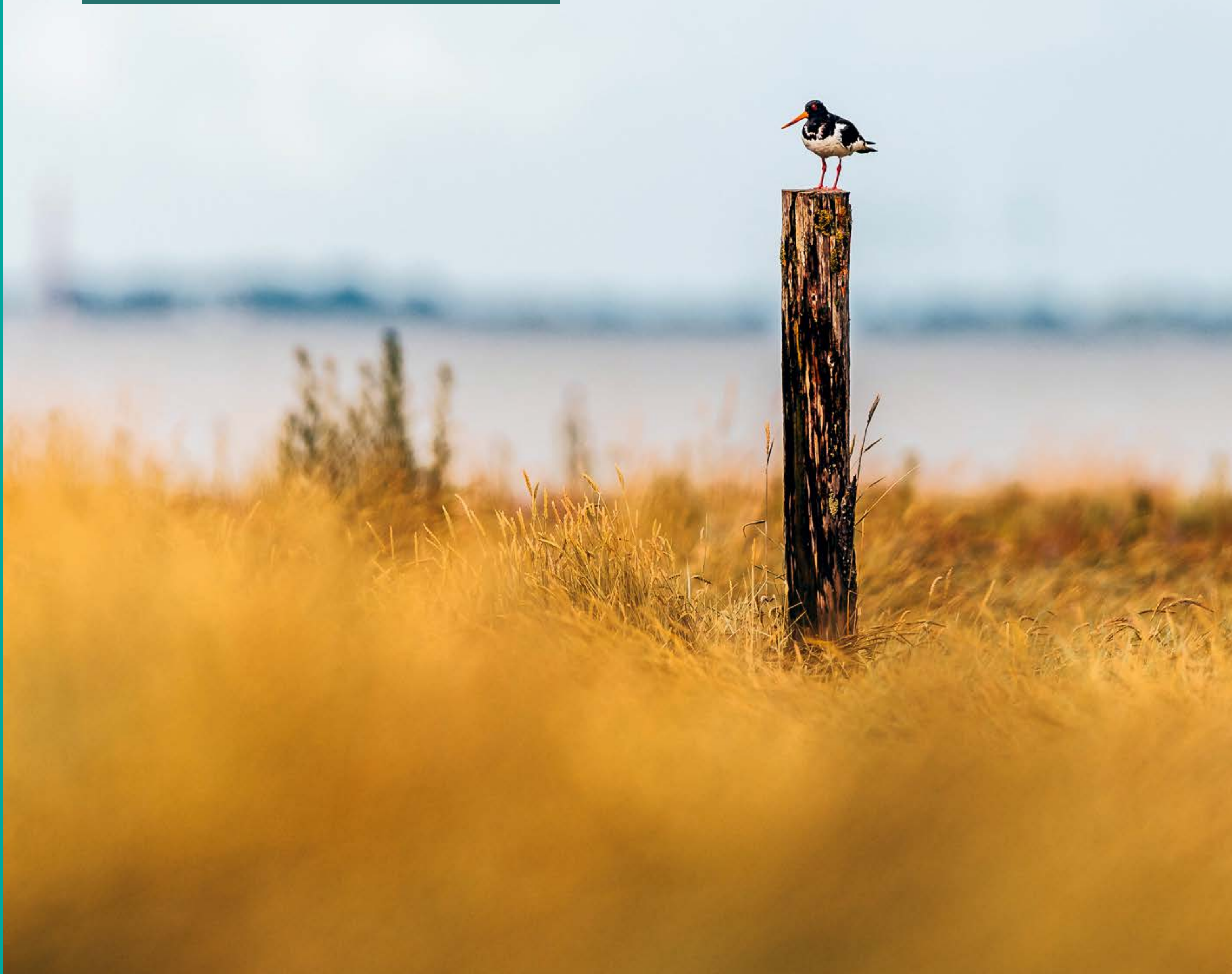
The flex market covers the entire power grid, down to local grids in municipalities.

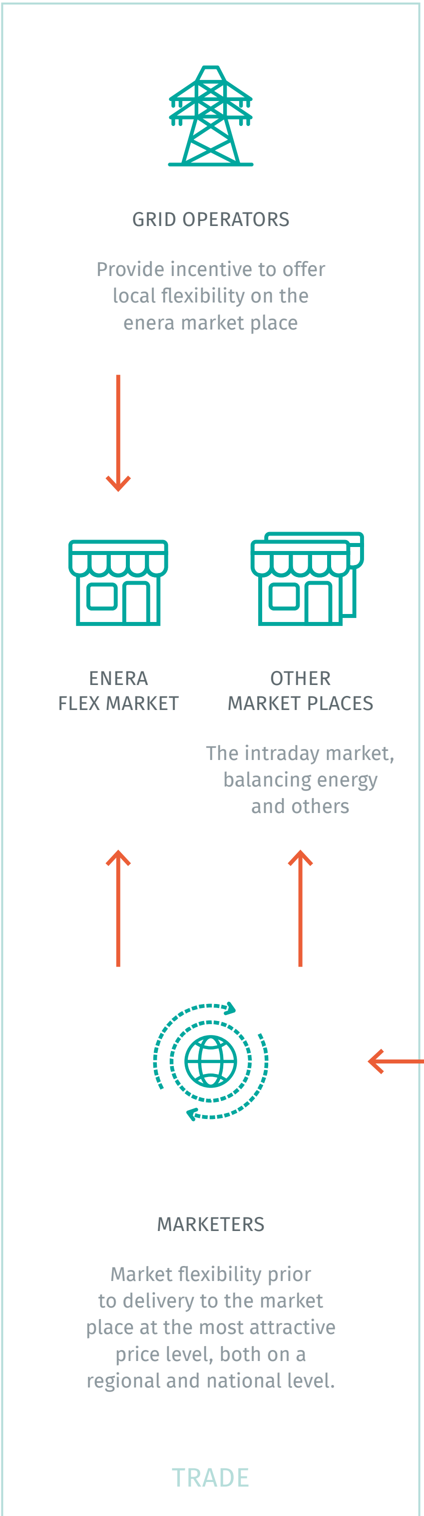


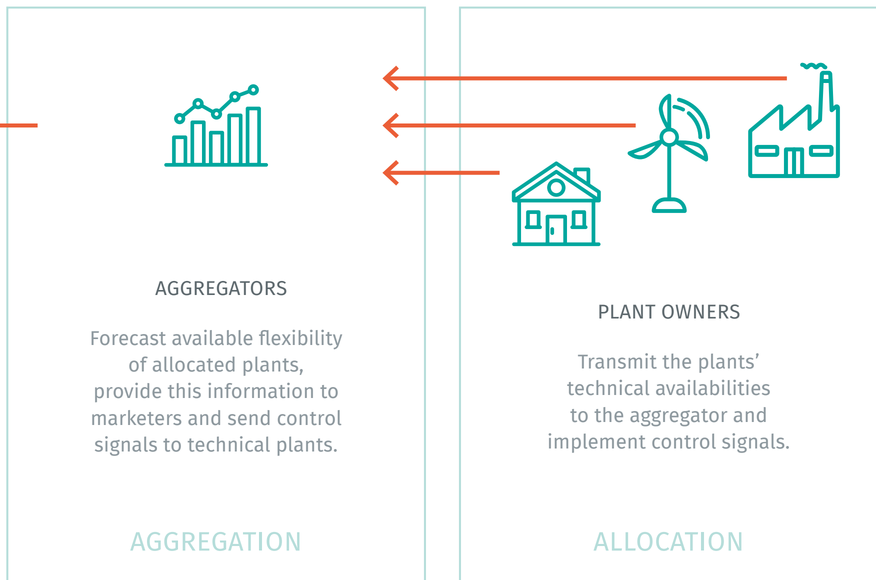
## WHO PROVIDES FLEXIBILITY?

On the generator side, biogas, photovoltaic and wind power plants were all represented on the flex market, while a power-to-gas plant, industrial customers and small devices pooled via virtual power plants were incorporated as consumers. In addition, large-scale storage systems were integrated into the market; these were able to provide flexible active power in both directions. This has created an extensive and distributed flexibility offer for the grid. Marketers initially registered plants for participation in the flex market; in a next step, grid operators reviewed the plants and allocated them to market regions.

## WHAT RULES APPLY ON THE ENERA FLEX MARKET?

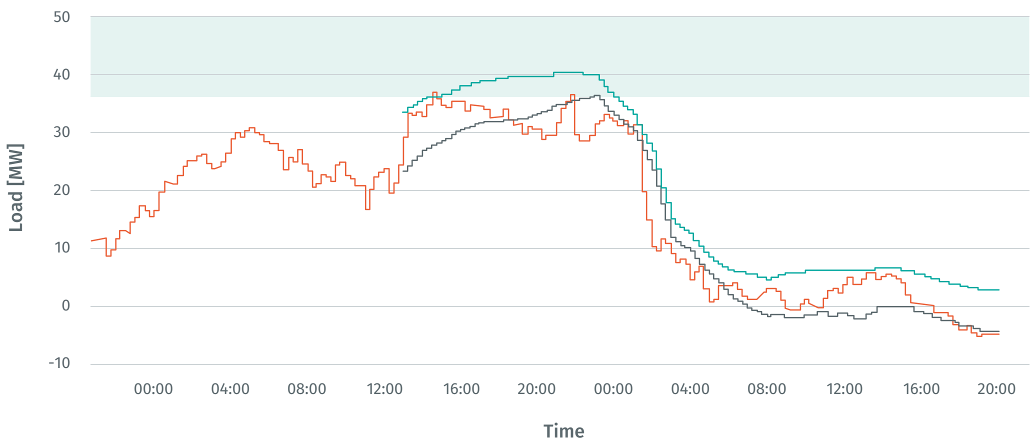
When defining market rules and processes for the flex market trading platform, the project team largely used existing wholesale electricity markets as guidance. As a transparent and non-discriminatory new market place, the flex market is open to all players within the energy system. When designing the market, the project team gave the aspect of grid-friendly trading high priority and ascertained that the enera market did not reduce liquidity on other markets – the flex market is an additional option for marketers. The product design further ensures that the input of renewable energy is not reduced as long as the grid can be relieved by reducing electricity generated by conventional power plants.

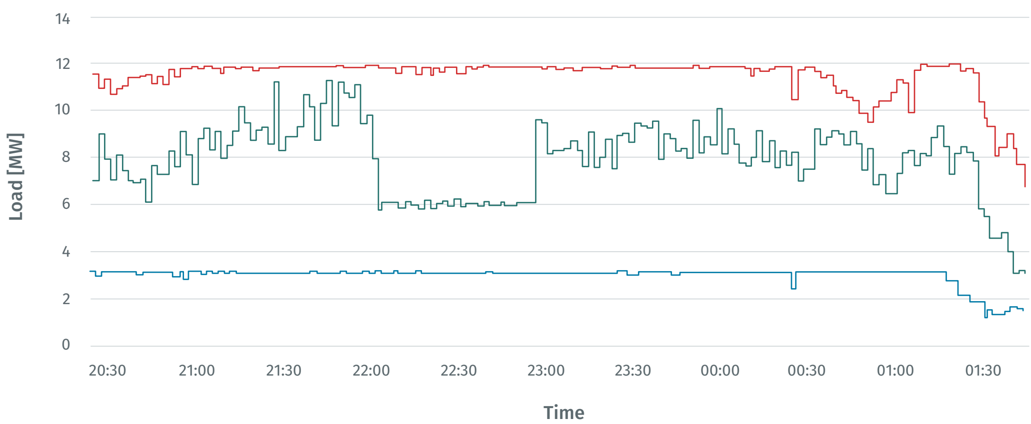


# A practical protocol

## Dispatchers and direct marketers prevent grid congestion




SOURCE: NETFLEX TOOL, EWE NETZ

### FIGURE 1 (TOP)

Forecasts for the Manslagt grid region on 11 October 2020, 1 p.m. (green: forecast on wind input; grey: forecast on the resulting system load) and the actual measured system load (orange); shaded area depicts the limit value of 36 megawatts for equipment.

### FIGURE 2 (BOTTOM)

Operation modes of wind farms at the Manslagt substation on 11 October 2019. The dark-green characteristic curve represents the plant with reduced input. The input of the other wind farms (red and blue characteristic curves) remains virtually consistent.

Local forecasts help identify imminent grid congestion, which can then be averted predictively via the flex market. In the course of this, the grid operators' dispatchers play a central role, as they decide whether or not to purchase flexibility. The following protocol illustrates how this process is put into practice, using congestion resolved during the field test as an example.

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Energy generation would usually be reduced across the board – thanks to the flex market, we can now react in a different way.

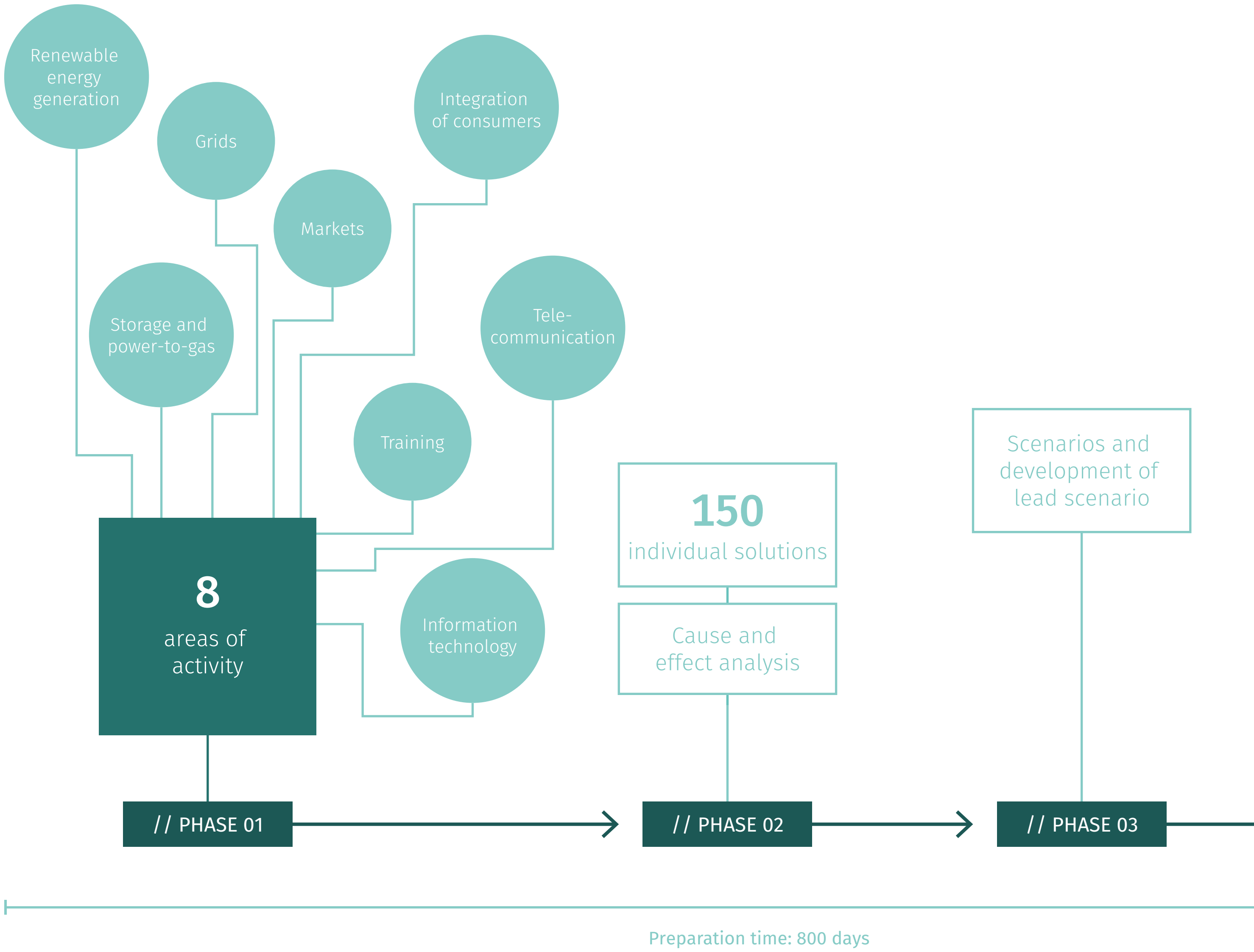
### FRIDAY, 11 OCTOBER 2019, 1 P.M.:

The forecast tool at the EWE NETZ control centre in Oldenburg warns of imminent congestion at the Manslagt substation in Krummhörn, East Frisia. The dispatcher analyses the local forecasts on wind power input (Figure 1, green characteristic curve) and the expected system load (Figure 1, grey characteristic curve); this load is the sum of input and consumption in the grid area at the substation. An approaching storm front is expected to feed so much power into the grid from 10 p.m. on that the limit value (Figure 1, shaded upper area) for equipment will be exceeded.

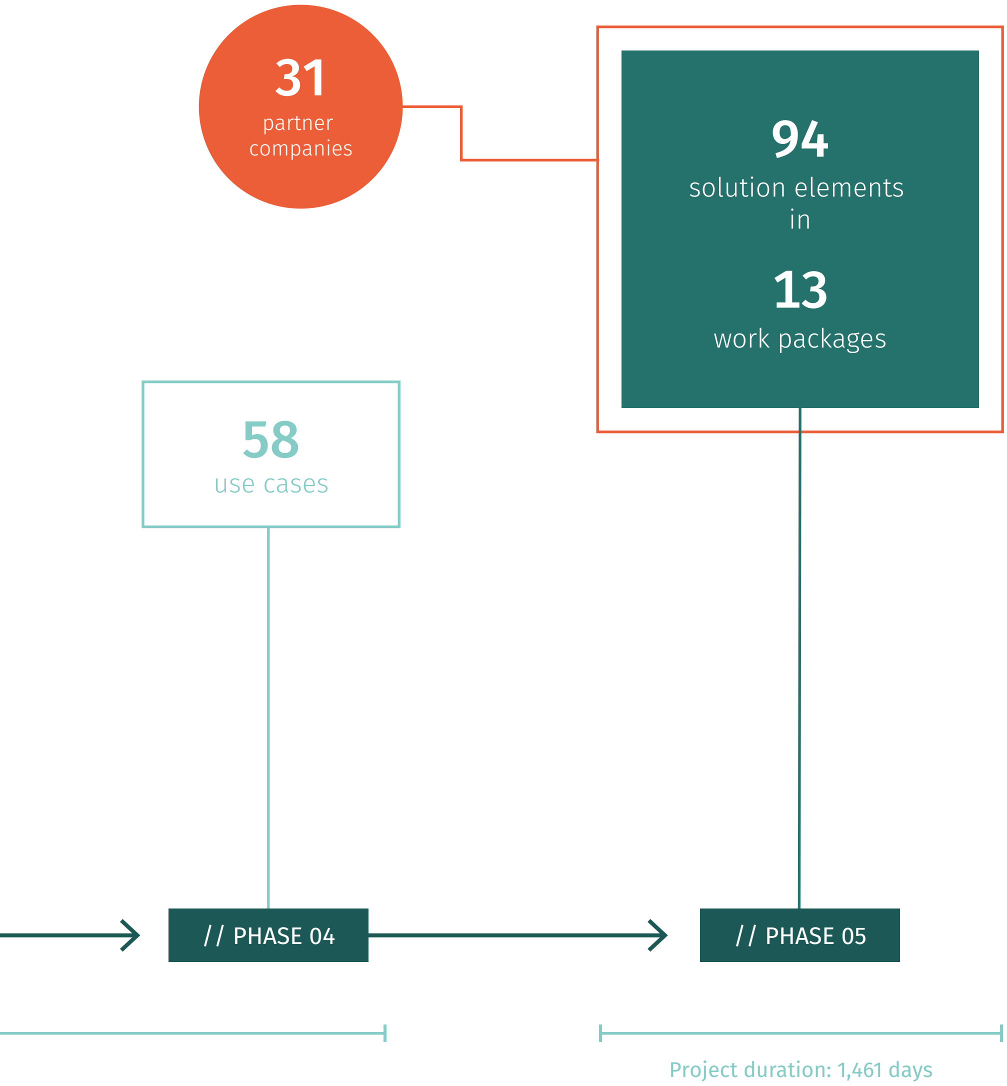
When congestion is resolved using conventional methods, situations like this are handled by means of feed-in management. Power generation would be reduced across the board in the grid region, for example by curtailing wind power plants. The flex market, on the other hand, allows the dispatcher to act in a different way: the grid operator for the Manslagt market region submits a demand for two megawatts of flexible power for the delivery period of between 10 and 11 p.m. to the trading platform. A flexibility provider then submits a matching offer, resulting in a successful trade at 3:27 p.m. The grid operator has no information on which marketer submitted the bid – nor do they know whether their demand will be met by an increase in consumption or a reduction in input. These decisions are made by marketers alone, depending on the plants available at the time of supply.

In this case, a direct marketer of wind power plants supplied flexibility. The marketer reduced input from 8 to 6 megawatts during the required period (Figure 2, dark green characteristic curve), thus relieving the grid of 2 megawatt hours for one hour.

Marketers benefit from the increased transparency the flex market offers. As they are not informed beforehand when plants are curtailed as a result of feed-in management, marketers may face high compensation payments when replacing lost energy by making purchases at a higher price from third parties. In contrast, when flexibility is made available via the flex market, marketers are aware of shut downs at an early stage, which gives them enough time to purchase the required energy at a comparably low price on the intraday market. //




# Committed to the energy transition: the enera consortium




## SOLUTION-ORIENTED

In a multi-stage procedure, partners from the fields of energy, industry, IT and science prepared the enera project, in the course of which they used a matrix to depict individual problems and solutions.

During these preparations, it became apparent that the challenges in grid operations could not be met by technology alone; the team therefore expanded the original smart grid framework to include market mechanisms. When it came to connecting grids and markets, IT and big data took centre stage, resulting in a focus on grids, markets and data.

Within the enera collaborative project, 31 partner companies and research facilities joined forces to develop and test solutions for the next steps in the energy transition. The project was initiated by consortium leader EWE with a project volume of around €170 million. As part of the SINTEG programme, the Federal Ministry for Economic Affairs and Energy (BMWi) funded the enera project with around €50 million, with partners contributing capital funds of around €120 million.

With a consultation document issued in 2013, the BMWi laid the foundation for the programme to fund “Showcases for Smart Energy”. The ministry sent this market survey to institutions and companies within the energy industry, describing key problems of the energy transition and promising funds for demonstration projects. The consultation document focused on issues that ranged from communication infrastructures to the grid expansion and market structures, thus addressing the major challenges currently facing the German energy industry. →

As the future consortium leader, EWE AG took up these issues and initiated a systematic project development process. The research project was prepared in a multi-stage procedure. First, the team pooled central challenges of the energy transition to create eight fields of activity: renewable energy generation; storage and power-to-gas; grids; markets; the integration of industrial and private consumers; telecommunications; IT; and qualification.

From the start, it was clear that, in order to meet these challenges, the relevant players in the energy system would need to work together, which in turn called for a cooperation with strong partners from the fields of energy, industry, IT, science and politics. To establish this consortium, EWE looked for partners that could contribute concrete solutions to the above challenges on the basis of the eight fields of activity. A vested interest in the joint development of solutions for the smart energy system of tomorrow was key for participation in the project.

In more than one hundred workshops with potential project partners, EWE developed an extensive cause-effect analysis, using a matrix to depict problems and solutions. This matrix was then used to derive 58 concrete use cases that were later integrated into the project's work packages. This process increasingly broadened the original smart grid framework; it became clear that it would take more than technical solutions alone to meet the challenges in grid operations: market mechanisms were just as relevant to the solution. When it came to connecting grids and markets, the key role of IT and big data took centre stage, resulting in the triad of grids, markets and data that defined enera. This triad also characterised the project outline that the partner consortium later used to successfully apply for SINTEG funding provided by the BMWi.

The implementation of the project finally began on 1 January 2017. In the four subsequent years, the project yielded numerous solutions for the digitised and flexibilised energy system of the future.

FURTHER DETAILS

**New business models in the digital energy system**
→ p. 122, Work Package 09

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It was clear from the start that it would take team work to meet the systemic challenges of the energy transition.

## NEW COLLABORATION FORMATS

Once the project had launched, enera continued to be defined by the fact that many partners with no previous points of contact were now working together. Start-ups in the digital economy, for example, successfully contributed innovative solutions to the project and presented their ideas at a pitch format to qualify for potential analysis. This combined the agile and user-oriented ways of working employed by young digital companies with the know-how of the established energy sector.

The pioneering spirit of enera sustainably enriched the corporate culture of many partners, beyond the scope of concrete results: in the energy industry, where companies operate critical infrastructures and thus have long relied on tried-and-tested structures, enera provided a tangible innovative boost, both in the field of technology as well as with regard to forms of cooperation. Over the course of enera, the consortium developed formats that are equally unusual for the industry, funding projects and major groups and that are characterised both by a user-centric, participative approach and their alignment with a new, digital value chain.

The consortium also observed a positive change in cross-company cooperation. In light of a political environment that is not always free from tension, it is not necessarily a matter of course for grid operators across all three voltage levels to tackle concrete problems together. The consortium also intensified the cooperation between science and the industry, involving research institutes from the fields of IT, business, energy and law as equal partners in virtually all work packages. //

## COOPERATIVE SPIRIT

In enera, cross-company teams developed solutions for concrete problems of the energy transition. This resulted in a network that has continued to promote cooperation, even after the project ended.

# “The most radical change since the liberalisation of the power markets”

## ULF BROMMELMEIER,

**when you assumed your role in enera, you aimed to break down established structures and convictions. What is your conclusion, now that the project has ended?**

ULF BROMMELMEIER We have set a lot in motion. Especially when it comes to data, we have seen a departure of kinds from old methods. Many companies in the energy sector now see digital approaches in a different light and have recognised that smart automations on the grid make sense. Critical infrastructures and machine learning go hand in glove and companies now understand the value of a good data base, as this helps improve forecasts, for example. And another thing has changed: the way companies communicate with customers. People are being invited to participate, the same way we did in enera with our road trips and barcamps, for example.

## Grids, markets and data were the main focal points – how did you connect these areas?

UB During our intensive pre-work, it quickly became clear that enera was not merely going to be the next smart grid project. While we did consider smart and automated grid management one of the key components in the project, we knew it wouldn't solve the problems on its own; we also needed to look at flexibilisation and digitisation. We wanted to use smart data to activate every player capable of stabilising the energy system; to connect renewable energy generators, storage operators and flexible consumers digitally and perfectly so that they can interact with one another and with grid operators. In European power exchange EPEX SPOT, we found a partner willing to cooperate in a collaborative project such as this one for the first time and to help us realise smart markets – not just on paper but as a real-world trading platform that connects grids to the market. The results have shown grid operators that they can find local purchasers for excess power instead of having to shut down wind power plants.

## So is digitisation the next step towards the energy transition?

UB Interactions between smart grids, the comprehensive flexibilisation of energy plants in the model region and the establishment of a digital value chain for the energy supply – enera is all of these things and, from our point of view, forms the next big step the energy transition needs to take. This meant we had to completely rethink the digital infrastructure; the conventional value chain of the energy supply needed a digital twin. We had to generate a tremendous amount of energy-related data across all partners and then transmit, organise, refine, protect and use that data in a grid-friendly manner. All of this was the result of two questions we asked more than a hundred companies and research institutes at the start of the project: what are the central challenges of the energy transition and what solutions can each of them contribute to enera to solve them? The result was a compendium of dense knowledge the like of which had not existed before in Germany. On 600 pages, we captured the German energy industry's point of view and gained around 30 partners. →

# "enera has created an eco system for the energy transition."

ULF BROMMELMEIER is Head of the EWE Digital Factory and project lead of the enera energy transition project. He studied geography and has almost 15 years of experience in managing complex projects in the field of renewable energies, strategy, M&A and energy system transformation. In the enera project, he combined years of experience and expertise in the energy industry with a strong digital and entrepreneurial perspective.

### enera presented a lot of ideas and solutions. What needs to happen for these innovations to be realised?

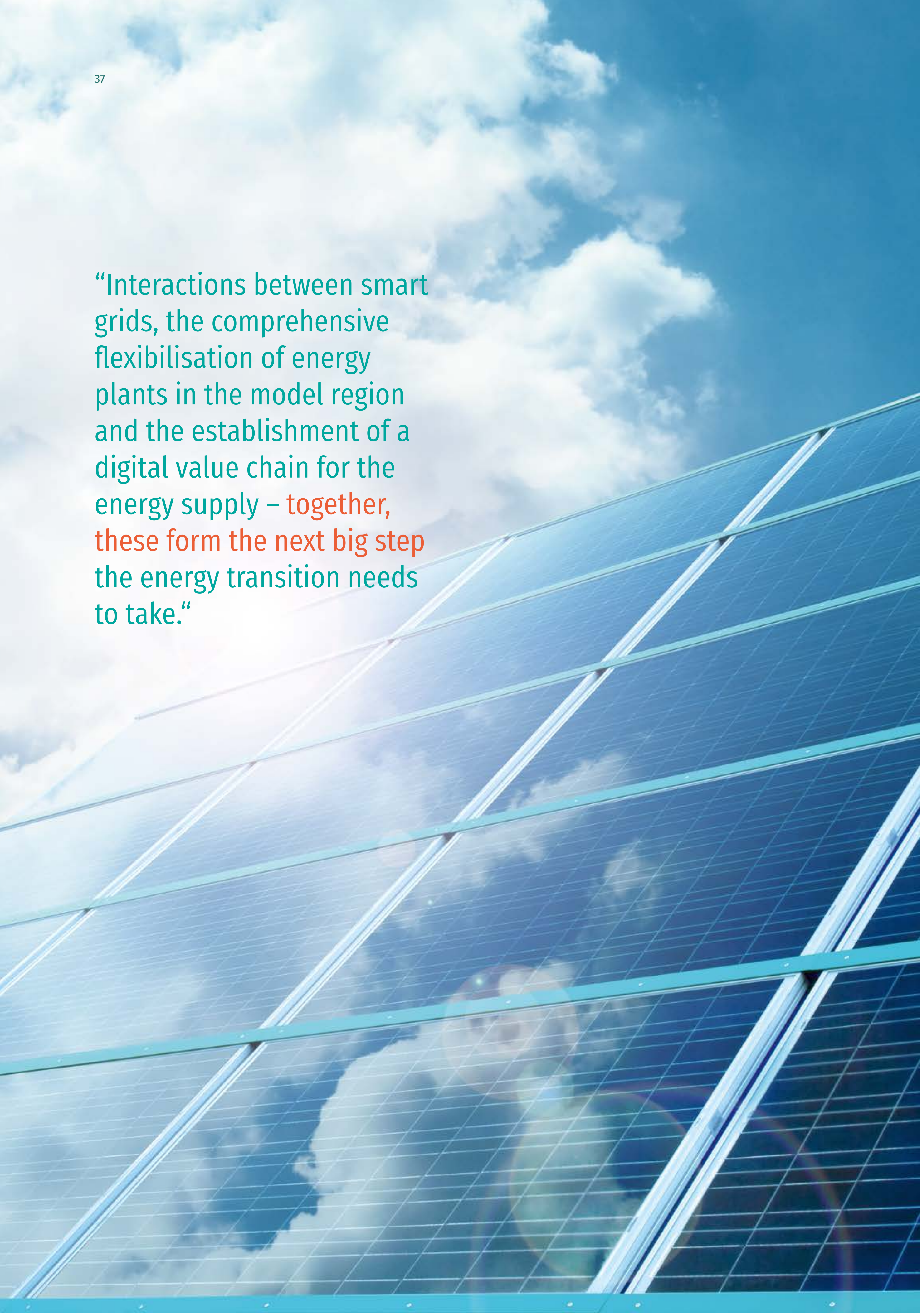
UB Digitisation has confronted the sector with the most radical change since the liberalisation of the energy markets. It requires technological adaptations as well as an increase in speed, the willingness to change and customer focus. The energy industry has massive deficits in these areas. Groups that have grown in a conventional manner are used to working in hierarchies; however, we can only pick up speed if we shift responsibility to the teams. Employees can then decide for themselves on which markets they want to offer their products, for example. This cultural change can only succeed if it is taken seriously and done professionally. And above all, it needs the willingness to make investments. Any company that thinks an innovation department is just for fun or treats it as an administrative unit within the company will fail when it comes to digital change.

### How has enera affected your company?

UB The entire innovation division as it exists at EWE today is a result of enera. This research project gave us the once-in-a-lifetime opportunity to change the way we think about and deal with things. The cross-divisional and cross-company cooperation within the project team played a huge role in that and allowed us to demonstrate how we can digitise the traditional value chain of the energy supply. enera used technologies such as machine learning and blockchain to develop digital business models and cooperated with start-ups to implement them. We were able to try out new ideas, put them into practice and advance them, experiences we are still using today. We felt an innovative boost in grid operations once we had implemented the smart grid operator, which included digitising the grid infrastructure as well as using smart forecasts and trading grid-friendly flexibilities. Thanks to these project activities, we are well-prepared for upcoming challenges such as the implementation of Redispatch 2.0. With our EWE Digital Factory, we have a department that develops digital and user-centric products for internal and external markets. With this, we aim to remain competitive in the long-term and operate innovative infrastructures to position ourselves as digital pioneers on the energy market. The project gave us an enormous boost towards achieving this role, as well as the necessary stamina.

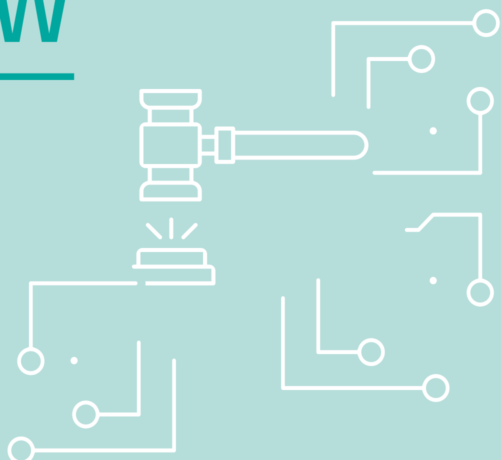
### What have you taken away from enera, besides the many concrete solutions?

UB From day one, we asked which companies really wanted to contribute and were honestly interested in working together to take the energy transition to the next level. This question drove the 31 partners and several hundred people who, after three years of preparation and four years of implementation, ultimately stand for enera. The project has now created an alumni network of sorts. A lot of the contacts within this eco system of the energy transition will continue to keep in touch, even if some people were only briefly involved in the project. We are united by our fundamental belief that being able to form partnerships is elementary. In enera, for example, grid operators on all levels cooperated in an extremely constructive fashion. Everyone was aware that good communications were key to bringing balance to the overall system. While a lot of providers offer individual solutions, no one provides a one-stop source, and that's why the logic of doing everything yourself does not work. Digital change in particular is something we can't manage on our own and will punish any company that doesn't act in the interest of a sharing economy. //



"Interactions between smart grids, the comprehensive flexibilisation of energy plants in the model region and the establishment of a digital value chain for the energy supply – together, these form the next big step the energy transition needs to take."

# The regulatory framework for the grid of tomorrow



enera developed a range of solutions to integrate renewable energies in a way that makes sense from an economic perspective. In order for these solutions to be used after the project has ended, adaptations to the legal framework are necessary. The following provides details on key recommended regulatory courses of action.

## 01 REFORM FEE AND LEVY SYSTEMS

A comprehensive reform of the energy pricing system should give generators, consumers and storage operators market-based incentive to act in a grid-friendly manner. This requires the following adaptations:

- Exempting power used locally by loads, storage systems and power-to-X plants during periods in which grids are overloaded from levies and taxes.
- Peak loads that occur during grid-friendly operations should not be considered when calculating output-based grid charges.
- Differentiating grid charges by time and area can contribute to the predictive curbing of grid congestion and optimise the grid-friendly use of flexible plants with smart meters.

## 02 INTEGRATE FLEXIBLE LOADS AND STORAGE INTO MARKET-BASED CONGESTION MANAGEMENT

Due to the increase in volatile renewable electricity and the delay in grid expansion, grids are increasingly overloaded. One reason for this is the unequal distribution of loads and generation. In addition, while prices on national electricity markets determine who is awarded the contract for generating electricity, they do not determine the location. As a result, congestion management will play an increasingly important role in future. Redispatch 2.0 currently only provides for the integration of generators and feed-in storage systems. As a next step, congestion management needs to be expanded by integrating flexible loads and power-absorbing storage systems ("Redispatch 3.0"). This would allow grid operators to use more renewable energy when re-dispatching and/or in the course of local congestion management instead of curtailing it, thus reducing re-dispatch costs as a whole.
The enera project has shown that predictive, as opposed to curative, congestion management works across all voltage levels, both in technical and procedural terms. With enough time to plan ahead, grid operators can assess where to use flexibility on the grid. Marketers are responsible for selecting and controlling flexible plants and can fall back on established control mechanisms with their virtual power plants. To use the potential of predictive congestion management as best possible, generators, loads and storage systems need to be integrated into the regulatory framework in a market-based manner.

## 03 PROVIDE EQUAL INCENTIVE FOR ALL CONGESTION MANAGEMENT TOOLS

enera demonstrated several new congestion management tools, including the automated regulation of generators in real-time within the scope of peak shaving, smart grid technologies and the market-based use of flexibilities. In general, the project showed that all these approaches work from a technical perspective and reasonably advance or supplement existing congestion management tools. In order to guarantee fair competition for these and other tools, it is vital that the Incentive Regulation Ordinance be adapted accordingly. Any costs for congestion management – whether they are caused by loads, storage systems or generators – must be allocated to the same cost category. If the use of loads and storage systems results in costs lower than those caused by the regulation of generators or use of smart grid technology, the former must be given priority, as this ensures that grid operators are given bias-free incentive to choose the most efficient solution.

### POWER-TO-X

Power-to-X methods are used to convert electricity for alternative uses and/or so that it can be stored. Excess electricity from renewable energy sources can thus be converted into gas, heat and synthetic fuels, for example, making power-to-X technology a key driver for coupling the power sector to other sectors, such as heat and mobility.

## 04 INVESTMENT SECURITY FOR AGGREGATORS WHEN TAPPING SMALL-SCALE FLEXIBILITIES

In order for distributed, small-scale plants to supply flexibility, they need the necessary hardware and must have efficient, digital processes in place. The enera project showed just how much can be done from a technical perspective and that small-scale flexibilities can be controlled with a high level of automation via virtual power plants. The necessary regulations are decisive in ensuring this can be done at a larger scale in practice, as is the digital implementation thereof by flexibility marketers. This initially requires accordingly high investments that can be encouraged by providing a reliable, stable legal framework. →

## 05 FLEXIBILITY PLATFORMS OPERATED BY NEUTRAL THIRD PARTIES

To ensure flexibility platforms are widely accepted, participants, regulatory authorities and the public must have faith in the concluded contracts. This applies in particular to situations in which pricing is subject to a high degree of freedom. The enera flexibility platform was developed and operated by EPEX SPOT as a neutral third party, independent of grid operators and flexibility providers. The platform gained the necessary trust of all market players by providing non-discriminatory access to all interested parties, by releasing anonymised trade data to the parties involved in the project and by monitoring trade.

## 06 AVOID BARRIERS TO MARKET ENTRY FOR VOLUNTARY FLEXIBILITY MECHANISMS

Voluntary, market-based flexibility mechanisms involve the risk of low levels of liquidity. This can be increased by low barriers to market entry, for example by simplifying certification procedures and using existing systems and processes. enera succeeded in maintaining low barriers to market entry by closely modelling the existing product specifications of the intraday market and by using the established M7 trading system provided by EPEX SPOT. Six large marketers provided a total of 360 megawatts of flexibility for trading – meaning around 20% of the input supplied by renewable energy generators in the model region was certified for the flex market.

## 07 CLOSELY MONITOR FLEXIBILITY MECHANISMS AND CREATE TRANSPARENCY

Flexibility mechanisms need to be closely monitored and must be free from distortion. Determining maximum price limits decreases the market power of individual players; this requires a clear policy, market surveillance and penalties for violations, which also make strategic behaviour such as inc-dec gaming more difficult.

## 08 BENEFIT FROM COORDINATION BETWEEN GRID OPERATORS IN REDISPATCH 2.0

To request flexibilities, enera developed and successfully demonstrated a coordination process for grid operators. Within the scope of Redispatch 2.0, congestion management requires grid operators across all voltage levels to cooperate closely in order to guarantee security of grids and supply with the highest possible level of cost efficiency. It therefore makes sense to continue to use the process developed in enera after the project has ended. The process simplifies the exchange of data as well as operational coordination while significantly improving the cooperation between grid operators across different voltage levels, a potential that should be used and further expanded.

## 09 CONSIDER INNOVATIVE ALTERNATIVES TO GRID EXPANSION WHEN PLANNING GRIDS

Flexibility also needs to be considered when planning grids. While peak shaving ensures that flexibility from renewable energy plants can be taken into account when planning grids, there are currently no similar regulations when it comes to considering flexible consumers and storage systems.

## 10 CONSIDER METROLOGY FROM THE CONSUMER PERSPECTIVE

The Act on the Digitisation of the Energy Transition (→ info box) aims to make power consumption transparent. However, it has led to metering devices that have a digital display but no digital connectivity being installed on the premises of around 80% of customers. The technical potential, particularly with regard to innovative apps that sustainably motivate consumers to save energy, thus largely remains untapped. Meter operators therefore need incentive to connect consumers digitally and create the infrastructural basis for digital services. To do so, meter operators will also need to equip those customers with an annual consumption of less than 6,000 kWh with smart meters.

### THE ACT ON THE DIGITISATION OF THE ENERGY TRANSITION

The Act on the Digitisation of the Energy Transition has laid the foundation for the rollout of modern smart meters. The act regulates the processes on the basis of which the previous analogue electricity meters will be replaced with new technologies as well as the time frame.

## 11 CONTROLLING PLANTS VIA SMART METERS

In order to operate smart grids efficiently, distributed energy generation and local power consumption must be measured and controlled continuously. The Act on the Digitisation of the Energy Transition obliges meter operators to install smart meters, which can also control certain generators and consumers. However, the concrete responsibilities and technical implementation for the grid-friendly control of generation plants and consumers have not yet been defined in detail. Grid operators will be obliged to develop an infrastructure that enables them to exercise control via CLS channels (Controllable Local Systems). Competent meter operators will act as service providers to distribution grid operators subject to this obligation.

## 12 CREATE SPACE FOR EXPERIMENTS RELATED TO NEW BUSINESS MODELS

The SINTEG-V experimentation clause (→ p. 65) has created a unique regulatory framework within which financial disadvantages resulting from the project-related, grid-friendly operation of plants are compensated. As a rule, this tool is well-suited to test new business models; in practice, however, it has been shown that the mere compensation of disadvantages does not provide sufficient incentive. Players had to risk disadvantages not being recognised; at the same time, they faced high bureaucratic obstacles when claiming said disadvantages. To demonstrate and test new business models under real-world conditions, it makes more sense to establish a system that also ensures that benefits remain with the players, up to a specific maximum.

# Smart ways to meet new challenges

## WHY ENERA?

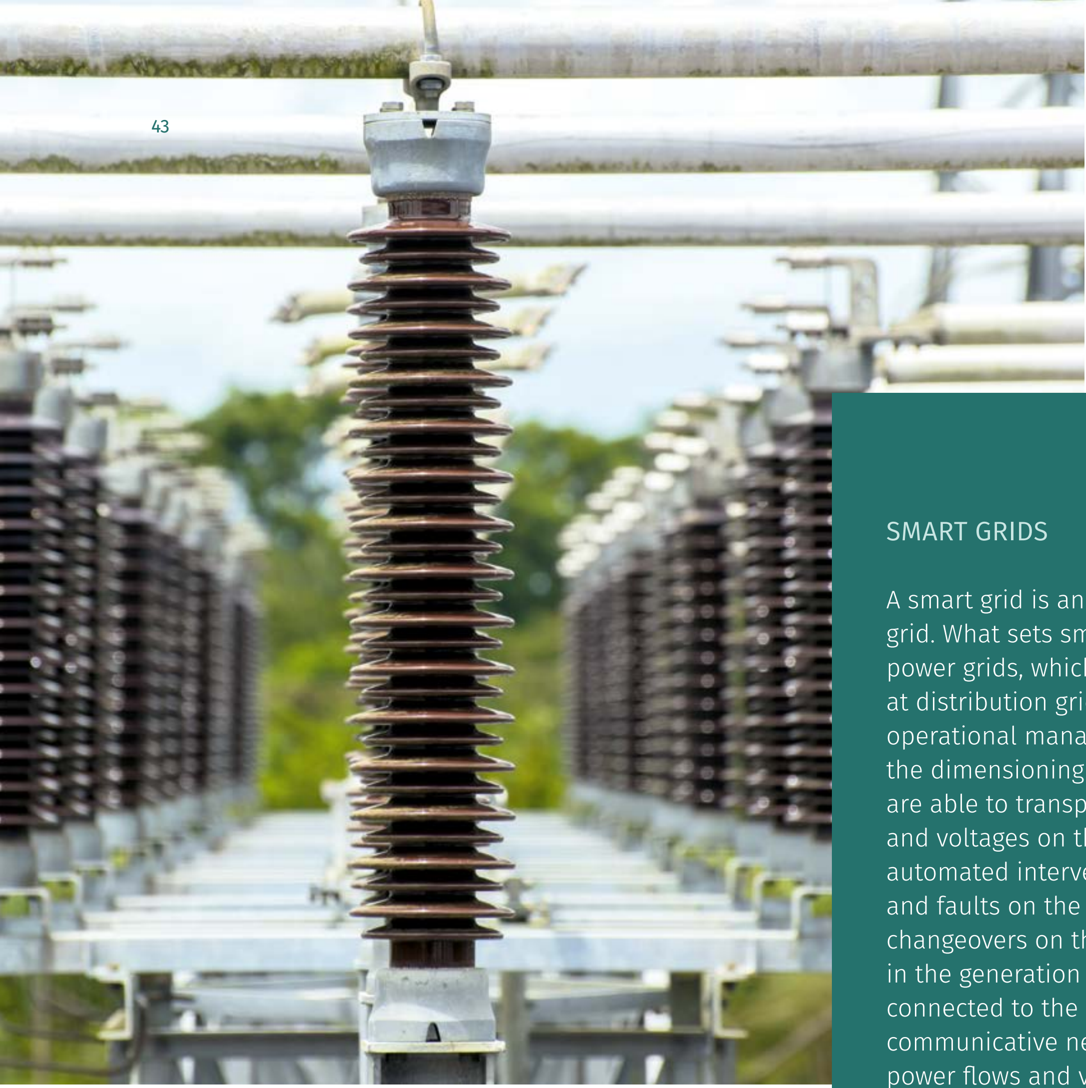
Germany is about to take the next decisive step towards the conversion of its power supply system. While the first phase of the energy transition was determined by the development of renewable generation capacities, in future the country will primarily focus on efficiently integrating increasing amounts of energy from renewable sources. Today, a little less than half the electricity consumed in Germany is renewable. As a result, grid operators increasingly have to take measures to ensure system security, such as the curtailment of wind power plants as part of feed-in management. This illustrates a fundamental challenge the energy transition faces: guaranteeing the profitability and security of supply of a system that is predominantly based on volatile electricity generated from the wind and sun.

The Federal Government has set climate protection targets that outline the path towards a climate-neutral and fully renewable energy supply, targets that result in profound changes to the energy industry's entire system. Politics has provided a clear schedule for Germany's exit from nuclear power and coal-fired energy generation. At the same time, renewable energy is being expanded, leading to tremendous challenges in grid operations that affect regions with a high input of renewable energy in particular.

Instead of conventional, large-scale power plants, the energy system of the future will incorporate many renewable energy generators, including wind, photovoltaic, biogas and hydroelectric power plants. More and more consumers are being added in the course of sector coupling; these include heat pumps, electric vehicles and battery storage systems as well as hydrogen electrolysis and methanation plants. The decentralisation and electrification of other sectors, including heat and transport, increases the complexity of the energy system tremendously. The parties involved must all collaborate if this change is to be managed efficiently; from enera's point of view, this requires digitising the energy system from end to end and increasing technical flexibility.

## SHOWCASING SMART ENERGY

enera is one of five projects within the "Smart Energy Showcase – Digital Agenda for the Energy Transition" (SINTEG) research programme, which aims to develop solutions for a climate-friendly, efficient and secure energy supply with a high percentage of renewable energy and to demonstrate these solutions on a large scale. Further objectives included promoting cooperation between the players on the smart energy grid, using the existing grid infrastructure efficiently and ensuring a lower need for expansion at distribution grid level.



enera met the SINTEG programme objectives, particularly by digitising, and increasing flexibility in, the entire model region, by the extensive use of innovative grid operating equipment and by providing an example of grid-friendly flexibility trade. The project coupled smart energy grids with smart market structures. In addition, enera has provided exhaustive solutions for the systemic transformation of the energy system while ensuring the highest level of security of supply and has illustrated the potential of data-based value added. The project resulted in more than just new ways and courses of action to help the energy transition progress. It also showed the economic opportunities that will arise once Germany assumes the role of an international leading market for the transformation of the energy system.

Scientists accompanying this project focused on the extent to which solutions developed by enera can be transferred to Germany as a whole, in the course of which they pointed out options for shaping regulatory and energy policy frameworks. The project also investigated the incentive mechanisms required to realise innovative approaches to integrating renewable energy. →

## SMART GRIDS

A smart grid is an actively operated power grid. What sets smart grids apart from passive power grids, which today are primarily found at distribution grid level, is essentially their operational management, which in turn affects the dimensioning of the power grid. Smart grids are able to transparently depict power flows and voltages on the grid, thus allowing swift and automated intervention in the event of congestion and faults on the power grid. This includes changeovers on the grid as well as intervention in the generation or consumption of customers connected to the smart grid. Smart grids require communicative network connections to ensure power flows and voltages on the grid are depicted transparently and to control grid operating equipment and grid customers. While Germany is primarily discussing smart grids in connection with the integration of renewable energy and new consumers, for example electromobility and heat pumps, international debates often focus on improving the quality of supply through automated fault finding processes.

## SMART GRID OPERATOR

he enera project uses the concept of the smart grid operator to describe the changing role of grid operations. The gradual transformation from power grids to smart grids has also changed the role of distribution grid operators. In the past, operations management focused on repair and maintenance measures and troubleshooting, particularly on distribution grids. In future, smart grids will expand these responsibilities: indiviudal pieces of grid operating equipment and the consumption of grid customers will be actively monitored and controlled. The use of flexibility markets for the predictive resolution of congestion, as demonstrated by the enera project, represents a key change in the role of grid operators. At the same time, grid operators have access to increased transparency on grid conditions and the beginnings of automated control in real time.

## FLEXIBILISATION AND DIGITISATION

The enera project is based on a systemic approach that combines solutions related to grids, markets and data. To connect these three fields, the project team first had to develop the digital infrastructure for the future energy system in the model region. By installing communication technology and sensor systems, the team ensured that information on distributed generators and consumers as well as on power grid conditions was available virtually in real-time. The SDSP data and service platform designed for this express purpose pools this information and makes it available to the various applications developed over the course of the project.

To increase the courses of action for grid operators on the smart grid, the project team installed and tested innovative grid operating equipment. Automated processes and reliable forecasts give control centres more leeway, thus allowing them to use power grid capacities in the best possible way and to efficiently resolve grid congestion. The enera flex market also provides grid operators with a market-based alternative to the curtailment of renewable energy in the event of congestion. For this, the team integrated generators and consumers into the digital infrastructure, enabling both grid operators and marketers to act on the flex market via virtual power plants.

## DATA-BASED VALUE ADDED IN THE DIGITAL ENERGY WORLD

In the energy industry, the traditional value chain has hitherto been based on the generation, transport, distribution and use of energy. The liberalisation of the markets also led to an increase in the importance of sales and trade. The energy system is now becoming more and more digital – which means it is also becoming faster, more efficient, dynamic and flexible. This is a prerequisite for integrating large amounts of renewable energy into the system, as enera has shown with the extensive use of sensor systems as well as by demonstrating the effect of smart grid operators and the flex market, for example.

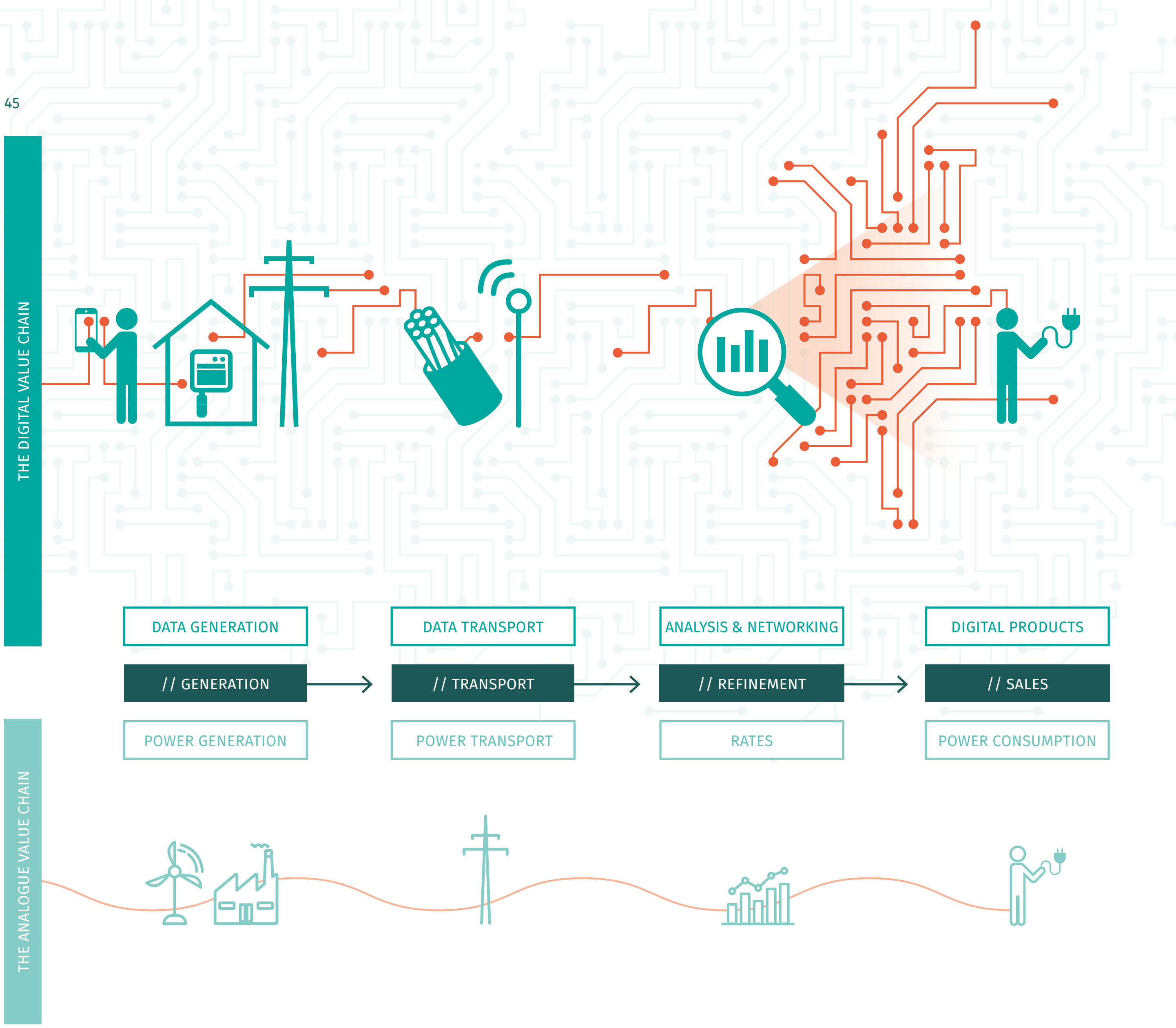
FURTHER DETAILS
**SDSP data and service platform**
→ p. 78, Work Package 02

Besides optimising the conventional energy world, digitisation has also given rise to something completely new: data-based value added. Here, energy consumers are more than power purchasers: they also generate data. Households, industry and trade are assigned new roles and are at the beginning of this new value chain, which initially includes the generation of data that results from the behaviour of generators, energy consumers and grid technology and can be recorded by smart meters. These data are transported via gateways and CDMA communication networks, for example, and can be stored on smart platforms such as the SDSP platform in enera. The raw data are structured and processed via platforms, microservices and by means of disaggregation to ensure they are available and can be used and distributed.

The applications developed in enera include apps to analyse energy consumption and input; the verification platform for the flex market; charge control systems for electric vehicle fleets; as well as smart objects that visualise energy consumption. Information and IT security as well as data privacy are key requirements each link in this value chain has to meet. Based on the data models required for these applications, the team advanced the Smart Grid Logical Data Model (SG-LDM), for example.

Over the course of enera, the team viewed the new, digital value chain as a whole and brought it to life. This entailed a fundamental shift in perspective: the team no longer viewed consumers as mere purchasers of energy; as application users, they were involved in the development process of data-based services from day one and their needs determined a product's design and functions. enera invited private individuals as well as commercial customers and experts from various disciplines within the energy industry to take part in numerous workshops, barcamps and other formats, where they developed data-based applications and business models together.

New, data-based business models are only viable if users are convinced that they can be trusted to handle sensitive information. This includes employing the principles of safety by design to ensure the utmost level of security and allowing users to elect which data is used, particularly if said data is also to be used for other than energy-related purposes. This may include

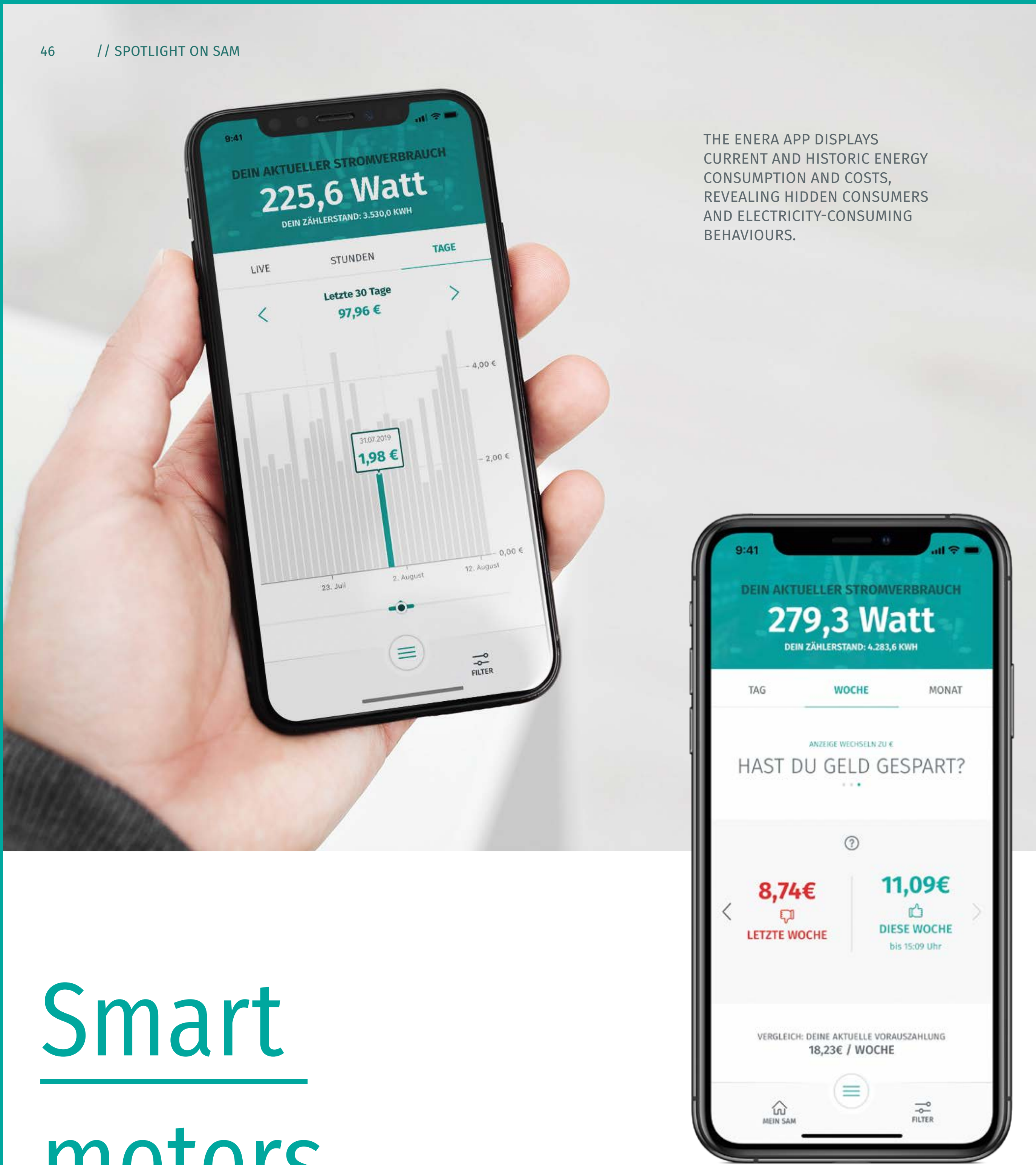



remote access to check if the cooker is still on, if there are any deviations in households of people in need and if there is water damage.

Data-based value added requires technologies that can process large amounts of data efficiently and can then make them available to various services, flexibly and in real time. This in turn requires modern platform technologies that make various microservices available to a wide range of applications at the same time, as opposed to isolated apps and data silos. Processing and analysing mass data with the aid of new methods such as artificial intelligence, machine learning and big data analyses gives rise to a range of options that far exceed the possibilities of conventional IT. To harness this potential, the energy industry in particular needs to raise awareness for the opportunities data science has to offer. //

## THE DIGITAL VALUE CHAIN

The digitisation of the energy supply has given rise to a data-based value chain. Households, industry and trade are at the beginning of this chain; these consumers purchase energy and at the same time generate data that then form the basis for innovative, digital products.




THE ENERA APP DISPLAYS CURRENT AND HISTORIC ENERGY CONSUMPTION AND COSTS, REVEALING HIDDEN CONSUMERS AND ELECTRICITY-CONSUMING BEHAVIOURS.

# Smart meters

## 700 households and municipalities join the field test

In 2020, energy consumption was still being measured by means of a tried-and-tested 19th century technology. With their horizontal, rotating aluminium discs and mechanical counters, Ferraris meters are still the standard in households and small businesses today. How fitting that these meters are housed in black boxes: after all, they are one reason why the energy system lacks transparency and can be considered a black box in itself.

In contrast, a smart meter comprises a modern metering device and a certified smart meter gateway as a local communication unit. Besides the gateway interface, modern metering devices, or electronic meters, are also equipped with a readout interface for customers; the latter was used in the project. The team installed a smart access module (SAM) on this optical interface – as a temporary alternative to the smart meter gateways, which at the start of the project were only able to provide measurement values at fifteen-minute intervals.

This combination of electronic meter and SAM was installed in more than 700 households and municipal properties. Over the course of the field test, enera demonstrated the benefits of smart metering at one-second intervals with these devices. Information provided in real-time allows the smart linking of consumption and generation; data with a high temporal resolution are also an essential foundation for the development of data-based products, services and business models.

The app identifies washing machines and cookers based on their consumption patterns.


THIS SMART ACCESS MODULE IS INSTALLED ON THE METER, WHERE IT RECORDS DATA. THEN THE ENERA APP IS READY TO GO.

## BENEFITS FOR CONSUMERS AND GRID OPERATORS

The consumption data formed the basis for the development of numerous applications and services; the raw data alone brought basic patterns of behaviour to light. In order to identify individual appliances within a household's load profile, the technology uses algorithms and machine learning processes that recognise washing machines and cookers, for example, based on typical energy intake patterns. Mobile apps visualise this consumption data so that users can see their consumption and the ongoing costs of their appliances and uncover hidden consumers, while comparisons with historic data allow users to determine the effects of energy-saving behaviour.

Besides the enera app for private customers, a range of other apps help make the current flow of energy in the user's household more transparent: owners of photovoltaic plants can use the EiVi smartphone app to find out how they can use as much of the solar power generated on their own roofs as possible. Smart mirrors are an even more haptic example, providing access to a range of consumption values via gestures. Smart access modules were also used to monitor the consumption of municipal properties, combined with a web application that visualises energy data and helps administrations manage energy efficiently. →

## // THE ENERA APP

The enera app displays the user's current energy consumption and costs to the second. When users take their smartphones and turn on any appliance in their homes, the additional consumption is immediately displayed, allowing them to track down appliances that consume a lot of energy.

## // THE PULSE APP

The Pulse app visualises consumption data as well as times of high grid loads. When households behave in a grid-friendly manner by consuming power outside of peak load times, they are rewarded for these micro-transactions via an integrated accounting system.

## // THE EIVI APP

The EiVi app visualises the input of solar power generated on the user's own roof. This smartphone app helps owners of photovoltaic plants find out how they can use as much of the solar power generated on their own roofs as possible at just one glance.

## // THE MUNICIPAL PROPERTY MONITOR

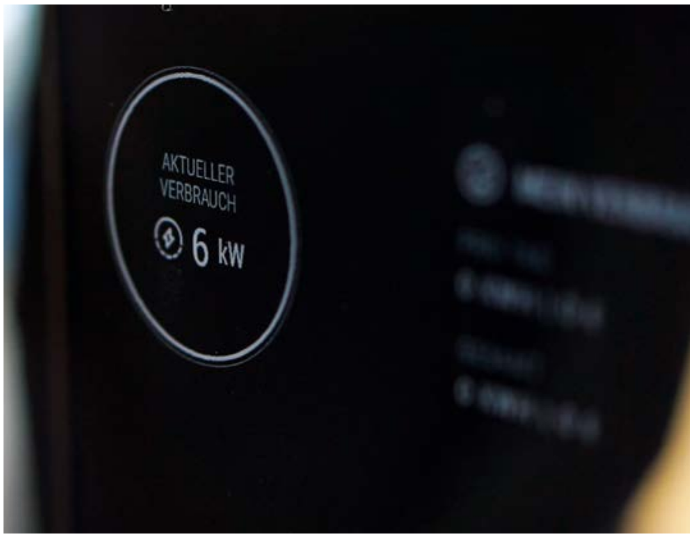
The municipal property monitor records consumption to the second and allows users to identify faulty devices via patterns in consumption. Municipal properties can be easily compared, providing a reliable foundation for planning and maintenance. The monitor helps administrations reduce their energy consumption, costs and greenhouse gas emissions.

## // SMART MIRRORS

Smart mirrors give users access to a range of consumption values via gestures, thus integrating the issue of energy into our everyday lives. Once variable electricity rates have become established, smart mirrors could also be used to control devices.

All applications have been designed for use with smart meters; since October 2020, smart meter gateways have provided the necessary, certified rate use cases that enable high-resolution data to be read out at one-second intervals.

Smart mirrors, for example, have already successfully read out and visualised consumption values recorded by smart meter gateways.





MIRROR, MIRROR, ON THE WALL – HOW MANY KW IS MY WASHING MACHINE USING AT THIS VERY MOMENT? SMART MIRRORS BRING TRANSPARENCY TO A HOUSEHOLD'S ENERGY FLOW.

| TYPE OF DAY | MEDIAN CONSUMPTION before 16 March 2020 | MEDIAN CONSUMPTION after 16 March 2020 | CHANGE IN PERCENT |
|---|---|---|---|
| WORKING DAYS | 10.55 kWh | 11.00 kWh | +4.3% |
| SATURDAYS | 11.49 kWh | 11.48 kWh | -0.1% |
| SUNDAYS | 11.94 kWh | 11.34 kWh | -5.0% |
| WEEKENDS | 11.72 kWh | 11.41 kWh | -2.6% |
| TOTAL | 10.91 kWh | 11.11 kWh | +1.8% |

### FLYING BLIND DURING LOCKDOWN

Due to a lack in data, many energy suppliers struggled to assess how the lockdown would impact energy consumption. Smart access modules, on the other hand, quickly visualised deviations in consumption, thus allowing suppliers to adapt electricity generation and purchases.

## DATA ILLUMINATE THE EFFECTS OF THE CORONAVIRUS PANDEMIC

Another benefit of the use of high-resolution electricity meters became apparent during the coronavirus pandemic, when millions of people were working from home and industry and trade temporarily shut down production. Initially, energy suppliers struggled to assess how this would impact energy consumption – lacking both the experience and the measurement values for this pandemic scenario. This is due to the fact that while the actual consumption of many industrial customers is measured at precise, fifteen-minute intervals, small businesses and private households generally only receive an annual statement on their consumption.

Many suppliers faced the problem of having to align the purchase and generation of energy with the change in consumption, without being able to quantify the effects of the coronavirus pandemic beforehand. Using the smart access modules as a data source, however, quickly allowed them to do so. A non-representative study among more than 200 households recorded the daily consumption during lockdown, differentiated between working days and weekends. The values were then compared to those prior to the closing of schools and shops in mid-March (→ table).

This comparison shows a clear rise of 4.3% on working days in particular. While energy consumption remains practically unchanged on Saturdays, there is a slightly lower demand on Sundays. In 42% of the households that took part in the study, consumption shifted from weekends to the working week. If we take the increase in a household's average energy demand of around 1.8% and project it for the year, this results in a median increase in consumption of around 70 kilowatt hours – roughly the annual consumption of an efficient, 150-litre refrigerator.

Some suppliers had initially estimated that the coronavirus pandemic would have a much higher impact. This example shows how precise metering can help energy suppliers react at an early stage, while at the same time enabling customers to assess how working from home and home schooling will impact their electricity bills. Metering at a large scale and in real time furthermore allows more precise forecasts; as a result, the energy system can be controlled in a more needs-oriented manner. //

# Grids, markets and data as the pillars of the energy system


// GRIDS

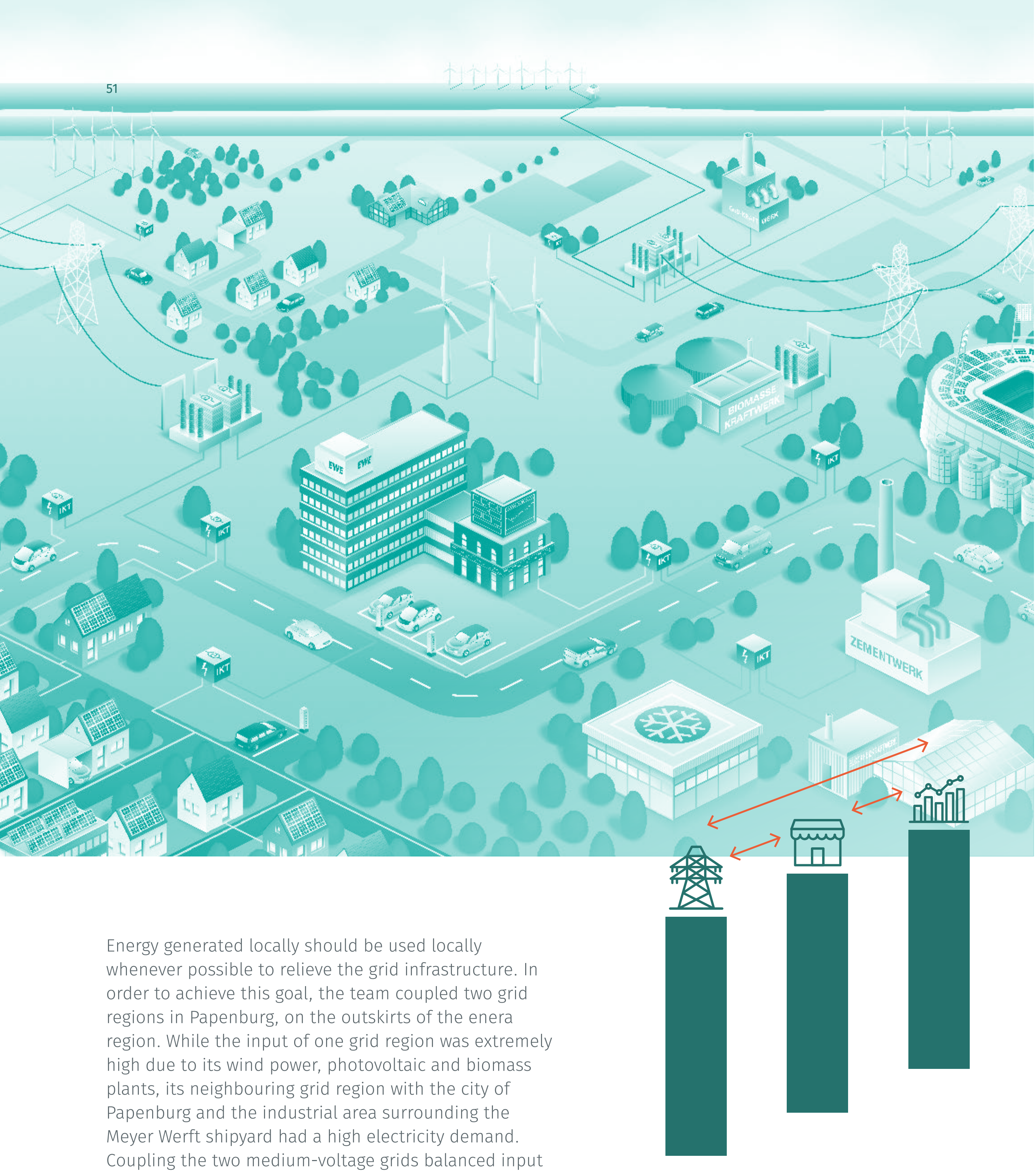
## WITH WITS AND COPPER

There are currently two dominant approaches that aim to guarantee system stability and security of supply for the electric energy supply in future: conventional grid expansion on the one hand and the modernisation of infrastructures by means of smart grid operating equipment and optimised capacities on the other – summarised in the concept of the smart grid.

The enera project successfully demonstrated how active grid operation management and grid-friendly trading on the flex market can contribute to the integration of renewable energy. To increase technical flexibility in the model region, the project upgraded generators and consumers, used innovative equipment, installed storage systems and plants to couple sectors and introduced power electronics and control agents, thus providing more options to stabilise grids for both active and reactive power.

While a lack of measurement and forecast data meant that many approaches to smart grid management could previously not be tested, this now became possible, thanks to the sensor systems installed as part of the enera project. The clear boundaries of the model region further allowed the project team to test systemic interactions between various components of the smart grid. The team also installed smart access modules to be able to gather comprehensive consumption data from private households and municipal properties, while the use of voltage regulators provided the technical foundation required to automate congestion management. This step was necessary in order to tap the optimisation potential through the use of flexibility and new data sources in grid operations.

In addition to automated congestion management as an innovative concept for operating distribution grids, the project tested other measures that pave the way from a passive to an actively operated, viable infrastructure, for example by constructing 210 regulated distribution transformers. These can improve voltage regulation on the grid so that more generation plants can be integrated into existing grids and allowed the team to investigate the impact of several transformers capable of independent control on the stability of the grid. With STATCOMs and STATCOM-compatible wind power plants, the project team tested another innovative voltage control technology in the field. These plants enable the control of reactive power on the grid, even in times of low input.

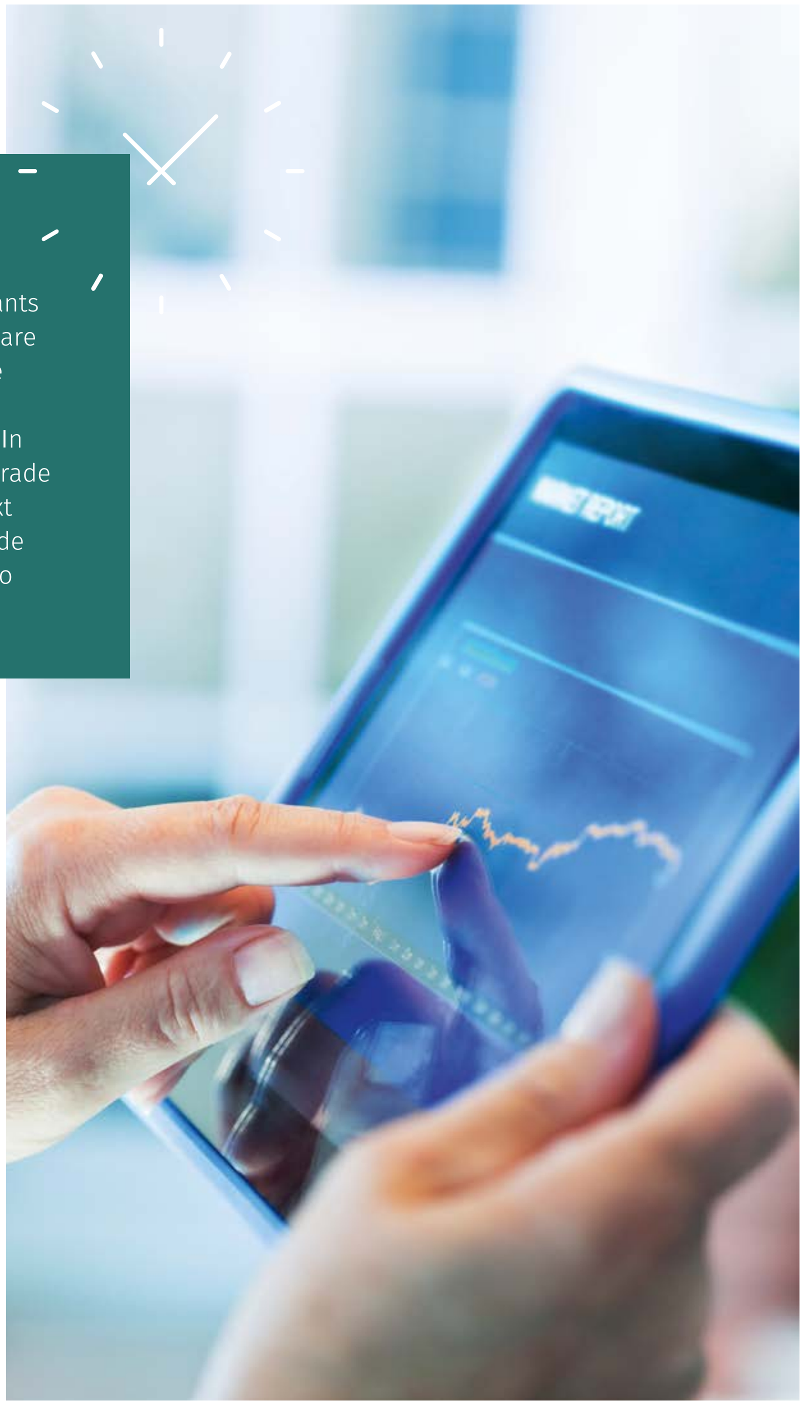



Energy generated locally should be used locally whenever possible to relieve the grid infrastructure. In order to achieve this goal, the team coupled two grid regions in Papenburg, on the outskirts of the enera region. While the input of one grid region was extremely high due to its wind power, photovoltaic and biomass plants, its neighbouring grid region with the city of Papenburg and the industrial area surrounding the Meyer Werft shipyard had a high electricity demand. Coupling the two medium-voltage grids balanced input and purchases on a local level and thus relieved the upstream grids.

The innovative concepts for managing distribution grids tested over the course of the enera project help guarantee a reliable supply even when electric energy is increasingly generated from fluctuating sources. The new grid operating equipment and functions have already been considered in tools used to plan grid expansions in a macroeconomic and efficient manner. enera also developed new approaches to forecasting grid conditions and advanced the technical cooperation between grid levels. →

## A FLEXIBLE AND DIGITAL SYSTEM

With its systemic approach, enera unites grids, markets and data. This creates more options on the smart grid, allowing renewable energy to be integrated more economically, and gives rise to new business models.



### INTRADAY MARKETS

On intraday markets, participants trade electricity supplies that are met the same day. Trades take place both on exchanges such as EPEX SPOT and off-market. In contrast, day-ahead markets trade electricity supplies for the next day, while futures markets trade supplies that are fulfilled up to several years in the future.

// MARKETS

## PURCHASING LOCAL FLEXIBILITIES

Previously, grid operators did not have access to market-based mechanisms for stabilising the power grid on a regional level. Congestion on the distribution grid is currently managed by curtailing plants centrally within the scope of feed-in management. For the first time, the enera flex market has now provided a market solution for the procurement of flexible active power that contributes considerably to grid stability across all voltage levels.

The flex market used established intraday markets as functioning role models, supplementing them with local order books for individual substation regions. In cooperation with the EPEX SPOT power exchange, the project team developed a trading platform for the enera flex market that grants both grid operators and marketers of regional flexibility access to the market. When congestion is forecast for a substation region, grid operators can submit their demand for flexible active power on the platform. Marketers then react to this demand by submitting bids to reduce feed-in or increase consumption.

Generators such as biogas, photovoltaic and wind power plants have been incorporated into the market, as have flexible power consumers that can adapt their consumption in a grid-friendly manner. The latter include industrial businesses and large-scale storage systems as well as smaller plants that are pooled in virtual power plants so that they can participate in the market. A wide range of technologies can be integrated into the market via these virtual power plants, including home storage systems, heat pumps and wallbox chargers for electric vehicles. The flex market could thus be of interest for consumers as well, as electric cars, for example, can be charged at a lower price when grids are congested. The flex market could also be significant to the hydrogen economy, which will be established over the coming years and is key to sector coupling. In order to use excess renewable energy to generate hydrogen in power-to-gas plants, we require market-based price signals.

The flex market provides transmission and distribution grid operators with an efficient, forecast-based congestion management tool that results in less renewable energy being curtailed through feed-in management. However, on the flex market, marketers are responsible for controlling individual plants, as opposed to grid operators, as is the case in feed-in management. This ensures that existing flexibilities are used especially efficiently – to manage congestion, as demonstrated in the enera project, as well as to balance energy to maintain frequencies or for other ancillary services. Virtual power plants can provide flexibility in areas with the strongest price signals that accordingly have the greatest demand, thus contributing to the efficiency of the entire power system.

With the flex market, enera has created the first market place for congestion management in Europe that has been modeled on the stock exchange. Although in the past various research projects ran field tests on prototypes of flexibility platforms, none of these were organised and operated professionally by a neutral third party – unlike the enera flex market, which can process thousands of orders per second and broker contracts between many different players. The market place was created for 23 parallel congestion areas in the model region and was in operation around the clock for more than one and a half years.

As a rule, open technology mechanisms for resolving congestion that integrate consumers, storage and input sources are more efficient than the direct curtailment of generators in feed-in management; in many situations, the flex market can therefore limit congestion management costs for grid operators. At the same time, this opens up new sources of revenue for flexibility marketers. However, market power and strategic behaviour may affect this economic efficiency, as in some local market regions, only very few plants provide input and only a few large consumers purchase electricity. The enera project therefore investigated on a scientific level how these undesirable effects can be identified and prevented from a regulatory perspective. →

## HYDROGEN AS THE KEY TO SECTOR COUPLING

As an energy source, hydrogen is multi-functional; as a result, it can be used either directly or indirectly in all sectors, for example as a synthetic fuel or as synthetic methane. Especially when it comes to industrial processes that cannot be electrified as well as heavy forms of transport, such as commercial vehicles, trains and lorries, hydrogen has a strong advantage and can connect the energy, industrial and traffic sectors. Green hydrogen plays a key role in terms of structuring renewable energy, with regard to both domestic generation and future exports. Combined with the smart use of the gas infrastructure and cavern storage, hydrogen can optimise the power grid expansion and provide all sectors with renewable energy at a large scale around the clock.

// DATA

## THE BASIS FOR IMPROVED CONTROL AND NEW BUSINESS MODELS

Energy consumers have moved to the front of the new, digital value chain.

Digitisation is changing established sectors fundamentally and gaining importance within the energy system as a central influencing factor. The fact that available data has improved both in terms of quality and quantity has revolutionised the options available to players and makes interacting with other industries easier. This is the basis for improving how an increasingly complex energy system is controlled and at the same time creates opportunities to identify and harness new potential to increase value.

enera addresses this potential, which is the foundation for new, data-based business models, products and services. In the course of this, enera pursues a cooperative approach when implementing innovations – together with project partners, innovative new economy companies and private users. The latter were at the very end of the energy industry’s conventional value chain, which starts with energy generation and progresses from transport to consumption. Now, these former “final consumers” have assumed a new role as suppliers of data and moved to the very front of the new, digital value chain that ranges from generation, security and transport to refinement and the utilization of data and forms the starting point for the development of digital products. Taking concepts identified within the team as a starting point, enera conducted potential analyses based on data science that were then transferred to prototypes in a structured process and turned into concrete, user-centric solutions.

Using smart networking and end-to-end digitisation, enera has shown how innovations can be developed within the energy system. In order to record, process and evaluate data, the team equipped various plants in the model region with sensor systems and actuator technology and integrated the plants into the communication network – the energy system became transparent. This allowed the team to gather information on the condition of any components within the energy system virtually in real time and to control components and processes. The project developed hard and software solutions as well as communication architectures to support the respective use cases in the best possible manner.

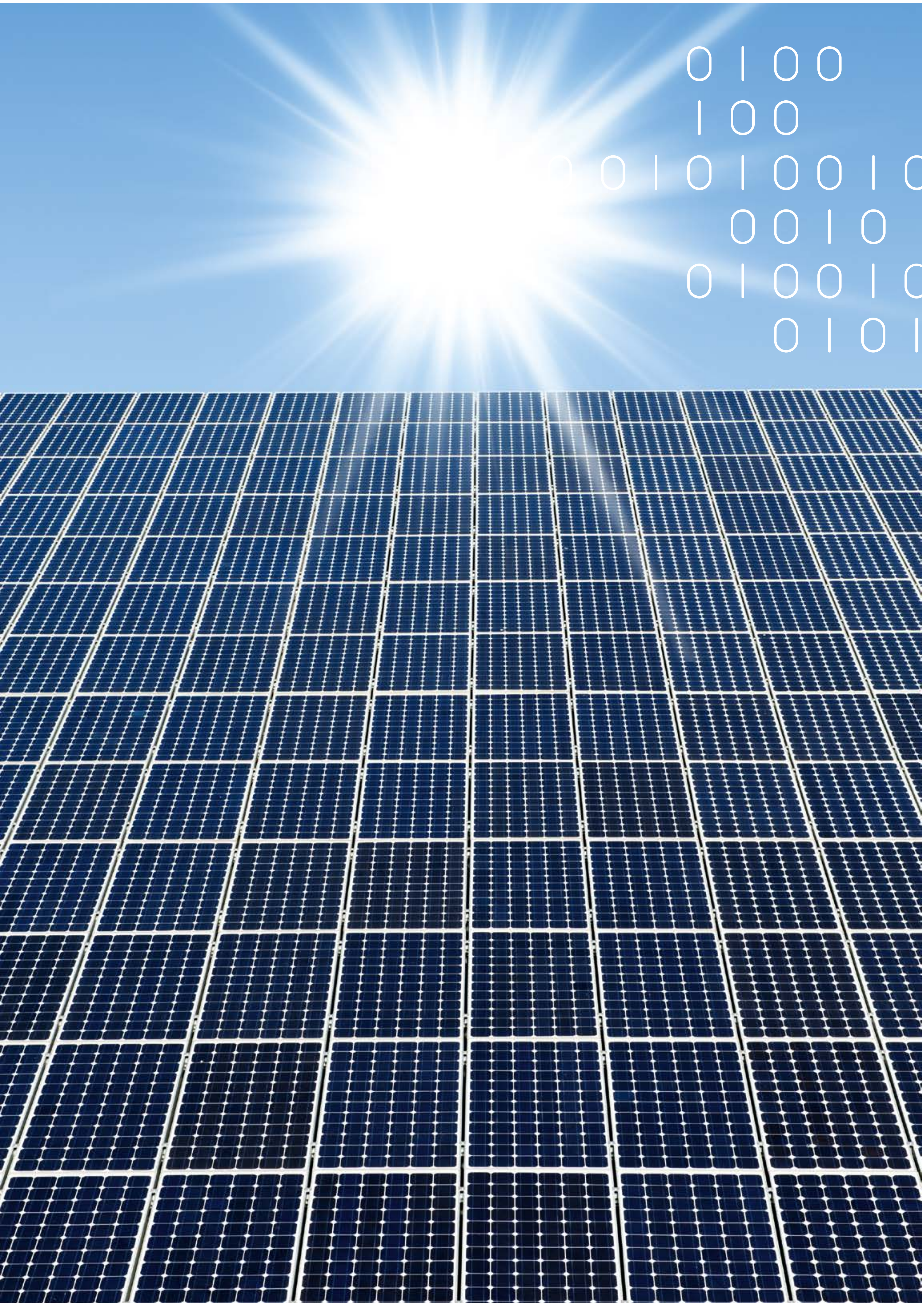
The Smart Data and Service Platform served as a central control centre and hub for all data, linking data generated in the model region to other information to create forecasts, for example, and to enable innovative applications and data analyses. When setting up the platform and the entire communication infrastructure, the team placed great importance on security, data privacy and standardised interfaces and advanced the development of information security standards as well as the Smart Grid Architecture Model (SGAM). As the state of the art changes over the course of four years, especially in the field of IT, the SDSP, originally planned and realised as an on-premises solution using local servers, was transferred to a more individual and flexible cloud solution while the project was still ongoing. //

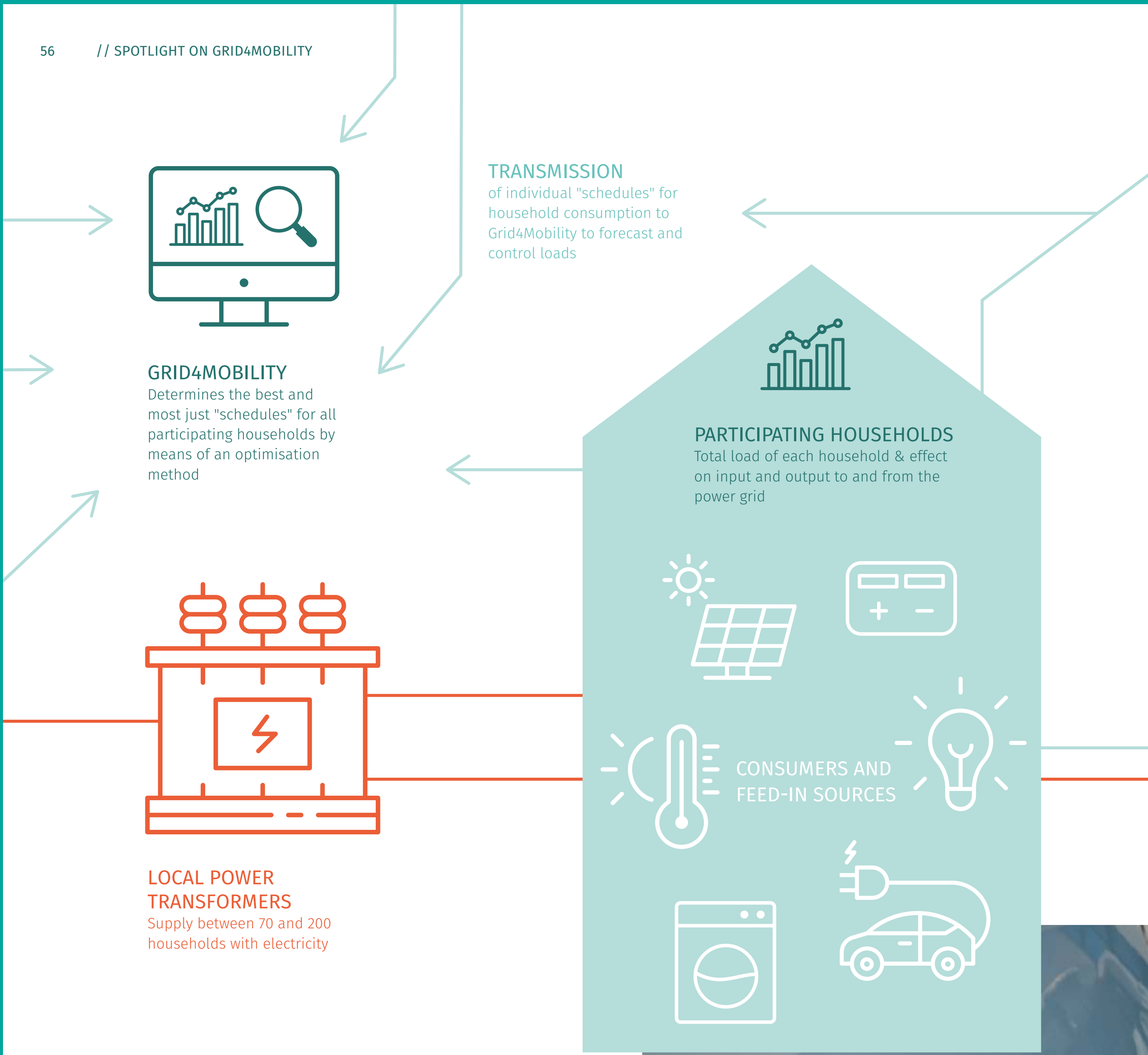
### FURTHER DETAILS

**Spotlight on SAM**
→ p. 46

**Courses of action to shape the framework of energy law**
→ p. 138, Work Package 08

**Flex market**
→ p. 24, Spotlight on the flex market
→ from p. 102, Work Packages 05, 06 & 07






## HARMONISING USER NEEDS AND GRID COMPATIBILITY

In the near future, power grids may face tremendous challenges due to the increase in electric vehicles. As public acceptance is essential to the success of electromobility, Grid4Mobility aims to harmonise net security and user needs. Often, a slight shift in charging processes and peak loads is enough to prevent bottlenecks. While users are generally still free to choose when to charge their vehicles, Grid4Mobility creates a virtual incentive system to make charging processes as grid-friendly as possible.

# An automated charge control system

## Every neighbour is an agent

CHARGING ONE ELECTRIC CAR IS NOT A PROBLEM FOR THE GRID. CHARGING AN ENTIRE FLEET, ON THE OTHER HAND, REQUIRES GRID EXPANSIONS – OR A SMART CHARGE CONTROL SYSTEM.

The energy transition is increasingly entering the mobility sector, where renewable energy is slowly replacing fossil fuels. This entails further challenges for the power distribution grid. In the near future, when more and more commuters finish work and connect their electric vehicles to the charging stations in their homes at the same time, bottlenecks in the low-voltage grid are foreseeable. This could be prevented by strengthening distribution grids, however, this is linked to major investments. Other possible alternatives to costly grid expansions include the balanced reduction in charging capacities for all users and the price-based prioritisation of individual connections. However, neither of these approaches to preventing bottlenecks consider the individual charging needs of all customers. Smart charge control systems are a fair, affordable and convenient alternative, as developed and demonstrated by the enera Grid4Mobility project. →

## ENERCOINS REWARD GRID-FRIENDLY CHARGING BEHAVIOUR

Even if large numbers of electric cars are connected to the grid at virtually the same time every evening, only a few vehicles will actually need to be available again within a short period of time. In principle, most batteries could be charged at sometime during the night, provided the needs of individual customers are considered and combined with smart charge management. In the Grid4Mobility project, a decentralised agent system automatically determines the order in which batteries are charged as soon as a bottleneck is forecast at the regulated distribution transformer. Every agent represents one household.

Calendar entries and historic consumption data provide information on how much power will presumably be consumed per quarter of an hour over the course of the next day, which forms the basis for an initial schedule. The agents then negotiate among each other, resulting in adjustments to the schedules to prevent bottlenecks at the regulated distribution transformer. This system aims to guarantee that vehicles of all households are available on time while at the same time improving the flexibility and grid-friendliness of the charging process.

Charging processes are all connected to a virtual pricing system: users who are flexible and thus demonstrate grid-friendly behaviour receive enercoins. Households can then use these enercoins to pay for their vehicle to be given priority in times of increased charging demands, which creates a non-monetary incentive to charge vehicles in a grid-friendly manner.

Schedules and negotiation results as well as forecast loads, loads that have been adapted for grid-friendliness and actual loads of all households are stored in an Ethereum blockchain in a transparent and verifiable manner. A large number of transactions can be documented in this decentralised register.

## A SHIFT IN LOADS PREVENTS GRID CONGESTION

The software used to control charging was first tested in the laboratory before undergoing a four-week field test with one vehicle. In the course of this, the wallbox used to charge the electric vehicle was embedded in a simulated local grid with a simulated bottleneck and other, generically-created model households. This smart charge control system can be realised with available technology, with the exception of the hardware developed specifically to provide the system with information on the battery's charging level. To implement the system throughout Germany, the smart meter gateway infrastructure could be used in communication, rating and accounting – this would require a nation-wide rollout as well as manufacturer-independent standards for the interfaces used to read out the charging state of electric cars and control wallboxes. At the dena Future Energy Lab, work on this is already underway: in the Blockchain Machine Identity Ledger project, team members are investigating interactions between blockchain-based infrastructures and smart meter gateways.

Grid4Mobility shows that smart, automated charge control systems actually do prevent bottlenecks on the simulated grid by shifting charging capacities temporally in a grid-friendly, user-oriented and needs-based fashion. As the agent system runs entirely in the background, participating households can charge their electric vehicles without sacrificing convenience. By integrating photovoltaic plants and storage systems into the system, charge processes could also be aligned temporally with solar power input, thus further relieving local grids. Beyond the boundaries of these concrete benefits, Grid4Mobility has also shown how blockchain technology can be used in a distributed and digital energy system in which many players interact. //

## BLOCKCHAIN TECHNOLOGY IN A DISTRIBUTED ENERGY SYSTEM

Blockchain technology has become widely recognised, at the latest since the hype around cryptocurrencies. The energy sector also has high expectations when it comes to this technology. Pilot projects focus on applications such as plant registers, proof of origin, invoices and electricity trading – in other words, on any area that calls for a large number of transactions to be documented and stored in a secure, unchangeable and transparent manner. enera uses blockchain technology to control the automated charging of electric vehicles.

# “We need incentives for artifical intelligence and digitisation”

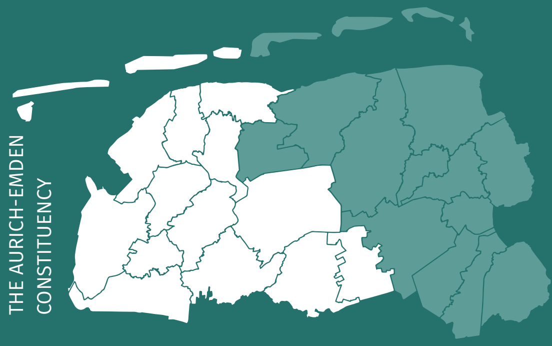
# JOHANN SAATHOFF,

**your constituency is located in the enera model region and you coordinate energy policies for your parliamentary party in the Bundestag. How far apart are East Frisia and Berlin when it comes to the energy transition?**

JOHANN SAATHOFF This project provided huge input for my work in parliament. In my home region, talks in connection with enera often went into great detail with regard to the energy economy, which was taxing, but at the same time showed us just how much expertise went into enera. Time and again I became aware of the untapped potential of our existing lines. Digitising and automating operations management can make our grids more efficient; we are not even using a third of the capacity of the German transmission grid, for example. And when distribution grids have too much or too little electricity, they can't even be connected directly to enable an exchange; they can only be connected via the transmission grid. In terms of grid expansions, we can save a lot of money if we not only create incentives with regard to concrete and copper, as we have in the past, but with regard to artificial intelligence and digitisation as well.

**enera provided a market-based solution for flexible generators and consumers to resolve bottlenecks on the grid, trading flexibilities for the regions surrounding a substation in East Frisia on the European power exchange. In the past, you sometimes seemed sceptical of market mechanisms – do you think a flex market is a reasonable solution?**

JS Markets aren't a universal solution. Introducing them in areas where they simply will not work will not save money, on the contrary; it can end up costing more. However, this does not apply to the market tested in enera. Local energy markets make a lot of sense, as less renewable energy has to be curtailed. We need non-discriminatory markets to trade flexible active power and procure ancillary services, as framework conditions within the energy system have changed dramatically. However, regional markets for grid-friendly flexibility can only work if we adapt the regulatory framework. In the political sphere, we can recognise a strong mutual willingness to make the field of power-to-X more appealing. After all, hydrogen isn't making any money at the moment. In contrast, there is a lot less agreement in a lot of other areas of the tax and levy system. →




JOHANN SAATHOFF is an SPD member of the Bundestag for the Aurich-Emden constituency, which is located within the enera model region.

In the Committee on Economic Affairs and Energy, he takes a close look at the energy transition and grid expansion. Johann Saathoff is the deputy spokesman on committee and the energy policy coordinator for the SPD parliamentary party.

### How many people in the model region are willing to contribute to the energy transition?

JS A lot of households took part in enera and made their power consumption data available. Which does not surprise me, as a lot of people in the region identify with the energy transition. Most of them understand that the fossil energy era is over and they are proud that so much climate-friendly power is generated in the north of Germany. Unfortunately, as yet we do not have flexible power rates that enable consumers to react to an excess offer of renewable energy. enera at least helped households track and evaluate their consumption in real time. People are definitely willing to change their behaviour. This support for the energy transition may have something to do with the fact that being on the coast, we are directly impacted by climate change and rising sea levels. I can tell people are taking a good look at these aspects, and not just in my volunteer work as chairman of the board responsible for maintaining our dykes in Krummhörn. East Frisia has an awareness of climate change that parliamentarians with a more alpine socialisation lack in Berlin.

### East Frisia is a pioneer of wind power, however, the construction of new plants is often met with resistance in other places. How can we create greater acceptance?

JS One argument is that more wind turbines mean more electricity will be curtailed and remain unused. However, if enera shows that flexible consumption, for example, can help solve this problem, the public will be more willing to accept the energy transition. I am happy to make the battery storage system connected to my photovoltaic plant available to absorb excess wind power. If ten thousand other people were to do the same, it would be of tremendous relevance, as this would prevent grid congestion and ensure energy is used sensibly. I am convinced that this is one way in which many people are willing to contribute to the energy transition, using their electric cars in a grid-friendly manner, for example. And accepting the fact that their batteries aren't always fully charged. The important thing here is that everyone benefit from renewables; everyone should be able to make private investments into renewable energy generation. And to ensure that everyone benefits from renewables, from millionaires to people on income support, I believe municipal holdings in wind and solar farms are the way to go.

### What are the next steps after enera?

JS The individual SINTEG programmes have come to very similar conclusions regarding the energy system of the future, which we now need to embed in law. However, my concern is that the final reports, and the findings from the research projects they contain, will be put on the shelf to gather dust – essentially dampening this innovative boost. We need to prevent that. Lengthy certification processes initially meant the SINTEG projects didn't have access to smart meters. enera was therefore only able to roll out several hundred smart meters instead of several tens of thousands, as planned, limiting the extent to which some solutions and data-based business models could be tested. However, if we parliamentarians are to finalise new regulations for a digital energy system, we need a sound basis for our decisions – we need to know what works and what doesn't. That's why I would like to see a large-scale SINTEG 2.0 research programme that reviews the many innovative approaches in terms of feasibility. //

"If flexible consumption means curtailing less wind power, the public will be more willing to accept the energy transition."

# From experiments to the energy system of the future

An overarching funding programme such as SINTEG with its five model regions has the potential to unfold its effects on both a national and international level. The forms of marketing flexibilities, innovative smart grid components and data-based business models tested in the model regions can be used as blueprints in all large grid regions across the German states (*Länder*).

FURTHER DETAILS

**The hybrid model**
→ p. 266 of the enera project compendium at www.projekt-enera.de

**Coordination between grid operators**
→ p. 112, Work Package 07

**Verification**
→ p. 112, Work Package 07

## THE SINTEG EXPERIMENTATION CLAUSE

In accordance with a resolution by the Bundestag, the SINTEG experimentation clause was added to the Act on the Power and Gas Supply and implemented through the SINTEG Ordinance. This enables project partners to obtain compensation for economic disadvantages that result from their project activities and at the same time grants grid operators the freedom to test the functionalities of flexibility platforms within the scope of the project.

## A FULL PACKAGE FOR THE GLOBAL MARKET

The SINTEG programme has developed pioneering solutions, and not just for Germany: they can be transferred to other countries as well. Accordingly, the SINTEG projects attracted international attention from the start. Among the ranks of European flexibility projects, enera has assumed a pioneering role, meaning there is a good chance the overall product comprising regulation, market design and technical solutions can be positioned on the global market. This also means that results that cannot yet be realised outside of the project in Germany due to the regulatory framework can still be exploited. However, in order to market solutions internationally, the industrial-political course must be set appropriately, accompanied by the strategic use of blueprints.

## THE ROLE OF ENERA IN REDISPATCH 2.0

enera has resulted in implications for the future legal framework as well as for the concrete design of regulations that have already been resolved. This applies in particular to Redispatch 2.0, which results from the Power Line Expansion Acceleration Act (NABEG 2.0). In this context, dispatch means power plant scheduling and deployment, while re-dispatch refers to changes thereof at short notice in the event of grid congestion. To date, deviations from schedule are ordered exclusively by transmission grid operators; in future, distribution grid operators will also be involved in re-dispatching. Another key change: while this only affects large-scale conventional generators to date, renewable power generation and cogeneration will be included in the reorganisation scheduled for October 2021, as distributed plants can usually help resolve local bottlenecks more accurately than conventional large-scale power plants. This is expected to reduce re-dispatch costs.

enera has shown how flexible players can balance fluctuations in power generation and consumption in a market-based manner on a local level. In enera, the team developed processes and tools that allow grid operators on different voltage levels to coordinate operations efficiently. Many components of the flex market can also be employed in Redispatch 2.0, including coordination among grid operators, forecasts for grid operators and marketers, verification processes and master data storage. enera also provides the know-how to include smaller and renewable energy generators into the new re-dispatch regime from an information technology perspective and to control them.

Findings gained in enera can also be used to integrate flexibility on the demand side as well as small generation plants into German re-dispatch mechanisms. Plants like these, which are not controlled through cost-based congestion management, would provide grid operators with a larger pool of flexibility and thus improve the overall efficiency of congestion management. This hybrid concept has been summarised in a paper compiled by the enera project. →

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Among the ranks of flexibility projects, enera has assumed a pioneering role throughout Europe.

## TRANSFERRING THE ENERA RESULTS TO THE WHOLE OF GERMANY

In order for innovations for the energy system to progress more quickly from laboratories to the markets, the German Cabinet passed an experimentation clause especially for the SINTEG programme. This ordinance compensates economic disadvantages that result from the testing of new technologies, methods and business models, allowing for the reimbursement of taxes on electricity rates arising from participation in the project, for example. In order for innovations to be employed outside of the experimentation clause, the legal framework needs to be adapted on a national and European level. Determining this need for adaptation was a key task of the team that provided enera with scientific support.

Simulations illustrate what transferring the project results to the whole of Germany would mean and the team set up four scenarios each for the future energy system in 2030, 2040 and 2050. The simulations allowed the team to assess the potential of flexible power consumption in individual regions; to investigate the integration of grid-friendly generators and consumers into the nation-wide power market; and to analyse the impact on the transmission grid.

Tools that help plan the grid expansion efficiently in terms of both business and the overall economy have been adapted to now consider active grid operations and regulatory requirements. In addition, the team developed recommendations on how to guarantee security within a highly-complex, digital energy system.

## THE NEXT STEP FOR THE FLEX MARKET

As a rule, the market solution with local order books developed within the project is a suitable tool to integrate grid-friendly adjustments to consumption and generation into the re-dispatching process. The enera team deliberated and tested the accompanying technical systems and processes thoroughly, at the same time establishing integral regulations and concluding contracts between all actors.

Currently, regulatory obstacles and a lack of incentive prevent the nationwide implementation outside of SINTEG. During the field test, for example, it became apparent that it is often not economic for consumer plants to offer their grid-friendly flexibility, primarily due to the taxes and levies on the power additionally consumed. These are particularly significant as electricity is subject to much higher taxes and levies than the energy carrier natural gas, for example. This means gas-based processes such as heat generation cannot be replaced by electricity-based processes, even in times of excess electricity – which makes no economic sense.

Reforming fee and levy systems so that flex markets can be used to create actual incentive to consume excess electricity locally in the event of congestion would drive the energy transition as a whole. Coordination mechanisms like these are fundamental to the flexible generation of green hydrogen using excess electricity and the integration of electric cars to stabilise the grid.

## CONNECTING ENERGY

The energy transition is too extensive to be viewed solely from the perspective of individual fields such as trade, transport and distribution; we need to view and implement this project of historic dimensions as a whole. However, bringing together experts from individual disciplines is just the first step: we also need to find a common language so that experts can develop and implement innovative ideas. enera has offered scientists and practitioners alike a format to develop and implement new ideas on the basis of concrete problems.

The solutions will stay with us after the project has ended – just as importantly, so will the trust gained between the key players of the energy system. This is the foundation that will allow us to work on concrete problems, long after enera has ended. //

# The work packages within enera

As a collaborative project that aimed to demonstrate the next major step for the energy transition, enera united partners from various fields and areas of competence, all of which contributed their expertise to develop interconnected solutions together.

Within 13 work packages, various industries as well as scientists and practitioners cooperated on concrete problems. In the following, these work packages will be introduced in detail.

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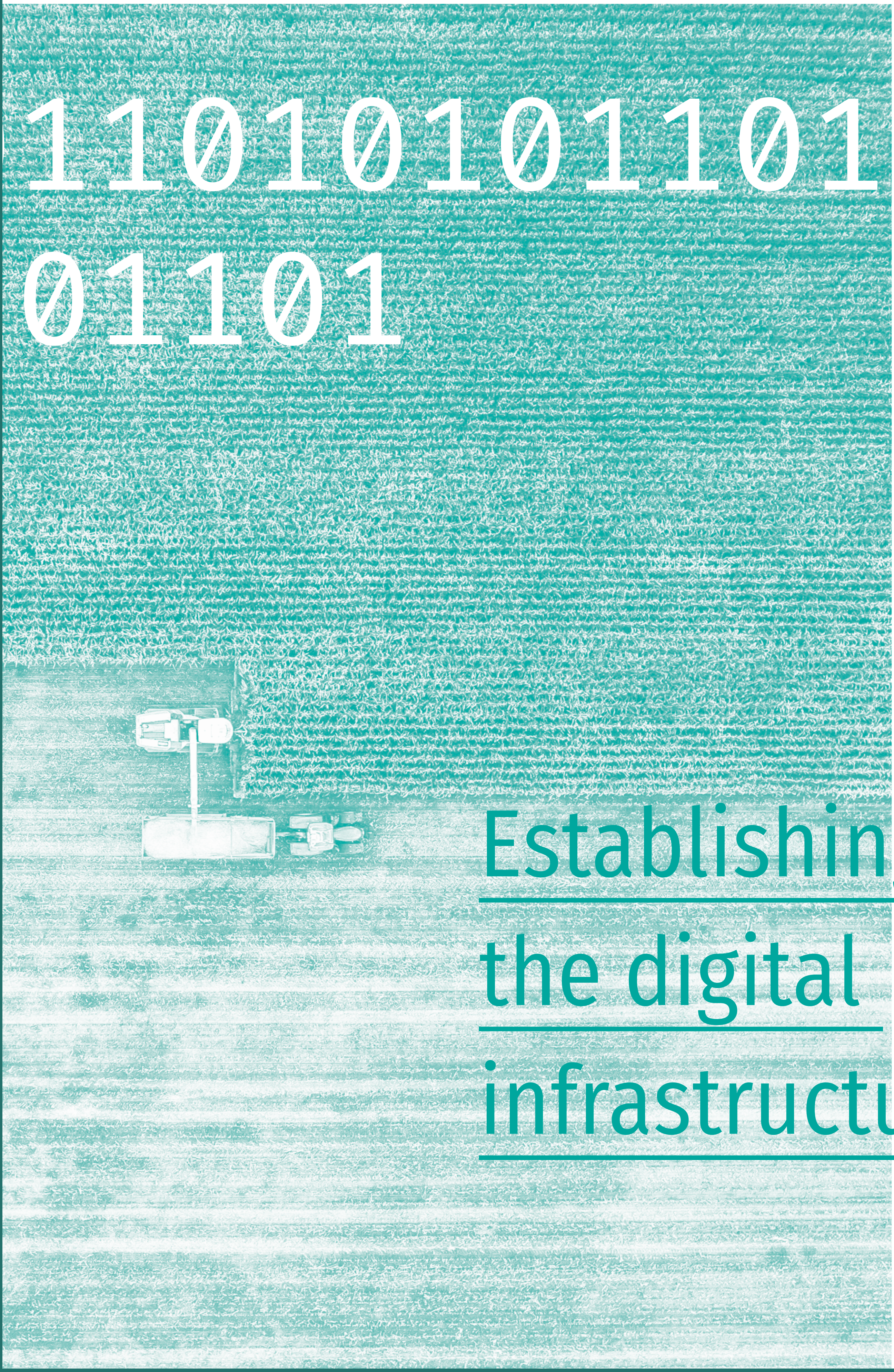
Connecting distributed generators and consumers to the IT system opens up new options for grids and markets.

CHAPTER I

# The Digital Infrastructure




# Establishing the digital infrastructure

The next step towards the energy transition is based largely on data. Without reliable forecasts and real-time information on distributed generators and consumers, power grids, trading platforms and the environment, there would be no smart grid and no flex market. The project teams therefore established extensive digital sensor systems and actuator technology for these core projects within enera.

In enera, almost all components of the energy system are connected; measuring and communication systems, data platforms and newly-developed interfaces ensure players can interact with one another. In addition, big data methods have turned these data into the basis for new business models.

Automated processes, reliable forecasts and innovative grid operating equipment expand the courses of action available to grid operators within a complex, distributed energy system. Smart grid operators have a range of new tools that allow them to utilize power grid capacities as best possible and resolve grid congestion.

However, besides opening up new opportunities, extensive digital connectivity also poses new challenges. Software and IT infrastructures need to be structured so that information is transmitted securely and reliably at all times, while new tools, processes and methods mean employees need specific qualifications.

The team in **Work Package 1** installed the communication infrastructure and measuring systems. These were then used to gather mass data from various sources; the data were then combined on a central data platform, for which **Work Package 2** was responsible. **Work Packages 3 and 4** tested innovative grid operating equipment, automated processes and tools for smart grid operators and put them into practice. **Work Package 12** was tasked with guaranteeing information and IT security for the entire project, while the team in **Work Package 10** ensured employees were qualified to handle the new technologies. //

# Data as the basis of the energy transition

THE DATA FOR THE ENERGY INFRASTRUCTURE ARE TRANSMITTED BY A SEPARATE RADIO NETWORK.

Digitisation plays a key role in the conversion of the energy system, providing real-time information on distributed generators and consumers, battery storage systems and grids. This enables operators to efficiently control and connect these plants. The digital sensor systems and actuator technology installed in Work Package 1 created the technical foundation for the flow of data in the enera project.

The team focused on rolling out smart meters and establishing a communication infrastructure in accordance with the requirements of the energy industry. In the course of this, we were tasked with digitally connecting more than 700 private households and municipal bodies; we also installed a designated radio network for the model region as well as digital measuring stations on the power distribution grid. Our responsibilities further included testing measurement and control technology.

In order to transmit and process data that has been generated in a decentralised manner, it is necessary to establish a secure and reliable infrastructure. Against this background, legislature resolved the use of certified smart meters, which will be the standard for electronic meters that communicate digitally in future.

## SMART MEASUREMENT AND CONTROL

At the end of 2020, the Federal Office for Information Security (BSI) issued the General Ruling on the Determination of Technical Possibilities for the Installation of Smart Meters, thus giving the smart meter rollout the go-ahead. This approval had originally been expected at a much earlier date, as the legal basis had already been created in August 2016 with the Act on the Digitisation of the Energy Transition. The basic concept is as follows: in order to use energy generated by an increasing number of photovoltaic modules and wind turbines as best possible, smart meters need to be rolled out on a large scale so that final consumers and distributed generators can react flexibly to local grid conditions by means of these interfaces.
Smart meters consist of a modern metering device and a communications unit, known as a smart meter gateway. The modern metering device is a digital electricity meter that records consumption and usage time and consists of an electronic measuring element and a digital display. These devices can be connected to the communication system. However, as this has not yet been done, they cannot be read out remotely.
Smart meter gateways are a necessity in order to securely integrate digital electricity meters into a communication network; this also enables the incorporation of other devices beside modern metering devices, including renewable power generators and heat pumps. Smart meter gateways and the technical operators responsible for said gateways have to be certified by the Federal Office for Information Security. By 2032, all consumers are expected to have been equipped with modern metering devices.

“In order to use generated energy as best possible, smart meters need to be rolled out on a large scale.”

## SECURE DATA TRANSMISSIONS BY RADIO AND CABLE

For the enera project, we first had to set up the information and communication technology in a way that ensured data on the energy flow in the model region could be transmitted reliably. There are a range of technologies to do so that can essentially be divided into wired and wireless; within the scope of enera, we primarily focused on Powerline and CDMA 450 technology. Depending on the areas in which they are used, both have advantages and disadvantages. →

“The energy transition and meeting climate targets are key concerns of mine. I want to play an active part in innovative projects that add value to the community. enera was innovative and successful in addressing these central issues.”

AGNETHA FLORE, OFFIS

Agnetha Flore is a Senior Researcher in the field of energy at OFFIS. She is a certified project manager with many years of experience in IT and organisational projects. Three years ago, she began focussing on R&D projects, specialising in the energy industry. Agnetha Flore also completed her doctorate on migration paths in smart grids in the energy domain.

Powerline technology uses the grid operator's existing power cable to transmit data packages – a process similar to that used in households, where devices that cannot easily be accessed via WLAN are integrated into the home network by plugging an adapter into a socket. CDMA 450, on the other hand, transmits data by radio – just like our mobile phones. As the enera model region is a more rural area and has the ideal topographical conditions to transmit data by radio, we selected this technology, which can also be used to transmit measurement and control data.

## ROLLING OUT METERS FOR FINAL CONSUMERS

When planning the rollout of the meters, we had to consider a number of technical and regulatory constraints. The selection of the measurement and control systems was followed by the establishment of backbone systems that are used to manage interfaces as well as meter and measurement data and to run function and interoperability tests. For the installation and operation of the meters, we developed guidelines for internal and external communications on the new business processes.
Due to delays in the certification process for smart meter gateways – the communication units of the meters – we were unable to employ this technology on time. However, as these data with their high temporal resolution were of key import for enera, we needed to find an alternative solution. After testing several systems, we ultimately combined smart access modules (SAM) with modern metering devices – in other words, electronic meters not equipped with a communication unit – installing them in more than 700 households and public properties. The modules use the optical interface of the electricity meter to read out power consumption data at one-second intervals and transmit them to a data platform via the customer's WLAN; an app can be used to visualise the power consumption measured in real time.

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All data needs to be recorded and digitised.

## REGULATING PLANTS USING SMART METERS

However, the communicative connectivity of smart meters can be used for more than just transmitting and invoicing energy consumption values. Generators such as photovoltaic and cogeneration plants as well as consumers such as heat pumps and electromobility charging stations can all be connected to an overarching energy management system using highly secure smart meter gateways. In the event of grid congestion, grid operators can use the interface of the controllable local system (CLS) to curtail individual plants as needed. Operators can even use control boxes with four power settings to integrate and regulate existing plants that are not compatible with CLS. As a result, generation and consumption plants do not need to be curtailed completely when problematic situations arise on the grid and can instead be used to resolve congestion in a staggered approach. We tested the latter within the scope of enera as part of the grid-friendly management of the charging station infrastructure.

## SOLUTION ELEMENTS

For detailed project reports, please go to the enera project compendium at: www.projekt-enera.de (German only)

**The rollout of smart meters**
→ p. 18

**Powerline**
→ p. 30

**Management via smart meters**
→ p. 34

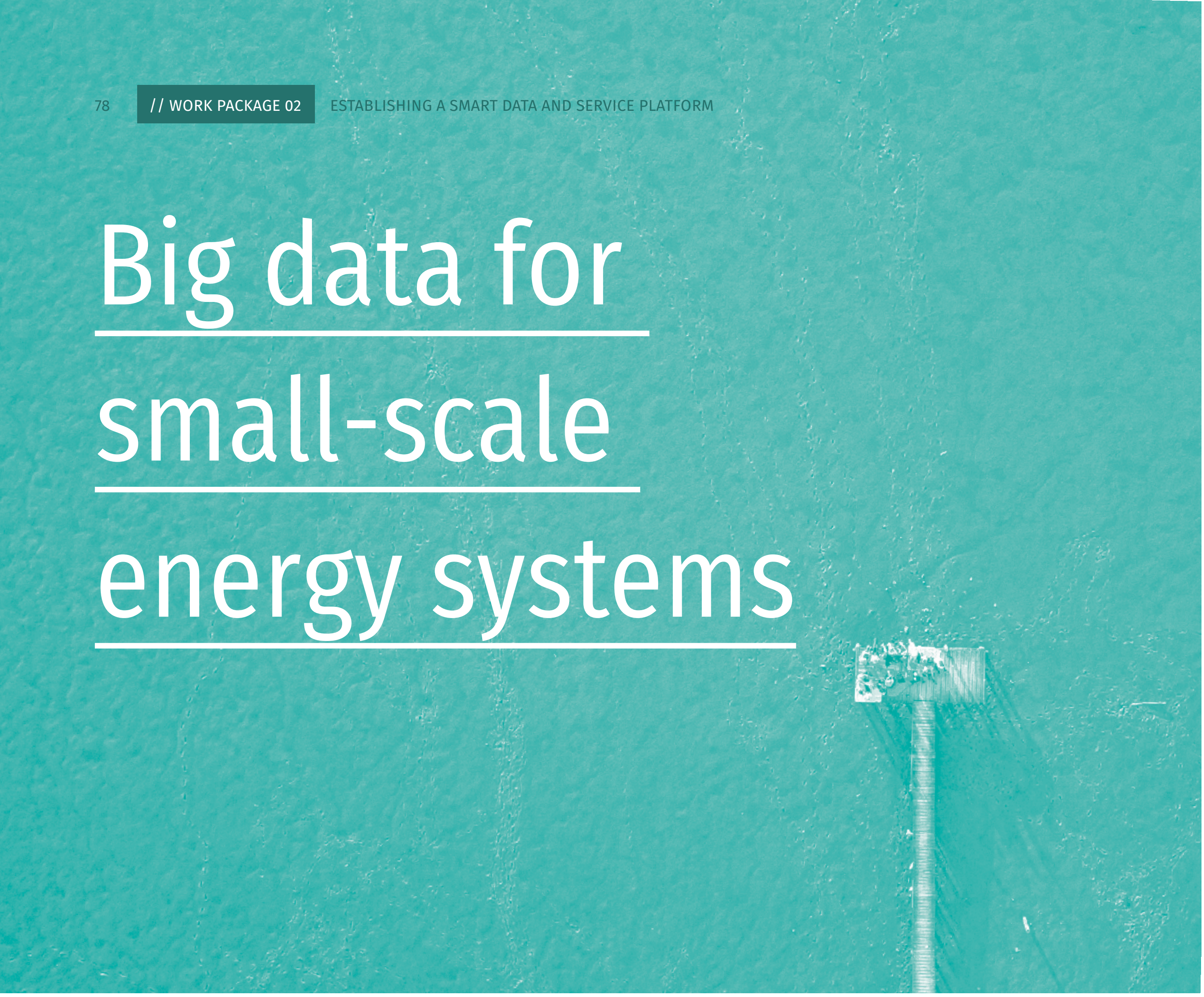
**Measurement and control**
→ p. 38

## MEASUREMENT AND CONTROL TECHNOLOGY ON THE DISTRIBUTION GRID

In order for grid operators to function as smart grid operators, operating controllable power grids efficiently and in real time, the data required for future processing and control needs to be gathered and digitised. As the project group in this work package, we therefore installed suitable measurement and control technology. First, we developed and tested a medium-voltage measurement concept for substations and switching substations and the communicative connectivity thereof. The same was done on the low-voltage level for substations and cable distribution cabinets.
We also developed a communication concept for the integration of voltage regulators and furthermore retrofitted substations and switching substations with medium-voltage sensor systems. Once it had been tested, the communication technology was used in several enera work packages during field tests. To prepare for this, we established a realistic communication infrastructure in an energy laboratory to check the robustness of the automated grid system. To guarantee IT security, we developed a manual for the devices employed and interfaces utilized, which served all project partners as a basis for their installations and connections. //

### PARTNERS INVOLVED:

3M Deutschland GmbH
BTC AG
devolo AG
EWE NETZ GmbH
OFFIS e. V.
PHOENIX CONTACT Energy Automation GmbH
Power Plus Communications AG
Theben AG



# Big data for small-scale energy systems

To advance the energy transition, we need to merge mass data from various sources – this is a foundation for efficient automation and control. Immense data pools also allow the development of new products, services and business models. In Work Package 2, the team established an IT platform as the central data hub for enera.

In the research project, the Smart Data and Service Platform (SDSP) served as an overarching collection of information and data for source and target systems. A wide range of energy-related data is fed into the platform, for example from power exchanges and virtual power plants. The platform records weather forecasts, grid conditions and household consumption data alike. However, the platform not only collects data, it also reviews and analyses them to determine connections, as well – providing a basis for business models across all levels of the value chain.

## SOLUTION ELEMENTS

For detailed project reports, please go to the enera project compendium at: www.projekt-enera.de (German only)

**The SDSP platform**
→ p. 44

**Smart energy services**
→ p. 48

**Mass data concept**
→ p. 50

**The Smart Grid Logical Data model**
→ p. 52

**Microservices**
→ p. 56

**B2B coordination**
→ p. 60

In our energy system, few large-scale conventional power plants are increasingly giving way to many small renewable energy generators. Coordinating these distributed plants in a market-oriented manner and integrating them into the power system is a central challenge. The big data platform ensures that all players can interact with one another seamlessly and that information is available across organisations. New functions, such as variable electricity rates, can be implemented by means of a software concept known as microservices. These autonomous services communicate via defined programming interfaces and simplify scalability, thus allowing for shorter development times and faster market launches.

## FROM THE DEMO VERSION TO A FULLY OPERATIONAL SYSTEM

After designing the SDSP, the team initially structured the platform as a development, test and demo system. To guarantee access to the data and services, we first had to obtain the consent of the various partners and set up access and authorisation management.
The infrastructure was incorporated into the operator's computer centre and operating processes.
As a next step, we focused on realising data-based, digital service offers, known as smart services. In the next phase, the developers then demonstrated the platform's stability and applicability and made the collected data available; this work was then documented and assessed.

## DATA FROM A RANGE OF SOURCES

Structured and unstructured data from various sources are fed into the platform, including historic and real-time information from national and local energy trading markets; wind power, photovoltaic and biogas plant schedules; consumption and generation forecasts for these plants; as well as input forecasts. Weather data on the current and forecast solar radiation as well as the wind force and direction are also included. Grid operators, for example, can use these data to forecast the input situation in the model region and to ultimately counter grid congestion at an early stage. The data gathered by the enera app used in private households are also stored on the platform. →

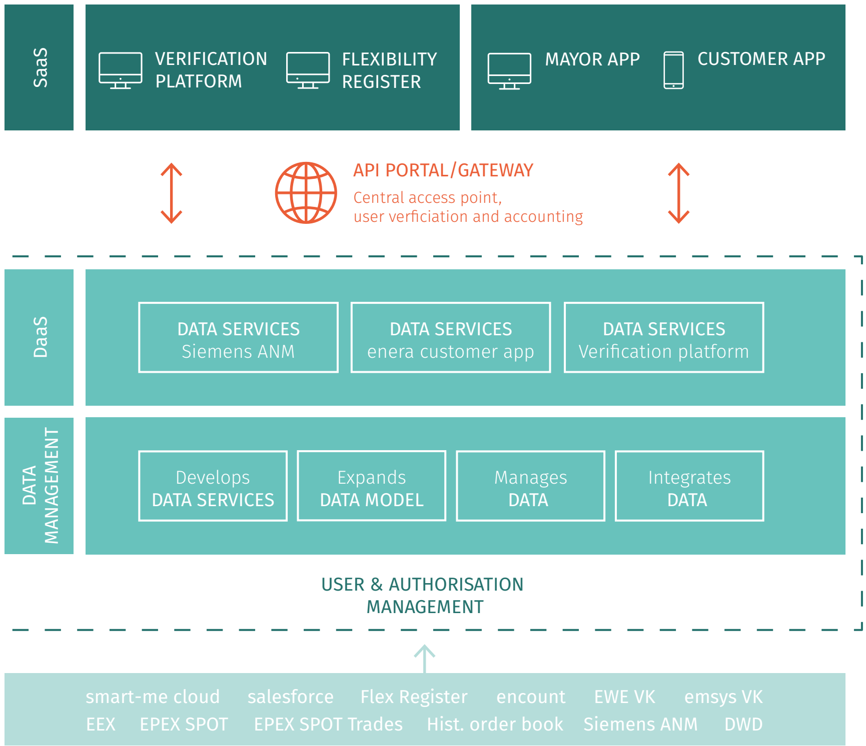
"When we started, we didn't know which deployment method – cloud or on-premises – was the right one for the platform. Now we do."

JENS WALTER, EWE AG

Jens Walter studied physics and has worked in IT Innovation at EWE AG for several years. His responsibilities in this role include supporting the digitisation of the EWE Group. This led to his involvement in positioning the Smart Data and Service Platform within the enera concept. Here, he coordinated the "Development and operation of the Smart Data and Service Platform" work package.

## DEVELOPING AND ESTABLISHING A SMART DATA AND SERVICE PLATFORM

The IT platform is the central data hub for enera and merges mass data from various sources – such as power exchanges, weather forecasts and consumers. These are the basis for ensuring efficient control within the energy system and at the same time enable the development of new products and services.




## OPERATIONS WITHOUT SECURITY GAPS

To validate the security of the SDSP and to obtain valuable findings on the operation of large platforms, the work package team conducted penetration tests. In the course of this, we employed the same means and methods any attacker would use to gain unauthorised access to the system. Our “ethical hackers” checked the verification platform for the enera flex market, the portal used to access services and data and the web services for enera customers. The result of these detailed tests: the hackers merely found weak points that were not considered serious and were easily rectified through software configuration settings and version updates. As a whole, the SDSP architecture meets IT security criteria. The hardware is housed in a certified computer centre and is operated according to the requirements for information security management systems in accordance with ISO 27001.

## STRUCTURING THE SEA OF DATA

With around 10 terabytes, enera generated an amount of data hitherto unavailable to the energy industry. The dimensions and degree of detail are both new, for example when it comes to consumption information. The data merged on the SDSP form the basis for realising services and products that have so far not been possible, by means of big data methods. The IT platform not only collects data, it puts them in relation to one another. By giving data a uniform structure, for example via the Smart Grid Logical Data Model (SG-LDM) used and advanced in this work package, we can use algorithms to realise concrete services and products on the basis of a number of different data sources.
These services and products are available to individual customers as well as the entire energy system and can be used by many different users for many different purposes – without having to connect new data sources. Applications range from the smart grid operator and flex market to the enera app. //

### PARTNERS INVOLVED:

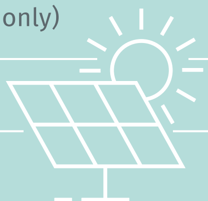
SAP SE
BTC AG
EWE AG
OFFIS e.V.
Siemens AG
Software AG
Jacobs University Bremen
EWE NETZ GmbH

CASE STUDY I

### NO REMUNERATION WITHOUT VERIFICATION

The verification platform is an excellent example of how different data need to be merged for new services. This platform is used to verify services rendered on the flex market at a later time. Grid operators check whether an agreed reduction in input or increase in load actually took place within the agreed period of time. This verification process uses numerous types of data that are fed into the platform: trades on the local trading market; plant schedules as well as the measured feed-in or energy absorption of generators and consumers; master data of plants registered for trading; balancing energy that has been requested; and the grid operator’s feed-in management activities. Without the linking of these data and the evaluation thereof, grid operators would not be able to track and invoice delivered flexibilities.

→ For more details, see p. 256 of the enera project compendium at www.projekt-enera.de (German only)



CASE STUDY II

### HOW MUCH INPUT IS PROVIDED BY PHOTOVOLTAIC PLANTS?

Especially in cloudy weather, photovoltaic plants have an extremely volatile input and part of the power they generate is often used locally, making it difficult for grid operators to forecast how much power small photovoltaic plants will generate and how much of that will be fed into the grid. enera developed and tested a data-based, mathematical method that enables grid operators to calculate the input of power without having to conduct metrological recordings on the end consumers’ premises. Based on data on solar radiation in the grid region as well as measurements at superordinate hubs, an algorithm extracts the percentage of photovoltaic input from the overall active power flow.

→ For more details, see p. 294 of the enera project compendium at www.projekt-enera.de (German only)



CASE STUDY III

### SUPPORTING DELIVERY SERVICES IN THE CLOUD

A demonstration showed how to efficiently link a pizza delivery service's business process. The delivery service has booked a variable electricity rate with its energy provider; prices vary by the hour. It also uses services that include the maintenance of the electric charging stations for its delivery vehicles. To support this customer, the energy provider needs data from several players: the energy supplier’s sales department has information on booked products and on the customer. However, in order to compile an invoice, the energy supplier needs data gathered by the grid operator at the customer’s measuring points.
In this case, the SDSP used microservices. These divide a software system into modules that are separated by function and data and depict business processes from initiation to pricing to accounting, for example. In the case of our fictional pizza delivery service, consumption fluctuates throughout the day, depending on the time, the day of the week and the season. At the end of the month, the platform retrieves the customer’s consumption data and invoices each hour according to applicable prices. The platform also determines levies, fees and taxes and invoices these together with the monthly fixed costs for the charging stations. The customer can track the current status of their consumption, invoices and statistics by means of a mobile app in real time.
With this case study, the project team demonstrated how complex business processes that involve several players can be linked via the cloud, saving time required for the development and market launch of new functions. The software concept of microservices thus simplifies the introduction of variable electricity rates, for example.

→ For more details, see p. 56 of the enera project compendium at www.projekt-enera.de (German only)

# A new colour for grid traffic lights

AT THE ENERGY LABORATORY AT JADE UNIVERSITY OF APPLIED SCIENCES, THE TEAM TESTED VOLTAGE REGULATORS THAT CAN CONTROL GENERATION PLANTS IN AN AUTOMATED AND NEEDS-ORIENTED MANNER.

The expansion of our power grids cannot keep up with the increasing output of renewable energy. Smart grids help absorb more green electricity; this changes the role of control centre operators – requiring them to take on increasingly complex tasks. The automated tools and processes defined and demonstrated in Work Package 3 can help manage these tasks.

In the past, loads on the power grid only flowed in one direction: from the large power plants, which primarily feed into the transmission grid, to the consumers, which are usually connected to the distribution grid. The renewable energy expansion has changed this. Distributed generators are predominantly connected to medium and low-voltage grids; when particularly high amounts of wind and solar power are generated, energy now flows from the distribution grid into the transmission grid.

A grid traffic light concept can help visualise areas in which this renewable energy cannot be fed into the grid due to a lack in capacities. The red phase signals that the stability of the grid is at immediate risk, meaning generators need to curtail renewable energy. The green phase, on the other hand, signals that the power grid is available to the market without any restrictions. With the flex market, a third, amber phase has been added, during which grid operators can use the market to take preventive measures to counter potential congestion.

enera has created the perfect conditions to take action during the amber traffic light phase. This task calls for new interfaces and automated processes in the control centres of the grid operators; these were designed, developed and tested by the team in this work package, allowing grid operators to forecast grid conditions and providing control centre operators with a preview of how congestion resolution will progress. These innovative tools help grid operators become smart grid operators, or Active Network Managers (AMM), using grid capacities as best possible as smart, predictive grid operators.

## NEW TOOLS FOR CONTROL CENTRE OPERATORS

Congestion occurs on the power grid when limit values for voltage and equipment capacities – from overhead transmission lines and cables to switching devices, transformers and measurement technology – are exceeded. Grid control centres determine and visualise congested areas based on measurement values from medium-voltage grids. In the event of imminent congestion, control centres take immediate action by reducing the input of wind power, photovoltaic and biogas plants – in the grid traffic light concept proposed by the German Association of Energy and Water Industries [Bundesverband der Energie- und Wasserwirtschaft, BDEW], this signifies the red phase. The traffic light concept aims to reduce the grid expansion in a smart and economically reasonable manner by using grid-friendly flexibility on the distribution grid.

### PARTNERS INVOLVED:

EWE NETZ GmbH
AVACON NETZ GmbH
Phoenix Contact Energy Automation GmbH
ENERCON GmbH
energy & meteo systems GmbH
FGH e.V.
IAEW at RWTH Aachen University
DLR-Institute of Networked Energy Systems
OFFIS e. V.
SIEMENS AG
TenneT TSO GmbH
BTC AG

//

**We automated parts of the congestion resolution process to relieve control centre operators.**

To prevent red phases and anticipate and resolve congestion predictively in amber traffic light phases, grid operators need to be aware of future conditions on the grid in advance. These conditions depend on energy consumption as well as input, which is in part determined by weather conditions. To date, measurement technology provides control centres with information on current conditions on medium-voltage grids but does not forecast the next minutes and hours, as these calculations were largely unnecessary in the past due to the clear direction of load flows and the corresponding buffers on the physical grids. However, detailed information on grid conditions is essential for predictive grid operations. enera therefore equipped specific substations with additional technology for measuring power and voltages and digitally connected them to the grid control centre.

To ensure grid operators can take action during the amber traffic light phase, the team developed new technical interfaces and functions for smart grid management. These pool weather forecasts and measurement values to calculate current and future grid conditions and also provide proposals on how flexible power can be used to avert imminent congestion. Based on these schedules, control centre operators can express their needs on the flex market. Upstream and downstream grid operators can cooperate closely in advance to ensure that reducing input or increasing loads on one grid does not lead to congestion on another.

If congestion cannot be resolved predictively, for example because no flexibilities are available on the market in the respective region or because these are too expensive, the traffic light switches to the red phase and the grid operator employs feed-in management. As this instrument will still be available, operators can use the flex market without putting system security at risk. The field test has shown that actions taken during the amber traffic light phase can resolve congestion, provided sufficient flexibility and liquidity are available. →

## SMART GRIDS IN NETWORK PLANNING

When planning the expansion of power supply grids, we need to consider the expected generation and consumption situations. As smart grid operators can improve the utilization of capacities on distribution grids, this also needs to be considered in network planning. On the one hand, this means depicting the interdependency between the use of flexible active power and the grid expansion; on the other, planners have to consider the impact of new equipment such as regulated distribution transformers and sensitive voltage regulators that control input sources within the scope of peak shaving (→ info box).
The grid planning software developed in enera depicts these complex interdependencies and helps planners determine the most cost-effective version for expanding grid capacities. The new planning process considers the expected addition of renewable energy generators that can be regulated in a grid-friendly manner on the one hand; on the other, it can also depict scenarios that arise from an increase in loads caused by power consumers such as heat pumps and electric vehicles. The process identifies the best possible expansion of capacities from both a business and an economical perspective.
In the project, we applied the planning tool to the example of a medium-voltage grid that supplies 40 low-voltage grids. The grid region has a high renewable energy input; the output of these generators is expected to double within ten years. For this fictional region, we ran through three variants that looked at conventional grid expansion, the use of regulated distribution transformers and the use of flexible power from peak shaving. The result: compared to conventional grid expansions, the other two variants offered clear financial advantages. The installation of regulated distribution transformers reduced costs by 8% while the peak shaving variant reduced grid expansion costs by 14%.

## AUTOMATIC CURTAILMENT

Due to weather conditions and the input of distributed generators, grid congestion is becoming increasingly common – and often occurs at different parts of the grid at the same time. To relieve control centre operators, enera used voltage regulators to automate parts of the congestion resolution process during the red traffic light phase. These regulators identify current bottlenecks and specifically actuate those generation plants that

### WHAT IS PEAK SHAVING?

Grid operators are obliged to expand grids to absorb renewable energy. However, distribution grids no longer need to be designed “down to the last kilowatt hour”, which would be extremely expensive. By embedding peak shaving in law, the grid expansion obligation is considered met if a maximum of three percent of the energy that can theoretically be generated in a year has to be curtailed. This allows significantly more renewable energy generators to be connected to the power grid without the need for expansions.

### SOLUTION ELEMENTS

For detailed project reports, please go to the enera project compendium at: www.projekt-enera.de (German only)

**Forecast-based congestion resolution**
→ p. 64

**Using flexibilities to resolve congestion**
→ p. 66

**Semi-automated grid operations**
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**The automation of distribution grids**
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**Reactive power, STATCOMS and loss models**
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**Input sources on grids dominated by converters**
→ p. 83

**Upgrading the grid laboratory**
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**Simulation: grid utilization**
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**Simulation: active grid operations**
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**Optimised expansion plans**
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**Validation of communication networks**
→ p. 10

can best resolve the congestion. In the course of this, the system only reduces as much input as is necessary to maintain grid stability. Once the situation on the grid has normalised, the regulator releases the generation plants. This automated and needs-oriented regulation reduces the temporal delays caused by manual operations and means grids can absorb more electrical energy generated by wind turbines and solar power plants, for example.
enera tested voltage regulators made by three manufacturers. Before the regulators were used on the public supply grid, they were subjected to a lab test that aimed to obtain functional proof that the regulators automatically stabilise the grid. To do so, we conducted 265 test runs on the three voltage regulators over a period of four and a half months. Ultimately, two voltage regulators proved successful. This ensured a secure and reliable supply to those customers on the public supply grid who were affected by the tests.
The regulators also needed to be compatible with the grid operators' technical, commercial and regulatory processes. The curtailment of plants within the scope of feed-in management, for example, must be made public and operators compensated. We therefore conducted a second test phase with the operative systems.

## USING SOFTWARE TOOLS TO SIMULATE OPERATION SCHEDULES

In addition to equipment such as transformers, smart grids provide grid operators with access to flexible active power to stabilise the grid. Operators have to plan the use thereof based on expected bottlenecks while also factoring in the element of uncertainty in forecasts. Simulations can help smart grid operators plan operations in the best possible manner; enera has developed software tools for this purpose that can be used to calculate how market prices will effect bidding behaviour on the flex market, for example. Providers of flexible active power could potentially change their marketing strategy on the national power market to influence local grid congestion and thus maximise their revenue on the flex market. In order to take counter measures, grid operators need to be able to monitor this potentially strategic bidding behaviour. //

"enera aimed to develop solutions that wouldn't gather dust on a shelf once the project ended. And we succeeded!"

DR.-ING. LUKAS VERHEGGEN, EWE NETZ

Dr.-Ing. Lukas Verheggen joined EWE NETZ in 2017, where he is currently part of the Energy Grid Development team in the Asset Management department and heads WP3 in enera. Before that, he researched the planning of smart distribution grids at RWTH Aachen.

# Smart grids as an alternative to grid expansion

**Innovative equipment helps us increase the capacity of the electricity grid, thus allowing more renewable energy to be absorbed while at the same time reducing costly conventional grid expansion measures. Work Package 4 assessed and tested three different kinds of equipment in the enera model region.**

If the existing distribution grid is to become a smart grid, it needs to be able to react flexibly to highly dynamic grid conditions. enera achieved this target by integrating flexible consumers and generators on the one hand and through network technology solutions on the other. As the project group responsible for Work Package 4, we illustrated how innovative equipment can increase grid capacities even further; one method worth mentioning in this context is the large-scale application of regulated distribution transformers. We also analysed other innovative equipment, including high-voltage compensation coils and superconducting fault current limiters.

Regulated distribution transformers had already become established prior to the project launch, however, they have only been used occasionally to date. In enera, on the other hand, we installed more than 200 devices throughout the region during the field tests – and reduced costs in the medium-voltage grid: these smart transformers helped avoid conventional grid expansions.

Another option to manage smart grids is the coupling of medium-voltage grids, a method that resulted from investigations conducted on superconducting fault current limiters; during the project, we investigated several variants thereof. Analyses and the subsequent field test showed that the coupling of grids by connecting two transformers in parallel is both technically feasible and economically viable.

PREVIOUSLY ONLY USED OCCASIONALLY, REGULATED DISTRIBUTION TRANSFORMERS HAVE NOW BEEN EMPLOYED THROUGHOUT THE ENTIRE MODEL REGION.

## SMART TRANSFORMATION ON A GRAND SCALE

Around 600,000 substations throughout Germany transform the voltage of the medium-voltage grid to the 230 and 400 volts used on local grids. Currently, conventional devices with fixed voltage ratios are prevalent; regulated distribution transformers, on the other hand, can vary transformation ratios, thus helping the grid absorb more solar power from photovoltaic plants that have been connected to the local grid without causing impermissible rises and drops in grid voltage. This would also allow grid operators to manage expected loads from an increase in heat pumps and electric vehicles more easily.

To date, regulated distribution transformers are only occasionally used on low-voltage grids; at the same time, the regulation of medium-voltage is still bound to the conventional voltage range. This is the only way for conventional local power transformers to comply with the provision of plus/minus ten percent voltage for low-voltage domestic connections. enera, on the other hand, aimed to investigate the impact of nation-wide use. We therefore replaced the conventional transformers at 210 substations in a specific grid region with regulated ones.

By using transformers on a large scale, we aimed to utilize a larger voltage range on the medium-voltage grid. A change in grid planning proved that this target can be achieved: by using this new technology, we were able to avoid having to replace a transformer at the substation between the high and medium-voltage grids.

## COUPLING GRIDS CREATES MORE CAPACITIES FOR RENEWABLE ENERGY

Coupling medium-voltage grids allows them to absorb larger quantities of renewable energy. On the one hand, two grids can be connected directly via two transformers in the same substation. On the other, they can be coupled via a decentralised control centre on the grid if the transformers are at different locations. In the first case, renewable power from the medium-voltage grid is split between two transformers, thus distributing load peaks, while the second case improves voltage stability.

Both coupling variants make it easier to connect renewable energy generators without the need for conventional grid expansions. However, both versions share the same disadvantage, namely that a reduction in grid impedance – AC resistance on the grid – means a corresponding increase in short-circuit current. However, this creates the risk of equipment being destroyed, which can be prevented by using a superconducting fault current limiter. enera investigated whether the use thereof makes it easier to couple medium-voltage grids. The use of superconducting fault current limiters results in a low loss of electricity – at their operating temperature of minus 196 degrees Celsius, they exhibit next to no electrical resistance. Another advantage is the fact that they are quickly ready for use after a short circuit.

We conducted a preliminary investigation to determine those areas in the model region where the use of current limiters based on superconductors would make the most sense from a technical and economic perspective. In the course of this, we considered various variants for coupling grids as well as expansion →

scenarios based on distributed generators and the rated output of the transformers. Our investigation showed that short-circuit currents would only rise to impermissible levels if grid operations changed considerably. However, as this constellation does not occur in the model region, superconducting fault current limiters are currently not a technical necessity, nor will they be in future.

Further investigations on the coupling of grids showed that the control centre variant with two transformers in different locations is exposed to too high a risk for a number of reasons, including transit flows and the unknown angle of voltage coming from the high-voltage grid as well as the necessary synchronisation of switching states. In contrast, the variant involving the parallel connection of transformers at the same substation proved technically feasible and economically viable. At the same time, we were able to prove our hypothesis regarding the distribution of peak loads in theory.

For our final demonstration, we determined the conditions under which grids can be coupled; how this can be implemented in substations from a technical perspective; and how this can be depicted in the grid control system to ensure secure operations. We successfully implemented and tested this concept in a substation. The field test confirmed that coupling significantly reduced and/or improved the redistribution of the power flow through the transformers, thus increasing grid capacities.

## HIGH-VOLTAGE COMPENSATION COILS FOR REACTIVE POWER MANAGEMENT

In enera, we analysed various technologies that provide reactive power, including high-voltage compensation coils. These help provide large, flexible quantities of reactive power, regardless of wind power input. Connecting the plant to substations on the high-voltage side ensures that several distribution grid areas can be corrected at the same time.

Across all grid levels, we evaluated the effect of this technology on reactive power transits from high and

BY COUPLING MEDIUM-VOLTAGE GRIDS IN SUBSTATIONS, MORE RENEWABLE ENERGY GENERATORS CAN BE CONNECTED TO THE EXISTING GRID.

### SOLUTION ELEMENTS

For detailed project reports, please go to the enera project compendium at: www.projekt-enera.de (German only)

**Superconducting fault current limiters**
→ p. 108

**Coupling medium-voltage grids**
→ p. 112

**Pooling the use of regulated distribution transformers**
→ p. 116

medium-voltage grids to extra high-voltage grids. In a preliminary analysis, the high-voltage compensation coil proved technologically sound and economically efficient. Our further investigations focused on effects such as voltage stability, the efficient use of equipment and the exchange of reactive power across grid levels. We established criteria for operating locations at hubs between high and medium-voltage grids, defined technical specifications and developed control concepts to optimise reactive power households across all grid levels. We recommend implementing the use of high-voltage compensation coils in the medium term as a project in cooperation with distribution grid operators and will pursue this issue further in the model region. //

PARTNERS INVOLVED:

EWE NETZ GmbH
FGH e.V.
AVACON NETZ GmbH

"The energy transition is one of the greatest challenges of our time. I am happy that we were able to contribute to that with enera."

BJÖRN WILLERS, EWE NETZ

Björn Willers studied electrical engineering and joined the Asset Management team at EWE NETZ in 2016. In enera, he focused in particular on the use of smart equipment and new operating modes that ensure a more efficient use of grids.

//

# Digitisation is breaking down established structures in the energy industry.

VIRTUAL AND AUGMENTED REALITY PLAY AN INCREASING ROLE IN TRAINING IN THE ENERGY INDUSTRY – PARTICULARLY IN SECURITY-CRITICAL FIELDS.

# The right qualifications for digitisation

**More digital, more flexible, more transparent: in the energy system, change is not limited to installing hard and software. Innovative technologies mean a range of new tasks for employees in this sector. New tools, processes and methods require comprehensive qualifications, for which Work Package 10 developed various training formats.**

As a starting point, the team conducted a comprehensive analysis to asses which areas have a particular need for training. Based on the results, we then developed trainings in different formats and on numerous topics: from online courses on blockchain technology and reactive power to training sessions on methodological issues. Employees can access all training components via a digital learning platform, including a guided virtual reality tour of a substation. Trainees and experts worked together to produce this 360-degree video. Virtual and augmented reality have huge potential, particularly when it comes to trainings in security-critical fields. In future, digital learning will play a more important role in trainings in the energy industry.

## NEEDS ASSESSMENT AND TRAINING PLAN

Digitisation has broken down established structures in the energy industry, changing fields of activity and giving rise to new requirements. Employees need to be made aware of these changes and trained in a coordinated manner. To define the exact training needs, we first conducted an exhaustive analysis of employees in the technical field, identifying both existing skills and skills that needed developing for enera. Based on these results, we then defined training components. Our analysis showed particular need for training in fields key to enera, including digitisation, increasing flexibility and smart grids as well as in grid planning and design, smart meters, regulated distribution transformers and battery storage. Over the course of the project, we reacted to these training needs with local information events, online sessions and other formats. →

## TRAINING COMPONENTS AVAILABLE IN A WIDE RANGE OF FORMATS

From interactive trainings on technical equipment to short films on matters related to the energy industry – the team used various formats to meet training needs. We summarised the content developed during the project in the form of professionally produced educational aids. Besides pure online and face-to-face sessions, our blended learning offer combined events held on site with internet-based learning. Project participants produced some of the trainings themselves and assumed the role of trainers, while other formats, such as web-based trainings, were realised with the support of experts in external production, graphic design and moderation. In total, we created a portfolio of around a hundred sessions for the project partners, using online, face-to-face, blended learning and digital reality formats.

## SOLUTION ELEMENTS

For detailed project reports, please go to the enera project compendium at: www.projekt-enera.de (German only)

**The needs assessment model** → p. 120

**Blockchain Technology & Reactive Power e-trainings** → p. 122

**Digital Reality** → p. 124

## THE DIGITAL LEARNING PLATFORM: THE ENTIRE TRAINING OFFER IN ONE PLACE

enera project partners can access all digital training components via the learning platform with its intuitive design. The platform can be accessed via mobile phones and works independently of company networks, thus allowing the flexible use of content, at any place, at any time. The platform has been used for a wide range of training purposes and was evaluated in the same way as every other activity and project related to the enera Qualification Centre.

## DIGITAL REALITY: VIRTUAL GUIDED TOURS OF A SUBSTATION

enera tested new approaches in a range of fields – and that includes training. One example of this is the 360-degree video that offers a virtual guided tour of a substation. The video was created in accordance with the co-creation approach by a group comprising apprentices; students taking part in a combined vocational training and degree programme; a training supervisor; and an expert on substations. During this innovative workshop, the group developed ideas on how to realise the video; an agency merely provided technical expertise and equipment and explained the principles of planning, production and publication. In a matter of days, the employees learned how to use virtual reality as a tool to convey highly complex content in a way that is easy to understand. A skill that can be employed in many other fields of the energy industry: virtual reality (VR) and augmented reality (AR) are gaining in relevance when it comes to conveying training content and process flows more efficiently, more effectively and with fewer entry barriers. The use of this technology avoids time spent on travel, while digital learning media can help increase safety, especially for apprentices. They can safely explore the surroundings and sensitive infrastructure of the substation using a pair of VR glasses, for example.

## E-TRAININGS ON BLOCKCHAIN TECHNOLOGY AND REACTIVE POWER

Blockchain technology and the energy transition are both based on decentralised structures. Experts are therefore currently discussing the use of cryptographically connected data sets in the energy industry of the future, something that has already been implemented in enera. A basic understanding of blockchain technology is essential to be able to

“enera was a project unlike any other; the list of project partners involved alone gives you an impression of the dimension of this project. enera and all its results have truly paved the way to the energy world of tomorrow – and I am proud that we were able to contribute to this demonstration of the energy transition.”

asses the areas in which the use of this technology makes sense, an understanding that is conveyed at the very start of an e-training produced exclusively for enera. In a next step, we need to look at potential fields of application in the energy transition as well as the resulting new business models – for example in electromobility and the power trade.
With the e-training on reactive power, we summarised another complex issue in form of an educational aid. In order to address players with different levels of knowledge, the training on reactive power begins by conveying principles before focusing in more detail on concrete use cases. Besides blockchain technology and reactive power, the trainings deal with a range of other specialist and methodological topics. //

PARTNERS INVOLVED:

EWE NETZ GmbH

DR PIA LEHMKUHL, EWE NETZ

Dr Pia Lehmkuhl is an “Oldenburger Deern”, a native of Oldenburg who has strong ties to the region and found a thematic home in WP 10.
The economist and jurist focused on education management in enera, in the course of which she was entrusted with developing the project’s proprietary Competence and Qualification Centre, eQC for short. The eQC was home to every question related to competence and training and thus contributed to the successful realisation of project targets.

# Smart and secure networks

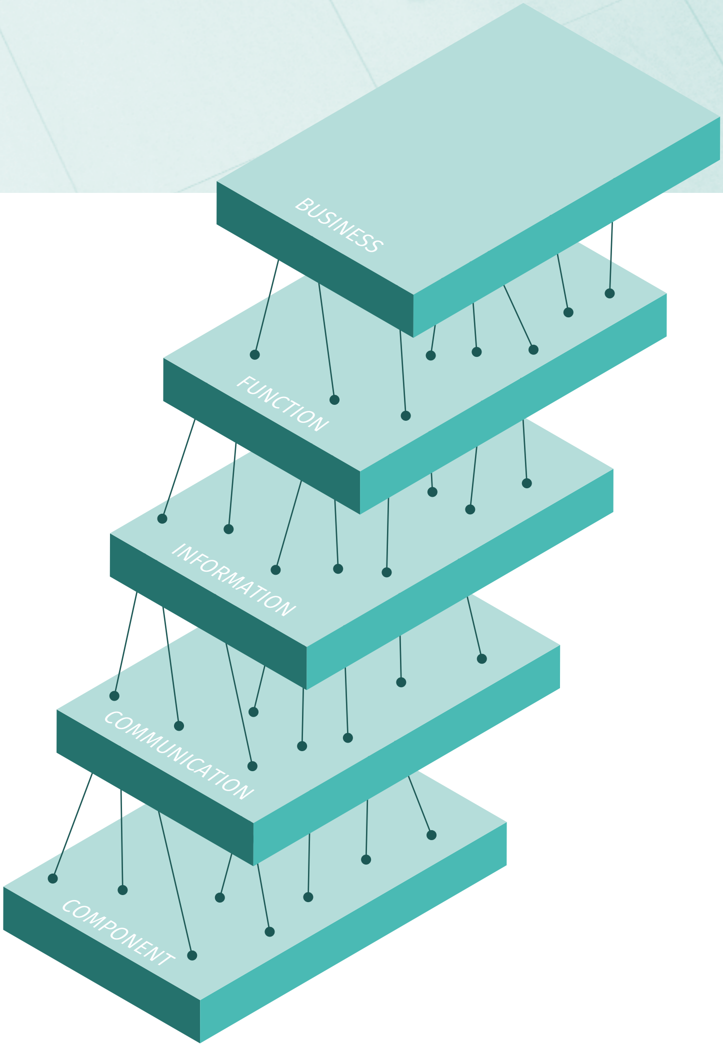
Distributed and digital smart grids increase efficiency – as well as the number of weak points. This makes it all the more important to ensure that a high level of protection can be maintained at all times, despite fundamental changes to the power grid. Work Package 12 aimed to guarantee information and IT security for the entire project.

From day one, enera focused on securing increasingly complex data flows and IT systems. The project comprises a number of individual digital systems – from apps for households and virtual power plants to forecast tools at grid control centres. All of these are linked to one another in enera and work together within an integrated digital system for which the team designed, modeled and assessed the IT architecture.

As a first step, we looked at each activity planned in enera to determine which functionalities and scenarios these resulted in within the integrated system. These use cases then served as the basis for our subsequent security analyses. To ensure a comprehensive level of information security, we developed a management system, already incorporating security requirements into the first steps of development. The team also provided the methodological knowledge and software tools necessary to use standards already established in the energy industry in the project. Our project results also served to advance the development of standards and culminated in recommended methodological courses of action.

## THE ENERA USE CASE

Use cases document a system’s functionality on the basis of simple models and are used in software development in particular to explain in simple terms what a system does from the user’s point of view. Accordingly, we used standardised criteria to document the activities planned in enera in 76 use cases. On the one hand, this was based on use case methodology, a procedure standardised by the International Electrotechnical Commission (IEC) that allows users to systematically document use cases. On the other, we used the smart grid architecture model developed on the basis of EU Standardization Mandate M/490. We also used guides to assess functional and quality requirements. →




## THE VARIOUS LEVELS OF THE SMART GRID

A complex smart grid has many weak points, meaning data privacy and information security need to be considered during the early stages of planning.

## EFFICIENT INFORMATION SECURITY MANAGEMENT

An information security management system (ISMS) covers employees, management principles, resources and security processes, whereby Work Package 12 focused on the latter. The team aimed to achieve a high level of security for all parts of the enera project in as efficient a manner as possible.
As a rule, institutions implement information security management systems in their own areas of responsibility, as most project partners have done in enera. In order to nonetheless achieve a uniform level of protection, we designed an overarching system based on the documented use cases. This system aimed to minimise the risks for business processes, data as well as information and communication systems in an energy system dominated by distributed input. To secure smart and complex power grids, information and communication technologies need to be in line with established procedures and standards. These include the international ISO/IEC 27000 series; basic IT protection as defined by the Federal Office for Information Security; and legal data privacy and data security requirements. The information security management system combines the different standards and can react to future laws and regulations.

## ASSESSING THE SECURITY OF THE IT ARCHITECTURE

The information and communication technologies developed in enera are part of a complex, innovative integrated system within which standards and models for energy and value-added services in particular need developing in a manner that guarantees data privacy and information security. In digital meters, for example, this applies to metering and regulation via smart meter gateways. Here, we conducted separate analyses on the basis of use cases.
To structure and present the results of the security analyses, we developed a dashboard that visualised protection needs as well as the implementation status of security requirements, for example. The dashboard can also be used to assess, categorise and compare architectural features based on a software-supported system of indicators.

## SECURITY BY DESIGN: A HIGHER LEVEL OF SECURITY FROM DAY ONE

On several levels, the team derived recommended courses of action from the experiences gained over the course of the project. We identified and documented gaps between standards in order to be able to close them in future standardisation processes. In particular, we recommend improving the methodology used to document use cases with regard to Security by Design. This principle of software development ensures that from day one, provisions are made to minimise damage should attackers take advantage of weak points, for example. In general, malicious attacks on the system are to be expected. In the long term, Security by Design can help achieve a higher level of protection as data privacy and information security are already considered during the early planning stages. As this also prevents costly rectifications, integrating Security by Design at an early stage is a much more resource-friendly solution that requires much less effort.

### SOLUTION ELEMENTS

For detailed project reports, please go to the enera project compendium at: www.projekt-enera.de (German only)

**ISMS and SGAM use cases**
→ p. 126

**Security by Design in use cases**
→ p. 130

**UCMR expansions**
→ p. 142

**Basic IT protection for virtual power plants**
→ p. 148

**Measurements and control via SMGW**
→ p. 152

**The Security Dashboard**
→ p. 162

**Third-party security requirements**
→ p. 166

**Regulated distribution transformer and voltage regulator penetration tests**
→ p. 176

**Assurance cases for surveying use cases**
→ p. 180

**Manufacturer-independent security architecture**
→ p. 188

## HACKING A REGULATED DISTRIBUTION TRANSFORMER

Even if security aspects are considered from day one when developing an IT system, users need to monitor and adapt vulnerable hard and software in ongoing operations. Many systems are subject to continuous change that may result in weak points. Penetration tests are an established method of identifying weaknesses, in the course of which testers attempt to penetrate the computer system using the same techniques employed in real attacks. During these penetration tests, we examined a regulated distribution transformer and a voltage regulator with regard to IT security. The results helped us improve the IT security of these systems.

## A SECURE DATA FLOW, INDEPENDENT OF MANUFACTURERS

For security reasons, information and communication technology in the energy industry has hitherto for the most part been operated in confined networks and without interfaces to public networks. Due to the increasing number of applications and stronger integration of systems, it is becoming more and more difficult to seal systems off like this – for example when it comes to controlling grid operating equipment, reading out smart meters and regulating distributed consumption and generation plants, all of which is usually conducted via mobile radio or broadband over power lines. Communication networks in the energy industry have to meet particularly high data privacy and data security requirements; the same applies to the infrastructure, including modems, routers and mobile phone masts. To be able to use this information and communication technology on a large scale, we developed an overarching, manufacturer-independent security concept in enera. //

### PARTNERS INVOLVED:

IABG Industrieanlagen-Betriebsgesellschaft mbH
OFFIS e.V.
Bosch.IO GmbH
devolo AG
EWE NETZ GmbH
PHOENIX CONTACT Deutschland GmbH
Power Plus Communications AG
Siemens AG
Software AG
TenneT TSO GmbH
Fraunhofer IESE

“More often than not, people are the biggest safety gaps.”

MARIE CLAUSEN, OFFIS

As a mathematician, Marie Clausen is responsible for the overall architecture and accompanying information security concept in enera. She used her many years of experience in use cases and smart grid architectures to compile the project use cases and related system architecture, which formed the basis for the evaluation metrics and information security concept.

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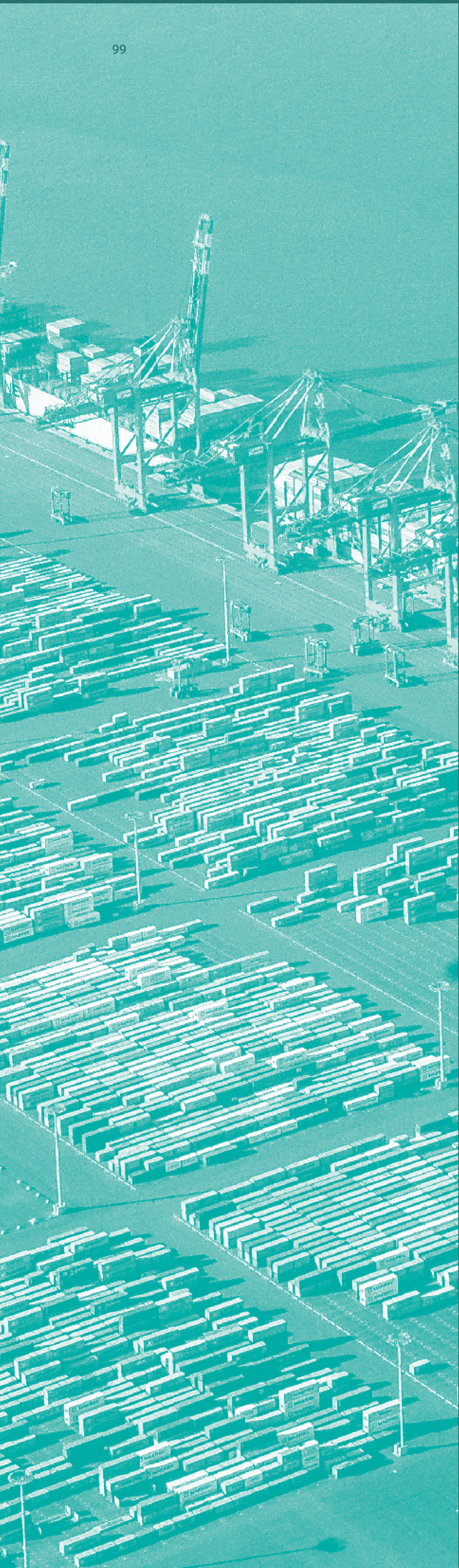
Energy generation from predominantly renewable sources needs to be in line with consumption.



CHAPTER II

# Flexibilities & Markets

# Putting a price on flexibility

The renewable energy expansion has increased the risk of congestion on the grid. This can be prevented in the long term, by giving grids an upgrade – or today, by ensuring generation and consumption are in line. enera has successfully shown how the latter can be integrated into electricity trading: on 5 February 2019, the project launched the first exchange-based flexibility market in Europe.

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250 plants supplied the enera flex market with more than 100,000 kilowatt hours of flexibility. 4,000 bids resulted in 130 transactions. On the flex market, three grid operators on the demand side were joined by six marketers on the supply side.

When the input from wind power, biogas and photovoltaic plants in a region is higher than its consumption, these climate-friendly power plants are currently curtailed, in other words, throttled or shut down all together. Known as feed-in management, this process ensures grid stability. However, this wastes energy and means operators need to be compensated – which amounted to more than €700 million in 2019, with an upward trend.

enera developed a market-based alternative to the curtailment of plants. The concept: in the event of imminent congestion on the grid, grid operators can use a trading platform to agree reductions in input or increases in supply in advance – in other words, they can purchase flexibility. Ideally, this means electricity is used locally, as opposed to being curtailed. Instead of resolving problems on the grid technically by employing feed-in management, the enera project uses the market.

Three enera work packages took a closer look at flexibility. **Work Package 5** selected and pooled generation and consumption plants and equipped them with communication technology. **Work Package 6** ensured marketers were able to engage in digital trade on the flex market by pooling these plants into virtual power plants. The team also took a closer look at how grid operators are integrated into the market and can use forecasts to generate demand. In **Work Package 7**, the team created the framework for flexibility transactions, defining a market design and developing a trading and verification platform.

# From heating elements to gas compressors: incorporating flexible plants

In order for electricity to be supplied securely and efficiently, even with a high percentage of renewable energy, distributed generators, consumers and storage systems need to react flexibly to current grid conditions. Work Package 5 identified the plants most suitable for smart congestion management and marketing on the flex market and how these can be connected from a technical perspective.

On one side, renewable energy generators were incorporated into the enera flex market: wind power, photovoltaic and biogas plants. On the consumer side, plants ranged from heating devices that only consume a few kilowatts to industrial megawatt plants: a compressor used to transport gas was integrated as well as a steam generator used by an industrial company. Storage systems of various sizes were also present: from small home storage systems for photovoltaic energy to batteries in the megawatt class.

In simulations and field tests, the team investigated how the various plants need to be integrated into the flex market, in the course of which we had to develop a number of components that had not previously existed in the energy system. We refined forecasts down to the local level and defined, programmed and tested technical interfaces between grid operators, marketers, power generators and consumers. Pre-defined energy quantities needed to be measured and billed.

Before the consumption and generation plants were connected to the flex market, we first used a simulation platform developed in enera to determine when and where a need for less input or more consumption arose on the distribution grid. As a next step, we then simulated the use of distributed plants to stabilise the grid. The platform can be used to run through scenarios, determine market potential and optimise the management of technical plants.

enera demonstrated that it is possible to incorporate industrial loads into grid stabilization, in terms of both technical feasibility and market conditions, despite the complex coordination this requires. In practice, however, we found that current framework conditions mean that in many scenarios, grid-friendly consumption is not attractive to companies. In these cases, taxes and levies are higher than the revenues that can be achieved on the flex market. To provide sufficient incentive for industry and trade, grid-friendly power consumption would need exempting from levies and taxes in part and peak loads would need to be taken out of power-dependent grid fee calculations.

By increasing the flexibility of wind farms, we were able to provide generation plants that allow sensitive adjustments; these ensure that grid operators only curtail as much power as is necessary to manage congestion.

By upgrading a wind farm and constructing a self-sufficient system that is able to set control values for reactive power, we also provided grid operators with new mechanisms for managing reactive power. →

USE CASE

## THE WIND LETS OFF STEAM

The concept is as impressive as it is simple: when the wind farms surrounding Varel in Frisia supply electricity in abundance, the local paper and cardboard factory flips a switch: electricity, and not gas, is then used to generate steam. This means the grid operator does not have to curtail any wind turbines – at the same time, the paper factory can heat its drying cylinders and heat consumers in an eco-friendly fashion. Ideally, production is $CO_2$-neutral to conserve the environment. However, before we were able to implement this concept, we first needed to put a lot of development work into the details. The production plant can only make extremely short-term forecasts on available electric power based on current consumption. The power available for the power-to-heat module fluctuates strongly, depending on paper production and the factory's need for steam; a high level of automation is therefore crucial to be able to regulate and market power. As there are many other players besides the paper factory that can consume power to stabilise the grid, a trading platform on which algorithms automatically align demand and supply is a necessity.

FOR MORE DETAILS, SEE

→ p. 112, Work Package 07

## SOLUTION ELEMENTS

For detailed project reports, please go to the enera project compendium at: www.projekt-enera.de (German only)

**Storage and system stability**
→ p. 194

**Gas-hybrid devices as flexibilities**
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**Biogas plants as flexibilities**
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**Industrial loads**
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**Simulation: flexibility**
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In Germany, there are more than 13 million gas heaters. Retrofitting one buffer tank with a 5 kilowatt heating element results in a calculatory load potential of 65 gigawatts.

In comparison, the combined pumped storage in the country can absorb an output of 6.7 gigawatts.

### HOT WATER AND WIND: THE TREMENDOUS POTENTIAL OF SECTOR COUPLING

But industry isn't the only field in which excess power can be used to generate heat; households can, too: in Germany alone, more than 13 million homes run gas heaters. Equipping the buffer tanks in these homes with electric heating elements would provide a huge potential of flexible loads. In a field test conducted in real households, we determined how this potential could be utilized to ensure grid stability in dependence on operating parameters. We also incorporated heat pumps, storage heaters and gas condensing boilers with integrated continuous flow water heaters. These gas-hybrid devices were developed as prototypes especially for enera.
A single heating device does not consume enough power to be used by grid operators to resolve congestion. However, by connecting several small devices to create a centrally-controlled pool, their power amounts to a relevant size available in a local grid region. In order to integrate small devices into the energy system in the model region as a regional, controllable load, we developed and tested communication hardware as well as software solutions. These clearly showed the role the outside air temperature and time of day play when forecasting the potential loads heating devices can absorb.
This field test showed that relevant loads are available to relieve the grid without limiting the plants' primary job – heating demands are still met with no loss in convenience.

### IN CELLARS AND CONTAINERS: FLEXIBLE ELECTRICITY STORAGE SYSTEMS

The team also integrated electrical home storage systems into the project. As the intake of a single plant is too low, they were connected through aggregators, which in this case were the system manufacturers.
As a rule, home storage systems are connected to a photovoltaic plant and store generated electricity that is not needed immediately in the home. Depending on solar radiation and electricity needs, these systems have free storage capacities that can be used to relieve the grid. Home storage systems, for example, can be charged with excess wind power. In numerous field tests with a total of 60 small-scale plants, we developed algorithms that allowed us to identify the loads home storage systems can absorb in dependence on solar radiation and the household's electricity needs.
We also incorporated battery storage systems in the megawatt class. With its lithium-ion batteries, the hybrid storage system installed in containers in the vicinity of the substation in Varel balanced frequency fluctuations on the grid. The sodium-sulphur batteries are especially well suited for storing larger quantities of electricity over longer periods of time. An industrial company built another storage system. The challenge here was to ensure grid operator requirements were in line with the primary purpose of operation.
The project showed that large-scale storage systems can be used to manage congestion in a number of different ways. They can absorb excess electricity generated by wind power plants, for example, and release it again as needed to resolve bottlenecks in active power. They also provide ancillary services to grid operators.

## RENEWABLES PROVIDE REACTIVE POWER AND INCREASE FLEXIBILITY

The enera flex market has shown how grid-friendly adjustments to generation and consumption can increase power grid capacities. Here, the focus is primarily on active power; however, for a three-phase supply grid to function, grid operators also have to provide for the right level of reactive power.

Plants that generate renewable energy supply reactive power free of charge within technical guidelines. Although this leads to higher losses in electricity at the plant, it also provides for economic grid connections and improves grid integration. In the project, we determined how much electricity wind power plants lose.

Wind turbines and photovoltaic plants can provide the necessary reactive power locally and based on needs. Due to their spread throughout the region, distributed plants can also provide ancillary services, supplying reactive power wherever it is needed, for example. To ensure wind power plants can react more effectively to the needs of grid operators, we conducted a field test to demonstrate one wind farm's ability to set control values for reactive power. The plant achieved a reactive power output of 6.9 Mvar, independent of potential active power. Retrofitting wind power plants in particular with full power converters in this manner avoids the expansion of larger capacitors and contributes to voltage stability on the power grid, regardless of winds.

enera did not test the integration of reactive power into the flex market; however, it would be possible to do so from a technical perspective and would make sense, provided the remuneration of power supplied results in economic advantages. This is the case when costs for upgrading the grid to stabilise reactive power are avoided.

Generation plants were particularly relevant to the enera flex market when it came to providing flexible active power. To do so, we installed cutting-edge telecontrol technology at ten wind farms connected to three substations – thus allowing a flexibility potential of around 80 megawatts of installed output to be used. These generation plants can be regulated sensitively and based on need; in addition, the increase in measurement data creates more transparency on the grid. //

### PARTNERS INVOLVED:

ENERCON GmbH
EWE VERTRIEB GmbH
EWE NETZ GmbH
Power Plus Communications AG (PPC)
DLR-Institute of Networked Energy Systems
microbEnergy GmbH
Theben
OFFIS e.V.
Schulz Systemtechnik GmbH
devolo AG
energy & meteo systems GmbH
EWE AG

"'When the winds of change blow, some people build walls and others build windmills.' Chinese proverb."

### RALF MARTIN MÜLLER, WRD

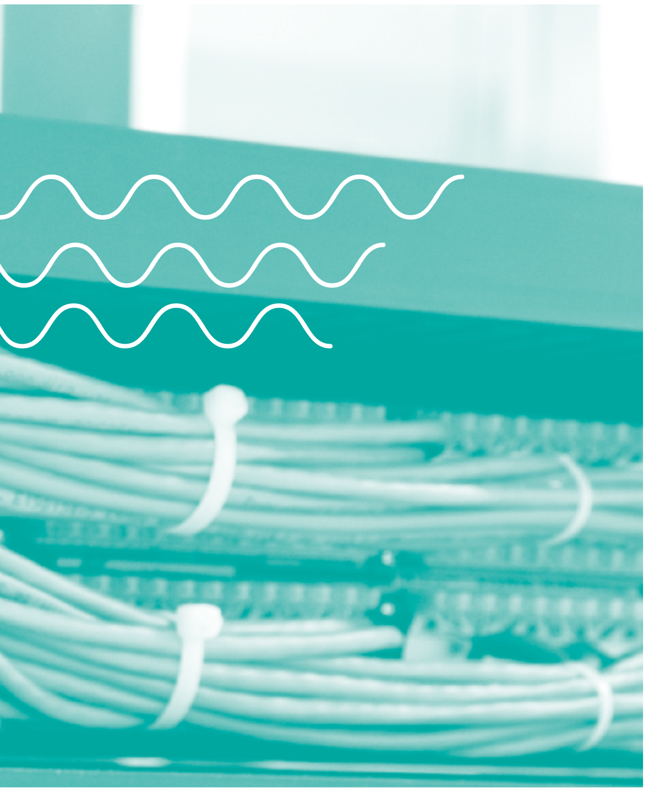
Ralf Martin Müller is a project manager at the ENERCON Research and Development Centre in Aurich. After studying electrical engineering, he assumed various leadership roles with a focus on renewable energy and sustainability. At ENERCON, he is currently primarily responsible for developing sustainable energy systems.

# Powerful communications

On the enera flex market, input and consumption are adjusted to relieve the grid and manage congestion. The grid operators' demands and supply of flexibility therefore need to be linked intelligently. So that both sides can communicate on the market, Work Package 6 developed technical principles and processes and largely automated sequences – as this is the only way marketers of virtual power plants can participate in the complex and highly dynamic local markets.

First of all, the team defined the trading product for the flex market: "flexibility" means the flexible provision of regional active power – for example by reducing input or increasing consumption. The product is in line with established standards of the national energy MARKET and has been incorporated into the exchange mechanisms employed by European power exchange EPEX SPOT. We excluded other product variants, such as black start capabilities and reactive power, as these are difficult to incorporate into standardised and existing processes.

In order for the trading platform to work, players first need to identify and state their demands and offers before delivering and paying for them, respectively. First, grid operators determine when, where and for how long they will require a specific quantity of active power. To do so, they use grid condition forecasts with high local and temporal resolution that are based on weather forecasts. These needs are then transmitted automatically to the flex platform. The virtual power plants also use forecasts to determine whether they can provide the requested power and submit bids. Once the flexibility contracts have been concluded, the plants ultimately need to be regulated accordingly and the



on weather conditions and uncertainties in forecasts.

## AUTOMATED TRADING VIA MARKET AGENTS

Local energy markets mean considerable operative effort for grid operators and marketers. The forecasts for every potential congestion region need to be updated continuously; flexibility demands have to be entered into order books and prices need to be adapted to market requirements at one second intervals. This complexity can barely be managed manually and therefore requires extensive automation. On the enera trading platform, market agents enable exchanges that are largely based on algorithms. This allows direct marketers of renewable energy to participate in the flex market with no additional manual effort and without having to continuously monitor every single bid.
The virtual agents act on the behalf of grid operators and marketers, submitting bids and documenting trades. The agents allow the automation of trade on newly created regional markets at low operation costs

generated power needs to be paid for.

## FORECASTS FOR REGIONAL MARKETS

Detailed regional forecasts on grid conditions are a requirement for grid operators to announce their concrete needs on the market in advance. For this purpose, enera developed tools that determine the expected power flow at the substations between the medium and high-voltage grids to identify expected bottlenecks. We also tested the use of this model between high and extra-high voltage.
On the basis of vertical system load forecasts, distribution grid operators can procure the required flexible active power in the exact place best suited for resolving the bottleneck. Forecasts include measurements on the actual power flow as well as the expected input from wind power and photovoltaic plants; historical data is also incorporated. Each component of the forecast is continuously compared to projections to adjust the forecast as quickly as possible. We successfully employed this method in field operations over the course of roughly one and a half years.
Within the enera project, we also optimised grid safety calculations for transmission grids. The e-Now platform provides visualisations; with the situational awareness tool, it also provides an instrument that recognises grid-critical conditions at an early stage. Grid operators thus receive regional alerts on grids and markets as well as

### SOLUTION ELEMENTS

For detailed project reports, please go to the enera project compendium at: www.projekt-enera.de (German only)

**Vertical system load forecasts**
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**Regional ancillary services**
→ p. 220

**The e-Now platform**
→ p. 222

**Automated market agents**
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**Virtual power plants**
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and with a high level of reliability. →

## AUTOMATICALLY CORRECTING THE BALANCING GROUP

When marketers adapt feed-in and consumption within their virtual power plant for the enera flex market, this leads to an imbalance between the traded position and the actual feed in the associated balancing group. The balancing group model ensures that only energy that has actually been generated is sold or supplied across regions. Therefore, transactions on the wholesale market or the inverse regulation of plants in another market region are necessary to correct the balancing group when behaviour has been adjusted on the flex market. We used corresponding algorithms to automate this process.

## VIRTUAL POWER PLANTS IN REGIONAL USE

Wind and weather conditions can cause fluctuations in renewable energy generation, while electricity consumption depends on individual needs – for example due to the use of powerful devices in private households and the industry. Virtual power plants balance these fluctuations by pooling generators and consumers, which are then marketed as a single plant on the energy markets. To supply the enera flex market with pre-defined quantities of active power, virtual power plants actuate individual plants so that the agreed schedule is kept in total.

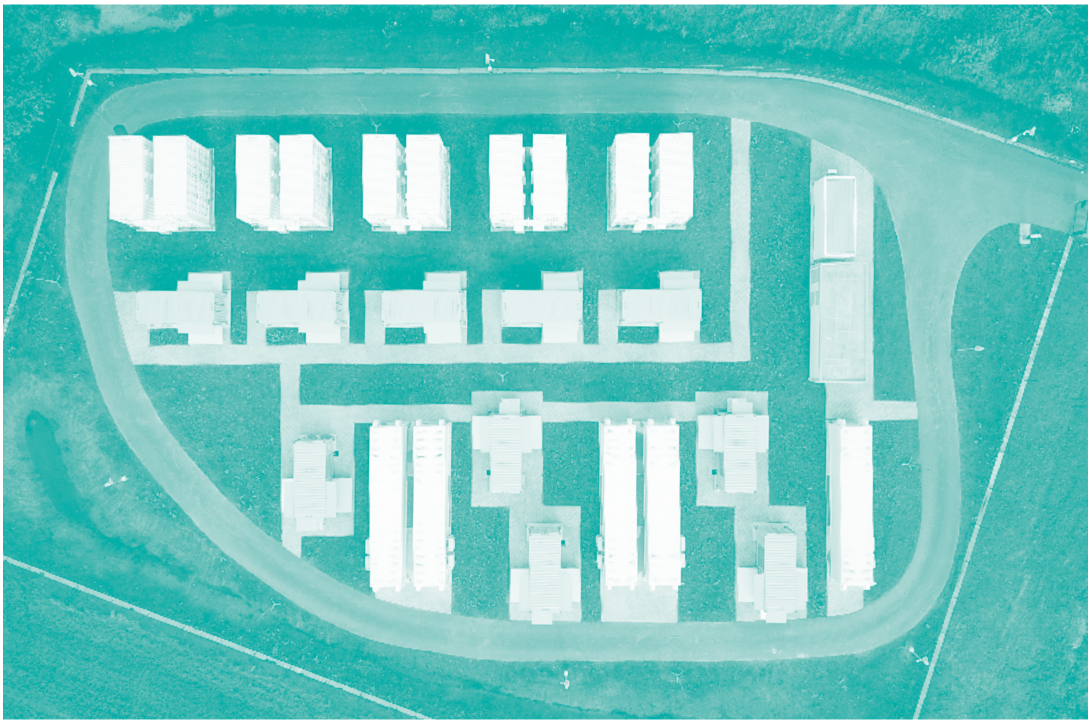
On the German electricity market, energy is currently marketed within four large control areas that are all subject to nationwide, standardised electricity prices. Over the course of more than one and a half years, during the demonstration phase of the flex market, four marketers and their virtual power plants were active on this electricity market for the whole of Germany as well as in the smaller enera market regions.

For this, we first needed to allocate the connected plants to the flex market's local order books, according to their locations. As a next step, we adapted the control logic of the virtual power plants so that these cost-effective plants could be used to stabilise regional grids. As direct marketers are also active on the wholesale market, we further needed to align the control algorithms for the regional flex market and the cross-regional market in the control areas to prevent conflict.

The virtual power plants are in constant contact with the trading platform, via the → market agents, and updates are transmitted continuously. This allows virtual power plants to use the connected plants

### PARTNERS INVOLVED:

TenneT TSO GmbH
energy & meteo systems GmbH
BTC AG
EWE AG
EWE NETZ GmbH
EWE VERTRIEB GmbH
Likron GmbH
University of Duisburg-Essen
AVACON NETZ GmbH



THE LARGE-SCALE HYBRID STORAGE SYSTEM IN VAREL SUPPLIES NATIONAL AND LOCAL MARKETS WITH BALANCING ENERGY.

"Integrating renewable energy into grids and markets is important; adding renewable energy is more important!"

"SINTEG/enera was one of the biggest projects I have had the privilege of coordinating on behalf of TenneT. The mission of this extensive project has helped advance the development of many facets of grid management and we have been able to derive many new insights for the future that will stay with us for a long time."

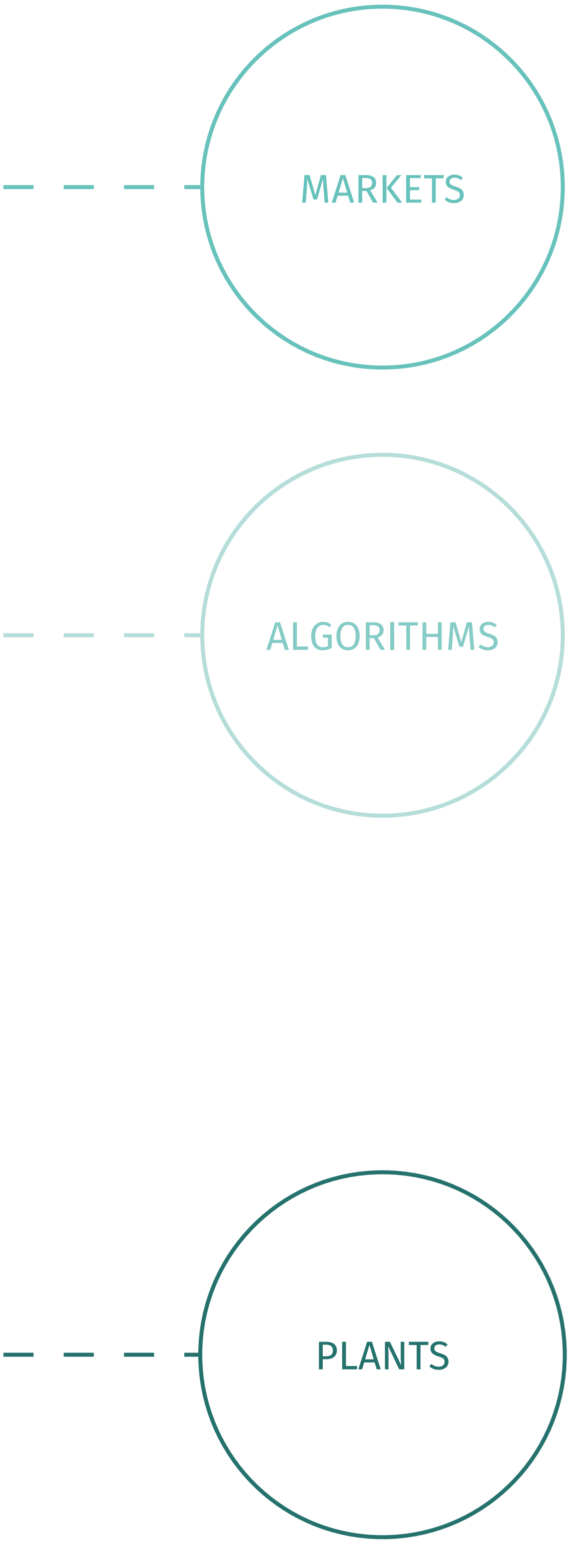
THOMAS KLOSE, ENERGY & METEO SYSTEMS

Thomas Klose completed his studies in industrial engineering at EUF, the European university in Flensburg. Since then, he has helped establish the Virtual Power Plant business unit at energy & meteo systems, where he is the specialised point of contact for various direct marketers and balancing energy suppliers. He headed the eTelligence and enera demonstration projects for energy & meteo systems. Since 2019, he has been involved in the design and development of a system to implement re-dispatching in distribution grids. In enera, Thomas Klose headed Work Package 6 "Activating regional ancillary services and other regional products on the market side".

STEFFEN HOFER, TENNET

Stefan Hofer is part of the strategy team at TenneT and has many years of experience in grid and regulation management. Within the scope of the enera project, he headed Work Package 6 "Activating regional ancillary services and other regional products on the market side", together with Thomas Klose of emsys.


Virtual power plants incorporate a range of different generators and consumers to stabilise the grid.




to react automatically to price signals.

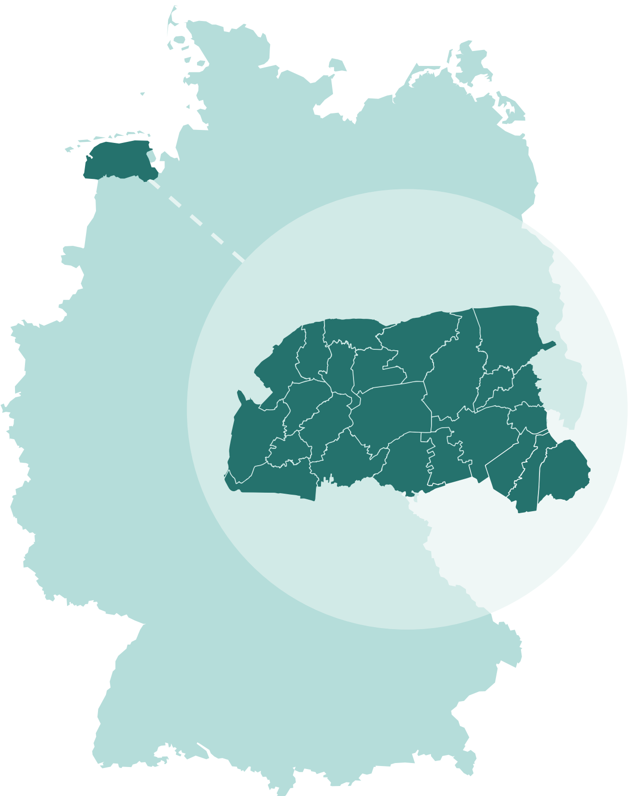
## HIGH COMPLEXITY OF COMMERCIAL LOADS

Besides renewable energy and battery storage, large consumers from the fields of industry and trade can meet the grid operators' demands for flexible active power – provided said power can be procured flexibly. When incorporating commercial and industrial loads into virtual power plants, short forecast horizons and volatile production processes pose the greatest challenges. Mastering these required intensive cooperation between marketers and plant operators during the project. We installed a power-to-heat module with an output of 20 megawatts at Varel Paper and Cardboard Factory [Papier- und Kartonfabrik Varel] and connected it to the flex market, for example. By making extensive adjustments to the automation technology, a compressor used to transport natural gas was furthermore able to absorb flexible loads. With a maximum capacity of 13 megawatts, the electric compressor contributed significantly to resolving congestion on the grids. These examples show how sector coupling can be used economically to relieve grids – using the compressor not only coupled the energy and heat sectors but the two distribution grids for power and gas as well.

## LARGE-SCALE BATTERY STORAGE ON THE FLEX MARKET

Four large-scale battery storage systems generate revenue by providing primary reserve, which is used to correct unexpected fluctuations in grid voltage in seconds. Located immediately next to a substation, the large-scale hybrid storage system in Varel with a total capacity of 11.9 megawatts is also active on the balancing energy market and has been integrated into the regional enera flex market. To do so, we automated the storage system's marketing, control and accounting processes and ensured they were in line with the various market requirements. //

# An alternative to curtailment: rewards instead of compensation



The national energy market
The 23 market regions in the enera model region

## THE GRID STRUCTURE IN THE MODEL REGION

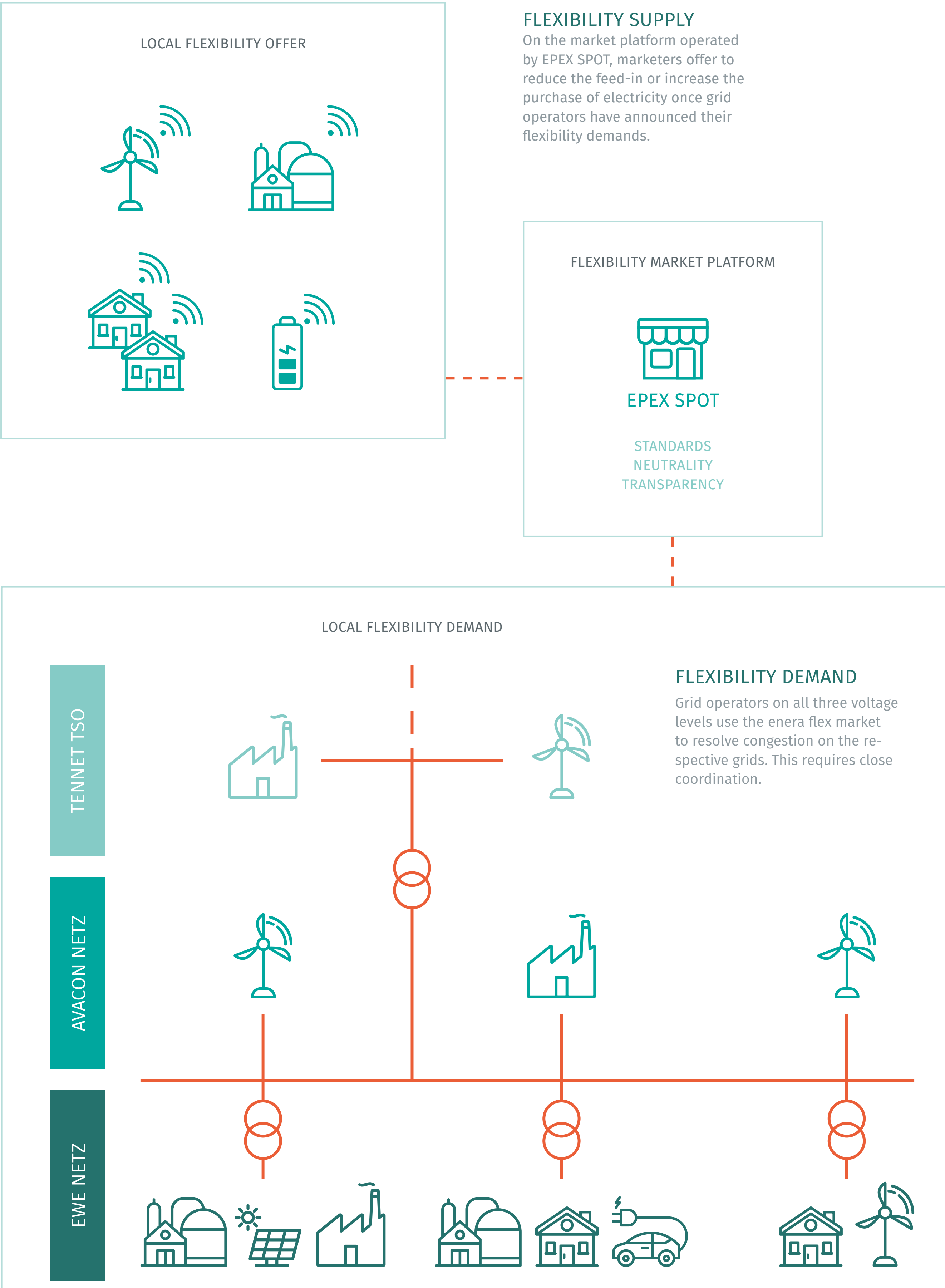
In the enera model region, EWE NETZ operates a 20 kilovolt medium-voltage grid and a low-voltage grid with 230 and 400 volts. The region has been allocated to the control area of transmission grid operator TenneT (maximum voltage: 220 and 380 kilovolts). Avacon Netz operates a 110 kilovolt high-voltage grid in the model region.

The enera flex market matches supply and demand for the regional "flexibility" product on a transparent market place operated by European power exchange EPEX SPOT. The Work Package 7 team determined the market design, created a proprietary trading platform for enera and developed the certification and verification processes.

To date, no mechanism for correcting imbalances in regional loads and generation is in place in national energy wholesale trade. In Germany, the price alone determinse who is awarded generation contracts – where said generation takes place doesn’t matter. For congestion management, however, the location of generation and consumption is decisive. The flex market therefore has a localized structure: grid operators can notify the trading platform of flexible power demands for regions that in part do not even cover 20 square kilometres.
The enera flex market was developed for a windy region so that the grid can absorb more renewable energy; it is, however, transferable, regardless of local circumstances. Other places could also use a market on which several players coordinate to resolve grid congestion. This technological and organisational solution enables efficient trade that reduces economic costs by curtailing less renewable energy. →

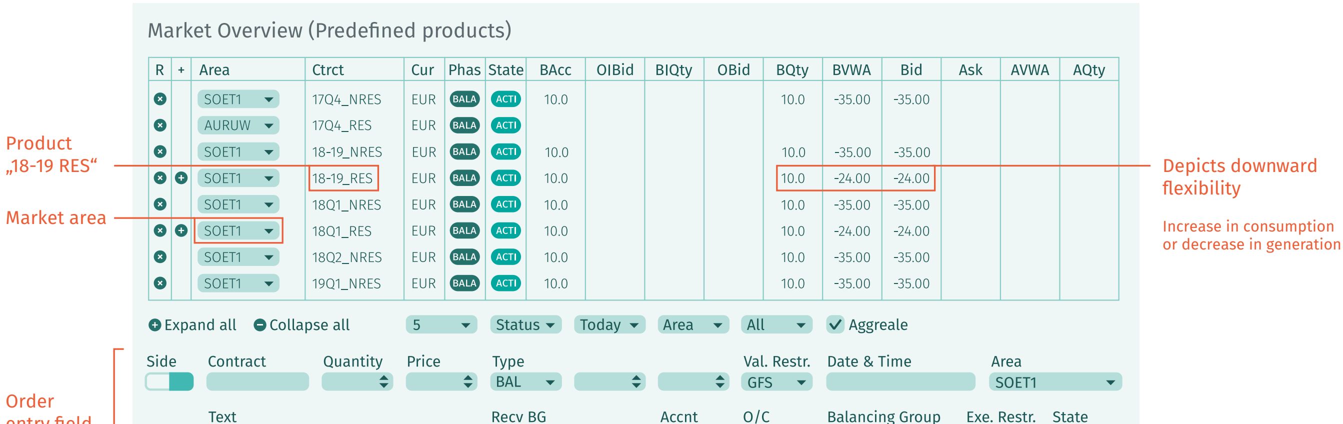
## FLEXIBILITY SUPPLY

On the market platform operated by EPEX SPOT, marketers offer to reduce the feed-in or increase the purchase of electricity once grid operators have announced their flexibility demands.




## FLEXIBILITY DEMAND

Grid operators on all three voltage levels use the enera flex market to resolve congestion on the respective grids. This requires close coordination.




THE ENERA FLEX MARKET USER INTERFACE

## RESOLVING CONGESTION THROUGH LOCAL MARKETS

The flex market does not trade energy; it trades standardised product of "flexibility". This essentially means a deviation from expected or scheduled behaviour that would have occurred without this trade. The market design is based on the stock exchange and aims to tap the greatest possible potential of flexible power to manage congestion. Order books have been allocated to market regions as defined by the grid operators and match supply and demand. A number of flexible generation plants, storage systems and consumers are on hand to resolve congestion within the 23 regions.

The rights and obligations of the individual players have been clearly defined, published and contractually agreed. Participants on the enera flex market assume roles that are also common on established energy markets. In general, owners of generation and storage plants commission a third party to control and market them; this aggregator then pools several plants and acts as a marketer of flexibility on the trading platform. The flex market allows plants to be pooled if they are connected within the same market region. Marketers are also active with their portfolios on other markets, such as the nationwide German wholesale market and the balancing energy market. On the flex market, grid operators are the only ones allowed to act as purchasers. Grid operators are responsible for releasing the plants connected to their grids for use on the flex market. The market and platform operator is a key player, determining the rules and design of the trade product, approving participants for trade and monitoring pricing.

## A CENTRAL REGISTER FOR FLEXIBLE PLANTS

Before a generator, storage system or consumer can be used on the flex market, the marketer needs to register the respective plant and have it certified. The connecting grid operator reviews the plants and allocates them to the correct market region. In enera, this corresponds to the transformer area of a substation between the high and medium-voltage levels and covers every plant that has been certified for the flex market in this region. In order to document the actual power supplied, the generators, storage systems and consumers have to be connected to the SDSP via an IT connection; the plants are also recorded in a central register, along with their master data. This ensures that flexible power, for example, is not offered several times over or by non-existent plants. →

### SOLUTION ELEMENTS

For detailed project reports, please go to the enera project compendium at: www.projekt-enera.de (German only)

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**Complementing Redispatch with the enera approach**
→ p. 266

“With its many captivating facets, amazing project members and a huge network, enera was the perfect point for me to enter the world of energy!”

“The enera flex market allowed us to match the power demand and supply at the right place and the right time, and thus relieve the power grids.”

SIMON VOSWINKEL, UDE

Simon Voswinkel researches congestion management on distribution and transmission grids at the Faculty of Energy Economics at the University of Duisburg-Essen. In enera, he was primarily involved in designing the flex market and the accompanying regulatory matters. Besides enera, he focuses on the distribution of redispatch costs among grid operators, European power market designs and the impact of strategic behaviour on the energy system.

JANA WILKEN, EWE NETZ

Jana Wilken is one of the first members of the enera team at EWE and played a key role in designing the overall project. As an industrial engineer with a focus on viable energy systems, she has accompanied the development of the enera flex market from day one. Drawing on her previous work experience, she always considered the grid operator perspective and thus contributed to the development of a solution that meets the interests of all stakeholders.

## TRADING ON THE PLATFORM

The structure of the enera flex market is modeled on the established, national intraday wholesale market. As with spot market trading, exchange operator EPEX SPOT monitors the rules and processes, which have been adapted specifically for the flex market. This makes connecting existing IT systems easier and at the same time ensures that traders already know how to act on the market.

Wherever potential congestion could occur, connection grid operators define local market regions that are then each allocated to an order book in which the demand of the grid operators is matched with flexible active power offers; both are anonymised. These bids contain precise and binding information on the quantity and price of the flexibility. The exchange orders bids by price limits and the time of entry for each price. Continuous trade allows market participants to be active at any time – 24 hours a day, 365 days a year.

The order books open on the day prior to delivery and are closed five minutes prior to the delivery period. A trade occurs as soon as demand and supply are matched; matching rules ensure that orders are concluded at the best available price. Once a

## REDISPATCH 2.0

The term dispatch refers to scheduling and deployment at large-scale power plants, while re-dispatch means changes to said scheduling and deployment made by transmission grid operators at short notice when grid congestion has been forecast. Redispatch 2.0 is the result of the Grid Expansion Acceleration Act and must be implemented from 1 October 2021 on. While to date this only affects conventional generators with an output of ten megawatts and more, renewable energy generation and cogeneration plants with a nominal capacity of 100 kilowatts and over will also be included in future. Feed-in management, or the curtailment of renewable energy generators in the event of grid congestion, will be replaced by this new process, which in future will also include distribution grid operators. Redispatch 2.0 thus means new tasks and responsibilities for all market players and will require the close cooperation of distribution and transmission grid operators in particular.

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Grid operators communicate with one another by means of a standardised and automated coordination process.

transaction has been concluded, the exchange informs the market participants involved.
Similar to the wholesale market, the fact that the exchange is operated independently ensures an anonymous market with transparent processes and price signals. As the trading system has already been introduced on a large scale, it can be used to manage congestion beyond the boundaries of the enera region. The system is able to process hundreds of thousands of market events and can interact with many standard IT systems.

### COORDINATION AMONG GRID OPERATORS PREVENTS SHIFTS IN CONGESTION

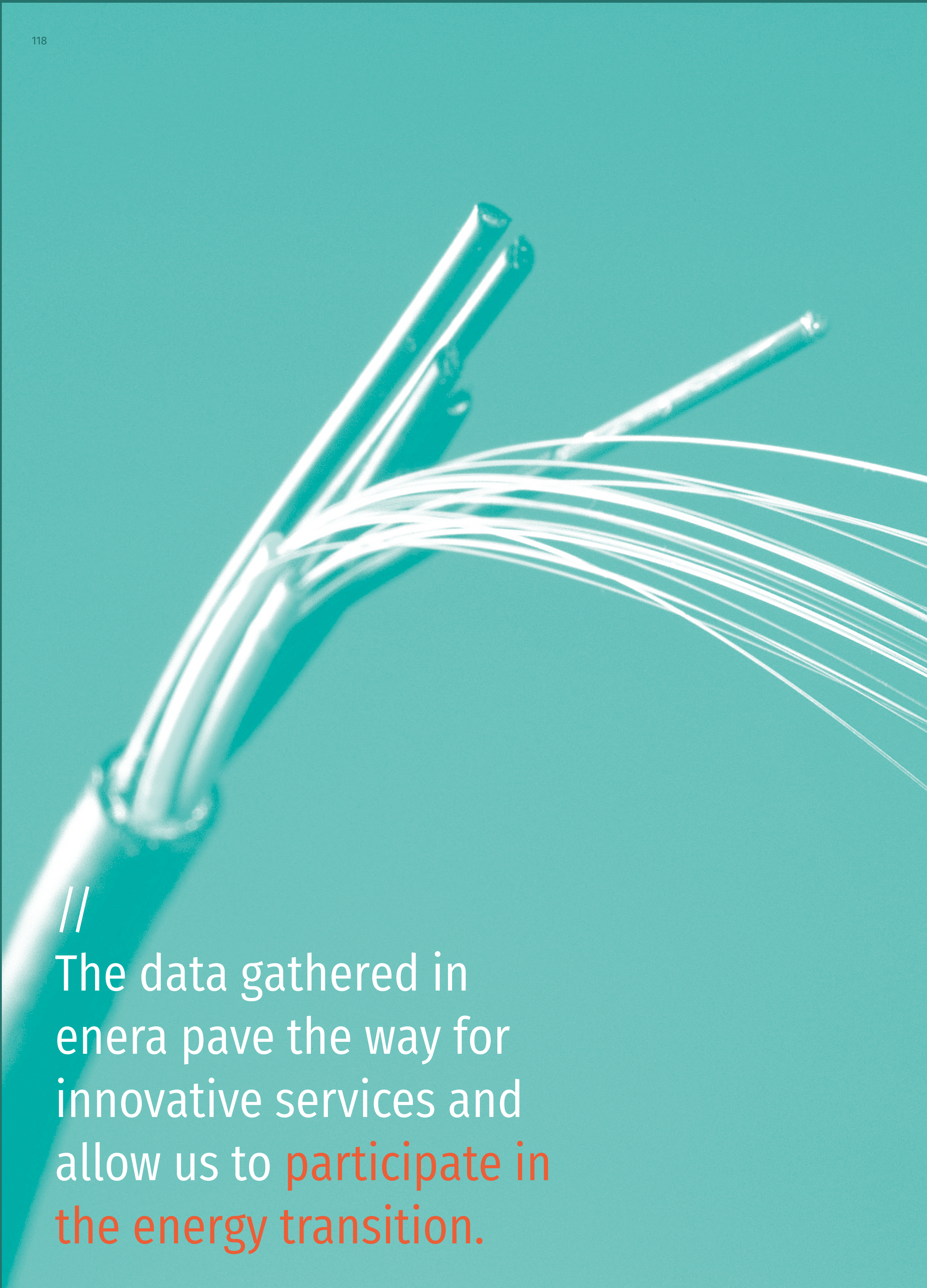
In order to ensure that the activities of one grid operator on the flex market do not cause congestion on the downstream grid of another operator, grid operators have to coordinate their activities. For this purpose, enera has developed a standardised coordination process for grid operators. If, for example, the flexibility demand of a transmission grid operator is to be met by a plant that is connected to a distribution grid, the transmission grid operator will need to intervene on the grid of the distribution grid operator. Before this can happen, every grid operator concerned therefore has to give their approval. Grid operators calculate potential capacity limitations and notify the upstream grid operator by means of a coordination process that has been standardised and can therefore be automated. This coordination process was developed from scratch for and implemented on the enera flex market and can support coordination even after enera has ended. It can also be used in a similar manner in Redispatch 2.0.

### THE VERIFICATION PLATFORM: MAKING FLEXIBILITY MEASURABLE

On the flex market, grid operators and marketers agree to operate plants differently than orginally planned. To verify that this agreement has been realised, they need to be able to identify whether flexibility has been supplied. To do so, grid operators follow-up to determine whether an agreed reduction in input or increase in load actually took place within the agreed period of time; only then do they initiate billing. This verification process requires a range of data from various sources that are merged on the proprietary verification platform. This platform is connected to the enera SDSP, which merges information on trade transactions on the enera flex market provided by grid operators, marketers and the exchange.
Depending on the type of plant, different data are required for verification. Photovoltaic and wind power plants rely on the sun and wind to generate power. Even if a plant has been curtailed, smart algorithms can calculate how much energy would have been generated without said curtailment on the basis of weather data that is accessible to the public.
In contrast to solar and wind power plants, biogas plants, storage systems and loads can be operated flexibly according to schedules. Marketers must submit these schedules to the verification platform in advance so that they can act on the flex market. If a plant then supplies flexibility, the schedule helps determine the extent to which this plant actually adjusted its behaviour compared to the originally submitted schedule; it also helps identify whether the agreed active power has been supplied and the trade transaction thus concluded.
If a contractually agreed delivery is not supplied, marketers have to pay a fine. However, this does not apply if grid operators intervene with a plant through feed-in management or by ordering balancing energy. In order to be able to differentiate these cases, corresponding data on feed-in management and balancing energy orders are also merged on the platform. //

PARTNERS INVOLVED:

AVACON NETZ GmbH
energy & meteo systems GmbH
EWE AG
EWE NETZ GmbH
Likron GmbH
TenneT TSO GmbH
University of Duisburg-Essen
EPEX SPOT SE



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The data gathered in enera pave the way for innovative services and allow us to **participate in the energy transition.**

CHAPTER III

# Data-based Innovation and Participation

# Business models straight from the living room

Many hundreds of households were integrated into enera by means of digital electricity meters. These provided the data that formed the basis for numerous innovative applications and solutions for the energy transition, ranging from algorithms that identify individual appliances in a consumption profile to smart mirrors that visualise power consumption to blockchain concepts for charging fleets of electric cars.

However, the people in the model region were far more than mere suppliers of data; enera included their ideas and suggestions on the energy transition in the project from day one. When it came to developing prototypes, enera involved the public as well – holding workshops in people's living rooms, for example. This led to the development of apps and objects that make saving energy in the household easier by making the flow of electricity in the home transparent.

The data recorded in enera have tremendous potential to add value, as they pave the way for new offers and services beyond the constraints of the energy system. While the **Work Package 9** team systematically explored the potential of data-based products and services, **Work Package 11** focused on helping the public actively shape the energy transition.

# Data as a new means of adding value


D igitisation not only opens up technical options for efficient grid operations; it also has tremendous potential to add value. Huge amounts of available, high-quality data enable new business models, products and partnerships. Work Package 9 systematically identified and harnessed potential to add value.

For the first time, the large-scale enera field test has provided data on generation, grid conditions and the consumption of several hundred households in one region to the second – making a black box transparent. This real-time information can serve as the basis for a wide range of new products and services, for example if it is tapped with the aid of big data technologies.

Digitisation is not only changing the energy industry itself; it is also making it easier to interact with other sectors. enera has given rise to new ways of working in which project partners, private users and digital economy companies cooperate successfully. Formats developed specifically for this project, and the tangible enthusiasm of the parties involved, have resulted in numerous concrete innovations. The profitable methods of cooperation are just as trailblazing as the technical innovations and services that have emerged from enera.

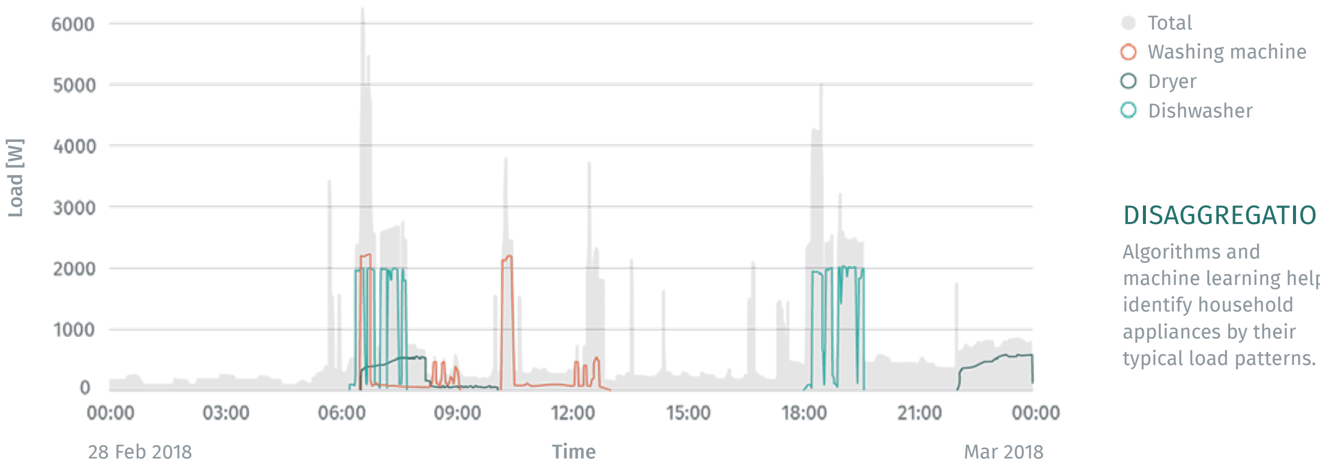
## SYSTEMATICALLY GENERATING INNOVATION

Identifying data-based business models, analysing their potential and then demonstrating them – in enera, these steps were part of a clearly structured innovation process that was supported by methodological formats developed within the project for this specific purpose. As a first step, the team generated ideas for new products and services, alternatively describing existing concepts in a way that allowed us to review their potential (see: Data Thinking and Innovation Friday formats). Promising approaches then underwent a detailed potential analysis (see: the Brainwave format as well as the methodology of exploratory space). The results of the respective use cases included improved forecasts, a new form of customer review and an algorithm to predict the ideal locations for charging stations. To test these results, we repeatedly extracted and loaded data, incorporated algorithms into control processes and developed applications that were available in an app store. The services developed in this manner form the foundation for new, data-based business models.

## DEVELOPING INNOVATION TOGETHER

Start-ups in the digital economy and established companies are often perceived as separate parts of the economy. One of the basic concepts of enera is to merge these two worlds and combine the know-how of the energy sector with the innovative spirit, the speed and the user-oriented approach of young digital companies. One example that signifies the success of this concept is the PitchX competition, where start-ups qualified to analyse the potential of their ideas in cooperation with experts from the industry. This is an unusual approach for a funding project to take and combines the pitch format so common to start-ups with the funding logic of demonstration projects. The winners in the three categories Digitisation, Energy Transition and Customer Interactions then developed innovative prototypes that solve concrete problems facing the energy industry: envelio added an automatic process for verifying data from a range of sources to a digital assist system for grid operators; logarithmo developed an app that depicts nationwide feed-in management in Germany; and Senselab.io designed an application that visualises the energy consumption of household appliances. In total, around 160 start-ups took part in PitchX and other pitch and workshop formats.

Established companies in particular merely have a rudimentary understanding of the value of data as a commodity. The Data Thinking format picks →




## DISAGGREGATION

Algorithms and machine learning help identify household appliances by their typical load patterns.

up on this and starts by conveying the principles of data science, machine learning processes and artificial intelligence to the employees of consortium partners. In a second step, employees are tasked with identifying concrete problems that are then solved with the aid of data science. This creates a broader understanding of how digital value chains work and how these can be exploited to develop and add data-based value.

The Innovation Friday format also promotes new ideas and ways of thinking. The concept here is to start with an idea and end with the outline of a business model, all in the course of one day. For this, we developed a format for tightly-organised, moderated workshops. While the format is modeled on the principles of design thinking, this methodological foundation can be expanded according to needs. After an initial test run, conducted with a handful of participants, the Innovation Friday concept was soon widely used throughout the project: several hundred participants met regularly to develop interdisciplinary ideas and design prototypes together. This is a rather unusual approach for a traditional funding project to take and resulted in concrete applications, including feed-in visualisation and the public storage system.

To progress from a concept to a data-based solution, we used the Brainwave format, a potential analysis method that was also developed specifically for the project. This format uses data science to solve concrete problems within 12 weeks. In this agile method, data experts and specialists in the respective fields work together, applying machine learning and artificial intelligence methods to existing data sets to increase the efficiency of energy-related processes and products. This resulted in the development of algorithms used to forecast grid conditions, lighting maintenance contracts and consumption data disaggregation, to name a few.

## THE KEY TO NEW SERVICES: IDENTIFYING CONSUMER APPLIANCES IN LOAD PROFILES

In the enera project, the electricity consumption of around 700 households was recorded to the second by equipping digital electricity meters with smart access modules, SAM for short. The data thus collected immediately allows the users of these smart meters to identify fundamental patterns of behaviour. In order for them to obtain further detailed information on their electrical appliances, the users' energy consumption needs to be broken down by means of disaggregation. To be able to identify individual devices within a household's load profile, we developed algorithms and machine learning processes that recognise washing machines and dryers, for example, based on typical energy intake patterns. This helped the households participating in the field test identify the consumption and current costs of their appliances, discover hidden consumers and assess the impact of changes in their own behaviour. A detailed receipt breaks down the annual electricity statement for the entire household – whereby customers can track every position in real time, at any time.
In the first field tests, participants with digital electricity meters still recorded the use of washing machines and dishwashers by hand; later on, these energy consumption measurements were provided directly by the consumers themselves. We then used this data to train various machine learning processes to recognise the profiles of these appliances within the household's overall profile. Processing and analysing the data provided us with valuable insights on disaggregation: measurements taken at fifteen minute intervals did not result in a sufficiently high resolution to reliably break down electricity consumption. While we were able to identify large-scale appliances under certain circumstances, this was much more difficult

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# The Brainwave format uses data science to solve concrete problems within 12 weeks.

SOLUTION ELEMENTS

For detailed project reports, please go to the enera project compendium at: www.projekt-enera.de (German only)



when it came to smaller consumers for lights and entertainment. However, we were also not able to identify every washing machine equally well. And even under ideal circumstances, a household's consumption cannot be broken down completely, as small consumers in particular get lost in the total consumption. In addition, the accuracy of the disaggregation models depends on the complexity of the household; if a lot of appliances are run at the same time, it is very difficult to separate them from one another. In order to develop extremely reliable solutions, training data would need to be gathered from far more households than was possible within the scope of the project. With this disaggregation method, enera has nonetheless created key principles for the use of data generated by smart meters.

## GRID4MOBILITY: ENERCOINS REWARD GRID-FRIENDLY CHARGING

Electromobility is a huge challenge for distribution grids. Without smart charge control systems, grids would need a massive upgrade when commuters all charge their electric vehicles at the same time after work. The Grid4Mobility project illustrates one way to avoid congestion on low-voltage grids, even without costly expansions; this method further does not require reductions in a household's installed power, which would slow down the charging process.
As only a few electric vehicles within the fleet need to be available in as short a time as possible, most batteries can be charged at some point during the night; an agent system automatically determines the order in which this will occur. Each charging procedure is documented in a decentralised Ethereum blockchain and is linked to a virtual pricing system. Users who are flexible and thus demonstrate grid-friendly behaviour receive enercoins. Households can then use these enercoins to pay for their vehicle to be given priority in times of increased charging demands.
A field test has shown that this control system works from a technical perspective; in a simulation, we were able to demonstrate how controlled charging prevents grid congestion. As the agent system is run entirely in the background, participating households can charge their electric vehicles without sacrificing convenience. →

## DATA-DRIVEN FORECASTS

In order to integrate renewable energy into the grid in the best possible manner and resolve congestion, we need forecasts on local system loads that are as precise as possible and made as early as possible. The forecasts on grid conditions developed within enera allow predictive grid management. Currently, this is of great import: Redispatch 2.0, a new industry agreement to secure grid stability, is largely based on projected figures and forecasts.

For forecasts on grid conditions, the expected output of wind turbines and photovoltaic plants is of particular relevance. To date, weather forecasts alone are used for this purpose. In data-driven forecasts, on the other hand, the model is additionally trained using historic data. Variables including wear, faults, changes in yield due to clouding and temperature effects are also captured. The project has proved that machine learning can help us improve the quality of our forecasts.

## LARGE-SCALE BATTERIES DESIGNED FOR DISTRICTS

Investors struggle to calculate complex storage solutions for individual districts. Within the project, we developed a software that uses simulations to provide a basis for the optimal design of public storage systems that store the excess electricity generated by photovoltaic plants in a central neighbourhood battery. This energy can then be reclaimed for domestic use, as marketable balancing energy and to charge vehicles. The software solution allows specialists to configure solar power plants, the battery and households and further enables them to determine annual consumption, the number of persons and floor space for the latter. The programme provides a tool to create scenarios that can be used to compare the profitability of different battery capacities, for example; the software can then immediately visualise the data generated in the simulation.

## SMART MIRRORS AND LIGHTING MAINTENANCE CONTRACTS: NEW APPLICATIONS FOR HOUSEHOLDS AND BUSINESSES

A look in the mirror shows the current flow of energy in the home. Photovoltaic plant operators glance at their smartphones to see how they can use as much of the solar power generated on their own roofs as possible. And an augmented reality app scans appliances and displays their current energy consumption. These are just a few examples of applications developed and tested within enera. They support consumers' efforts to save energy and help distribute loads to prevent grid expansions as far as possible. In the following, we will introduce some applications that have been developed into prototypes.

Electricity meters are usually located in parts of our homes that go unnoticed. By visualising consumption data in smart mirrors, on the other hand, the issue


ENERGY AT A GLANCE:
SMART MIRRORS VISUALISE CONSUMPTION DATA.

### PARTNERS INVOLVED:

BTC AG
Bosch.IO GmbH
EWE AG
EWE NETZ GmbH
Fresenius University of Applied Sciences
OFFIS e.V.
Power Plus Communications AG (PPC)
Siemens AG
Software AG
the peak lab. GmbH & Co. KG

of energy is integrated into our daily lives. Once variable electricity rates and smart meters have become established, smart mirrors will be the perfect supplement. As they employ a decentralised data collection method that protects personal data, these mirrors are also a user-friendly alternative to the data-hungry services of market-dominating Internet companies.

Start-up Senselab.io used augmented reality to visualise the energy data of consumers. Customers use the camera in their smartphones to identify electrical appliances such as cookers and washing machines; the SAM AR app then provides information on the energy consumed by these household appliances and suggests ways to save electricity. In the spirit of gamification, the app provides playful access to the issue of household energy: scanning certain appliances triggers games that motivate customers to use the app.

To visualise household electricity consumption in a playful and emotionally appealing fashion, Dutch start-up CareToSave developed a smart toy polar bear. Its coloured LEDs are coupled to a smartphone app via Bluetooth; the app records the current data generated by the digital electricity meter. Depending on consumption, the prototype of polar bear Hyko lights up in different colours, thus animating users to save power.

The restoration assistant uses data on buildings and their surroundings to calculate basic energy consumption; this includes data on the year the building was constructed, the outer surfaces and the district's purchasing power. An algorithm then determines consumption; the app compares this to actual energy consumption and that of comparable buildings. This allows users to determine the potential savings restoration offers.

With lighting maintenance contracts, service providers agree to modernise and maintain a company's lighting system. Customers benefit from lower costs for electricity thanks to efficient and eco-friendly lighting, without having to make a large investment. Currently, companies have to undergo a costly process to determine whether a conversion would be profitable in five or ten years. enera developed an algorithm based on artificial intelligence that uses actual loads and building data to predict when businesses would benefit from a modern lighting system, providing companies with a reliable assessment of their savings potential in seconds. //

"The recipe for a new business is a good combination of a partner network, artificial and natural intelligence, and luck. enera was our kitchen – the meal a success!"

DR MATTHIAS POSTINA, EWE AG

Matthias Postina is Head of Data Science at EWE and responsible for the EWE Digital Factory. In enera, he coordinated and headed the development of data-based business models across all partner companies. After studying computer science in Germany and the USA, he was active in the field of science for many years, where he specialised in the management of complex corporate architectures in times of digital change over the course of his doctorate. During his time at a renowned German research institute in the field of computer science, he gathered practical experience in the energy industry and joined EWE AG in 2012. Here, he established the Data Science team and specialised in the use of artificial intelligence to develop data-based business models.

# From the user's perspective

DIALOGUES AND CARGO BIKES: DURING THEIR ROAD TRIPS, THE ENERA TEAM TALKED TO MANY PEOPLE IN THE MODEL REGION.

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Voluntariness, trust, a local context and low entry barriers are prerequisites for successful public participation.

enera involved people in the model region in a number of ways – for example via apps, at prototype workshops held in people's living rooms and at the enera Frisian Festival. After all, broad acceptance is essential if the conversion of our energy system is to succeed. Work Package 11 aimed to motivate the public to not only understand the energy transition but help shape it as well.

How do interfaces need to be designed to make household energy consumption transparent and saving electricity easier? In enera, this was not up to programmers to decide; instead, we involved the people in the region from day one. We would also not have been able to create the database for the solutions developed in enera without the participation of hundreds of households.

In the space of roughly one year, 1,500 people volunteered to field-test digital electricity meters and make their consumption data available to the project. To recruit these volunteers, we ran campaigns on social media channels, in local newspapers and placed cinema and radio ads. Above all, we gained their support by meeting the public in person at a wide range of events. Project members travelled the region on cargo bikes and discussed the energy transition – at barbecues hosted by sport clubs, at country women's meetings and trade associations.

## HOW CAN WE INVOLVE THE PUBLIC?

Voluntariness, trust, a local context as well as low entry barriers – supported by scientific knowledge, we defined these criteria as prerequisites for successfully involving the public at the start of the project. Other helpful factors include semi-public spaces that facilitate encounters and the exchange of information in neighbourly and extended social networks. However, communicating among equals is key. The formats used within Work Package 11 were all guided by this principle, while human-centred design provided the key methodological approach. This iterative method is also used in software and application development, where potential users repeatedly define requirements and are involved in evaluations and solution-finding processes. Accordingly, we first aimed to find out more about the needs and interests of people in the model region in connection with the energy transition, conducting qualitative interviews to obtain information on the household's technical equipment as well as on digital and social networks and personal values. With the aid of the results of these surveys, we then defined personas, fictional users that represent specific groups.

## TRAVELLING THE MODEL REGION ON ELECTRIC CARGO BIKES

Two enera road trips supplied further information on the public's motivation. For one week per trip, two project members toured the model region on electric cargo bikes. In around 600 face-to-face conversations, on social media, in the press and on the radio, they provided information on the project and established contacts. Three barcamps raised further public awareness: in this format, a total of 190 participants determined the agenda themselves, negotiating a range of topics that included mobility and renewable energy and discussing the link between life, learning and digitisation. We also organised other local events with trade and business associations and at energy dialogues. Our cooperation with the municipalities led to the enera Frisian Festival, for example, while our contact with a university resulted in students producing social media posts and a report on enera for a TV programme. →

## WORKSHOPS IN LIVING ROOMS: USERS DEVELOP PROTOTYPES

enera aimed to help people in the model region participate actively in the energy system, as opposed to being passive users. We cooperated with potential users to develop corresponding interfaces between people and the supply grid in accordance with the principles of human-centred design, inviting them to take part in prototype workshops and other formats, some of which were even held in people's living rooms. The interfaces developed in these workshops included a mobile robot that monitors the home; an interactive mirror; automated daily energy reports; a plug-and-play system to record meter readings; and an illuminated cube that visualises a household's energy data. Twelve of these ideas were developed into initial prototypes.

The interactive mirror is an excellent example that allows us to illustrate the process from its conception by potential users to the finished product. We started by looking for an object that can blend discretely into our homes while at the same time granting access to information on the state of the house; this resulted in the development of the smart mirror concept during a workshop. The first prototype was presented at a barcamp and received positive feedback, particularly in terms of design; participants also provided further ideas on how to expand functionalities and integrate the mirror into smart home environments. This involved connecting it to a smart meter, which was realised during a hackathon: the mirror was then able to display the data generated by the digital meter in real time. Up until this point, the mirror had been designed exclusively as an output medium; to enable interactions as well, we installed a camera and 3D motion control. These allow users to control various applications with hand and finger gestures, without touching the mirror's surface. In addition, face recognition technology enables personalised use.

## DRUMMING UP INTEREST FOR THE FIELD TEST

One of enera's key targets was to achieve more transparency on energy consumption and use data for the energy transition. We therefore needed to find volunteers willing to make their energy consumption data available. In particular, we found these volunteers at informal and neighbourhood events as well as at events hosted by clubs and associations: at Rotary and Lions Clubs, sports clubs, local groups of the German Life Rescue Association and Country Women's Associations [Landfrauenvereinigung]. A community challenge also advertised the field test: in a Refer a Friend programme, participants collected points and rewards, which also garnered coverage on social media. We also placed ads in regional newspapers and on billboards and ran one radio and one cinema ad. In the space of roughly one year, 1,500 people volunteered to take part in the field test; in the homes of roughly half of these, we ultimately installed digital meters and a communication module.

## APPS MAKE ENERGY CONSUMPTION TRANSPARENT

Users can access the gathered data to the second via the enera app, which displays costs alongside current and historic consumption values. Users can take their smartphones and turn on any appliance in their home to find out more about its consumption, which is immediately displayed in real time. They can also see whether they have consumed more or less over a specific period of time compared to a reference period. Tips on how to save energy and useful information on sustainability at home round off the scope of functionalities. Some people used the app to track the cause of high electricity consumption, for example, while others determined whether it costs less to bake your own bread in your own oven than buy it from a bakery.

The project team developed other applications besides the enera app, always with a focus on visualising data flows and helping users understand, interact with and benefit from their own energy households. The Pulse app visualises consumption data as well as times of high grid loads. Households that behave in a grid-friendly manner by consuming power outside of peak load times, for example, are rewarded; for this purpose, we integrated a per-second accounting system for micro-transactions.

The HomEnergy app provides more transparency, making it easier for people to optimise energy consumption in their own homes, for example by comparing daily and average values. Easy-to-understand diagrams visualise consumption flows, for example, broken down into individual appliances. →



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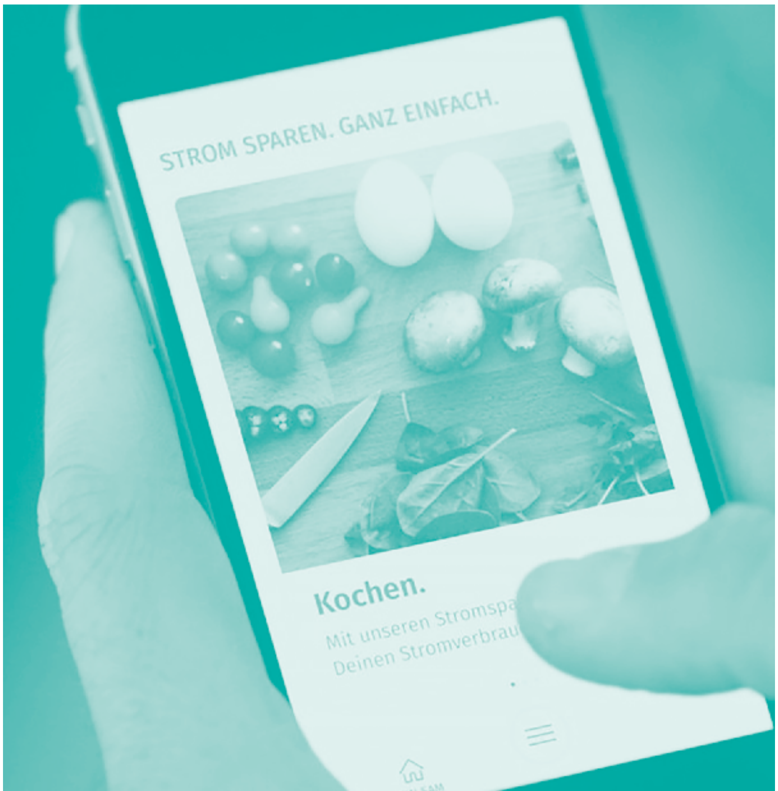
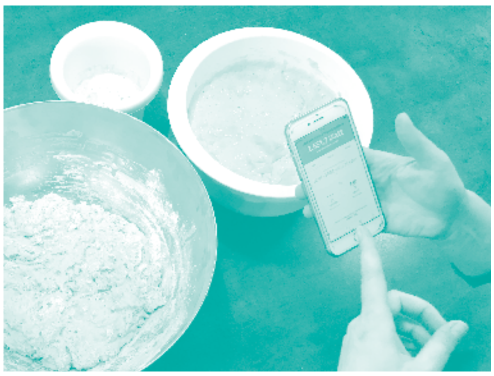
The enera app displays current energy consumption at a glance.




SOME FIELD TEST PARTICIPANTS USED THE ENERA APP TO DETERMINE THE ELECTRICITY COSTS OF THEIR COOKING AND BAKING ACTIVITIES.



## PARTNERS INVOLVED:

EWE AG
the peak lab. GmbH & Co. KG
Aurich county

ABOVE:
PROJECT MEMBERS RAISED AWARENESS FOR THE PROJECT ON TWO TOURS THROUGH THE WINDY MODEL REGION.

RIGHT:
CONVERSATIONS AMONG EQUALS: THE ENERGY NEEDS OF THE PUBLIC TOOK CENTRE STAGE.

BELOW:
THE MUNICIPAL WEB APPLICATION MAKES THE ENERGY CONSUMPTION OF PUBLIC PROPERTIES TRANSPARENT.


## SOLUTION ELEMENTS

For detailed project reports, please go to the enera project compendium at: www.projekt-enera.de (German only)

A PLAYFUL APPROACH TO THE ENERGY TRANSITION: SOME PROTOTYPES WERE DESIGNED WITH THE AID OF LEGO BRICKS.

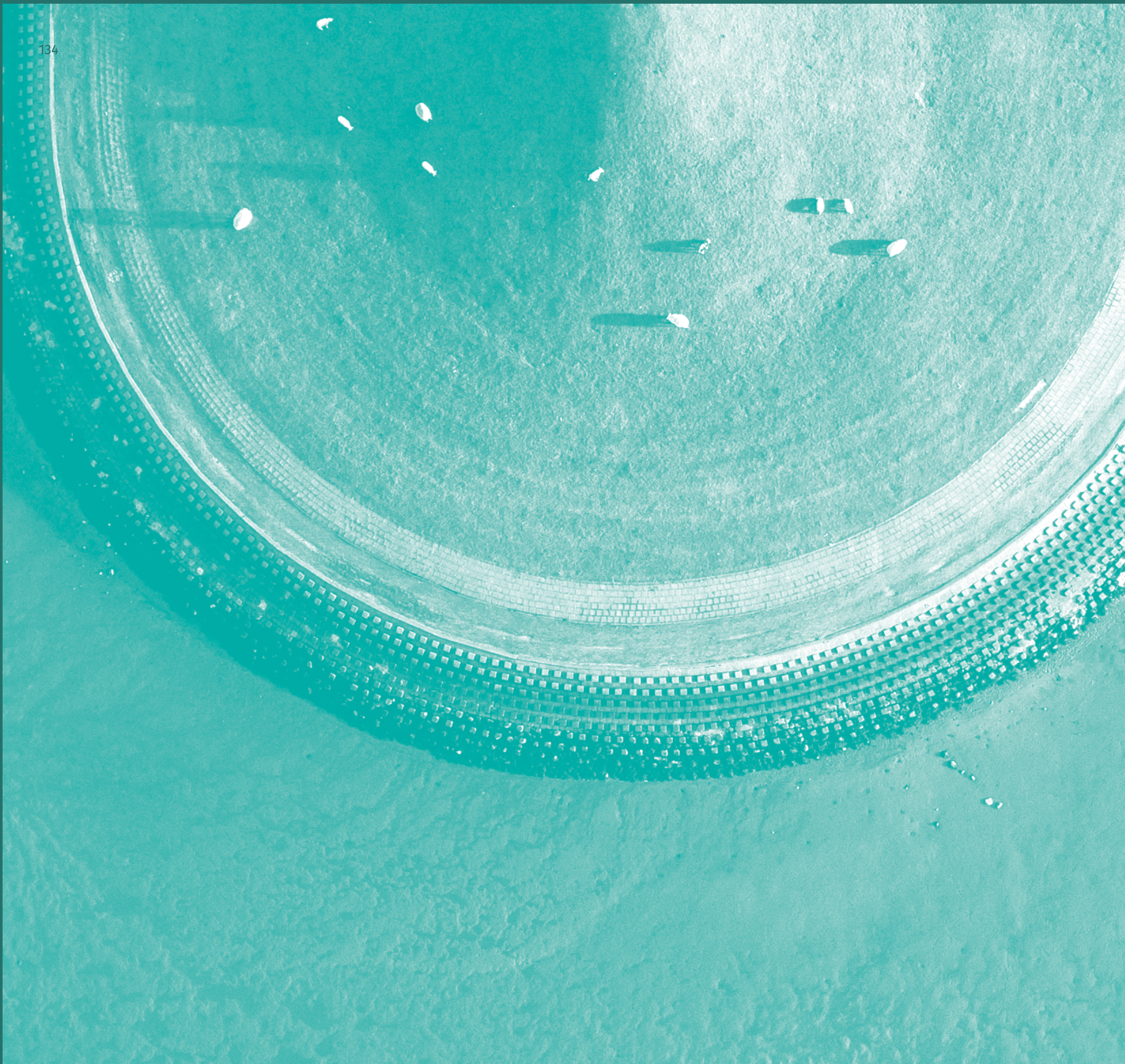
## REDUCING ENERGY CONSUMPTION IN SCHOOLS AND TOWN HALLS

The project also monitored the consumption of municipalities in the model region, in addition to that of private households. Energy consumed by 50 public properties including schools, nursery schools and administrative buildings were recorded to the second and visualised in a web application. Currently, meters are usually read once a year in order to bill electricity, which makes it difficult to derive concrete potential savings. The municipal web application, on the other hand, helps municipalities analyse consumption and recognise patterns: two similarly sized primary schools are easy to compare, irregularities caused by faulty appliances soon identified. This also provides a more stable foundation for planning and maintenance, making it easier for administrators to lower their energy consumption and greenhouse gas emissions. The app has now been expanded to help municipalities optimise their gas and water consumption. Other functions include alerts in the event of striking deviations in consumption as well as regular energy reports. //

"Talking to people, understanding their needs, is certainly fun and worthwhile – it's also absolutely essential if we want to find really good solutions."

FRANK GLANERT, EWE AG

Frank Glanert joined consortium leader EWE AG around 20 years ago and has worked in regional development and the energy industry ever since. During this time, the trained carpenter and civil engineer worked in various departments. In enera, he focused on addressing people in the region and implementing a human-centred design approach.



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In order to implement the approaches developed in enera throughout Germany, regulatory requirements need adapting.

CHAPTER IV

# Legal Framework and Transferability

# One model for the whole of Germany?


enera developed a range of solutions to integrate renewable energies in a way that makes sense from an economic perspective. However, in order to implement approaches such as the flex market, the framework conditions of energy law need adapting. And we need to determine the extent to which the solutions tested in the model region can be transferred to other regions in Germany.

Scientific simulations allow us to make statements on the transferability of the smart grid operator, the flex market and their incorporation into grid operations. To achieve this, the project modeled scenarios that extend as far as 2050 and depict regional differences in the energy system and various courses of development.

The project investigated the regulatory and legal obstacles currently facing the flex market as well as incentive mechanisms for market participants. These aim to make innovative approaches to integrating renewable energy more appealing to grid operators on the one hand; on the other, tax and levy burdens on suppliers of grid-friendly load increases and feed-in reductions need to be reduced.

While **Work Package 8** illustrates courses of action to shape the framework of energy law, **Work Package 13** focuses on how enera can be transferred to the whole of Germany.

# Putting the project into practice

The flex market has shown how a market-based solution can help resolve grid congestion without curtailing renewable energy. Currently, solutions like these cannot be employed outside of projects such as enera due to regulatory and legal obstacles. In order for the flex market to actually be put into use, framework conditions need to be reshaped in a number of fields.

What incentives do flex market participants need, which legal adaptations are necessary and what role would grid operators play? Work Package 8 analysed all of these questions. The results of our scientific investigations have led to comprehensive recommended courses of action.

There is currently no economic appeal for grid operators to use flex markets. Simply put: the regulatory status quo means there is money to be made in grid expansions; in conventional congestion management and alternative approaches to integrating renewable energy, on the other hand, there is not. The project therefore developed an incentive mechanism that can create the framework within which flexibility markets are brought into play as another means of integrating renewable energy, in other words, to resolve grid congestion.

Similarly, being active on the flex market is currently not worth the while of suppliers of grid-friendly increases in load, especially when energy carriers that have relatively low fee, tax and levy burdens are replaced with flexible energy in the course of sector coupling. In addition, remuneration for green electricity may distort pricing on the flex market. Side payments could remedy this, as the model developed in enera has shown. enera also found solutions for problems caused by players dominating the market and strategic behaviour.

## PROVIDING NEW INCENTIVES

If flexibility markets are to be used to resolve grid congestion, the legal framework needs adapting. The FlexShare and FOCS approach developed in enera aims to create a cost-efficient and technology neutral framework in which cost risks are split between grid operators and grid customers. Operating expenses incurred for the flex market and capital expenditures for grid investments would be treated equally. This approach could be realised using mechanisms already found in the applicable Incentive Regulation Ordinance. With the aid of simulations, the project team has shown that this concept could benefit the entire economy. We also investigated incentives at the interface between grid operators and grid users that result from differentiating grid charges by space and time, a model that aims to relieve the grid during peak load times. Our analysis confirmed that users can be involved more efficiently when charges reflect grid costs more effectively. However, interdependencies with the flex market require careful review.

> We need to change the incentive system so that alternatives to grid expansion are more appealing.

### SOLUTION ELEMENTS

For detailed project reports, please go to the enera project compendium at: www.projekt-enera.de (German only)

**Incentive mechanisms**
→ p. 382

**Game theory and grid operator incentives**
→ p. 386

**Grid expansion strategies**
→ p. 390

**The gas grid as flexibility**
→ p. 394

**Legal assessment of the flex market**
→ p. 400

**US market roles and business models**
→ S. 404

**Side payments**
→ p. 408

## ARE GRID OPERATORS CAUGHT IN A PRISONER'S DILEMMA?

While the new regulation concept would promote the use of flexible consumption loads and generation, losses of efficiency may occur in the coordination among grid operators. However, that they cooperate is becoming increasingly important: distributed generators, storage systems and flexible consumers have led to a rise in resources that can be employed in a grid-friendly manner on distribution grids. However, the use thereof may have an unintentional negative impact if grid operators do not coordinate their actions. A game-theoretical analysis – when managing congestion, grid operators may find themselves in situations that correspond to the prisoner's dilemma or a game of chicken – proved that a lack of information about other grids may lead to problems. The same apparently also applies if there is a lack of incentive to cooperate with other grid operators to find efficient solutions. Within the scope of enera, we therefore developed a game-theoretical model that provides incentive for the coordinated use of grid-friendly flexibility. The results of our analysis indicate that a regulatory framework is necessary for grid operators to coordinate their actions in an economically efficient manner; this framework needs to secure the exchange of information in particular while also providing incentive to exhibit cooperative behaviour. This could be achieved through mechanisms that ensure every grid operator shares in the benefits of the ideal economic solution. →

## REASONABLE GRID EXPANSIONS: ECONOMIC VS. BUSINESS PERSPECTIVES

To help grid operators more precisely calculate the impact of the current and/or adapted regulatory framework on their monetary success, enera developed a method to assess the economically optimised expansion of capacities. The method considers both conventional and new measures to expand capacities, i.e. traditional grid expansion, peak shaving at generation plants and the purchase of flexibility.
Grid operators can compare various expansion strategies within the defined regulatory framework and determine which is the most advantageous from a business perspective as well as the best implementation date. At the same time, we investigated the impact of an adapted regulatory framework on various expansion strategies, thus allowing initial statements on the effect of adaptations. By comparing these to economically optimised grid expansion plans, we were able to identify disincentives in the regulations.

## SIDE PAYMENTS PREVENT DISTORTION ON THE FLEX MARKET

The flex market aims to use the most economically efficient solutions without putting system security at risk. Our analyses of the regulatory framework have shown that for many suppliers, reducing the feed-in of renewable energy to relieve the grid is not worth their while, mainly due to the distorting effect of market premiums. Bids submitted by renewable generators should also consider guaranteed remuneration in accordance with the Renewable Energy Sources Act and/or market premiums for direct marketing. According to the regulatory status quo, these would not apply on the flex market when feed-in is reduced in a grid-friendly manner, nor would compensations be paid, as plants are not curtailed by grid operators.
This problem could be solved by the proposed side payments, as the project has shown. These are additional payments that amount to the value of the market premium and are paid to direct marketers once the voluntary curtailment of renewable energy has been agreed on the flex market. Suppliers would lower their bids on the trading platform accordingly and thus no longer be at a disadvantage caused by the distorting effect of market premiums when compared to competitors that offer flexibility through storage systems and consumption loads. A simple quantitative analysis has shown that this method helps minimise total costs.

## LIMITING STRATEGIC BEHAVIOUR AND MARKET DOMINANCE

On regional flexibility markets, we can expect to encounter suppliers that use their market dominance to demand excessive prices; this could be countered by defining maximum price limits. Undesirable strategic behaviour is another problem that may arise in market-based congestion management: if traders expect bottlenecks, they could adapt their spot market bids to the enera flex market, encouraging congestion and making the resolution thereof more expensive. Targeted market surveillance could identify this strategic behaviour, which could then be punished, provided corresponding market regulations are in place.

## REMOVING LEGAL OBSTACLES

An ordinance has created a framework within which projects such as enera can conduct experiments and that permits temporary deviations from the general legal position. If solutions found within these projects are to be transferred to practice once these demonstration projects have ended, they need to be in compliance with German and EU law. Against this backdrop, we reviewed the legal framework for operating measuring points, grid expansion obligations, electricity storage as well as the responsibilities and unbundling of grid operators. We also analysed how grid operators could potentially influence the grid-friendly behaviour of grid users as well as the recognition of costs in incentive regulations from a legal perspective. Peak shaving through voltage regulators was another object of investigation; this grid planning option cannot be brought in line with feed-in management regulations. On the whole, it became apparent that many legal adaptations are necessary if we are to sustainably establish flex markets.

## INTEGRATING DISTRIBUTED DEVICES

Due to the electrification of the heat and mobility sectors, we can expect millions of new heat pumps, electricity storage systems and electric vehicles to be installed in the coming years. The potential of these devices is of economic import to the energy industry, as they can be used in congestion management, for example. However, these devices cannot currently be integrated from a technical perspective, or only at a high cost. Integrating individual plants and storage systems into the flex market requires automated, digital authentication. A decentralised identity register for devices, for example on the basis of blockchain technology, could close the gap for digital end-to-end connections, enabling devices to switch between ancillary services and private consumption flexibly and at short notice. //

### PARTNERS INVOLVED:

Jacobs University Bremen
University of Duisburg-Essen
Clausthal University of Technology
IAEW at RWTH Aachen University
Fresenius University of Applied Sciences
EWE NETZ GmbH
TenneT TSO GmbH
EWE AG

"We don't need to reinvent the wheel. We already have the economic tools we need to restructure the energy sector into smart grids; we just need to find the right combination. With its findings, enera represents a major step; now we need to pick up speed as we continue down this path."

DR MARIUS BUCHMANN, JACOBS UNIVERSITY

Dr Marius Buchmann has a doctorate in energy economics and is the project lead at the Faculty of Energy Economics at Jacobs University Bremen. Since 2017, he has been responsible for various projects in the fields of market design, smart power grids and the regulation thereof as well as for the work conducted by Jacobs University within enera.

# Simulating the year 2050

The enera project launched with an ambitious goal: to provide a blueprint for the energy transition. And it was actually able to demonstrate a wide range of innovative solutions in the model region. Work Package 13 used simulations to scientifically analyse the extent to which these solutions can be transferred to the future German energy system.

For the future energy system, we created four scenarios each for 2030, 2040 and 2050. These helped us assess the impact of the solutions developed in enera.

Our investigations focused on the effects of the nationwide use of smart grid operators, flex markets and their integration into active grid operations. During our holistic assessment of their transferability, we considered regional differences in particular and created several future enera scenarios to depict different courses of development.

These simulations allowed us to assess the potential of flexible power consumption in individual regions; to investigate the integration of grid-friendly generators and consumers into the nation-wide power market; and to analyse the impact on the transmission grid.

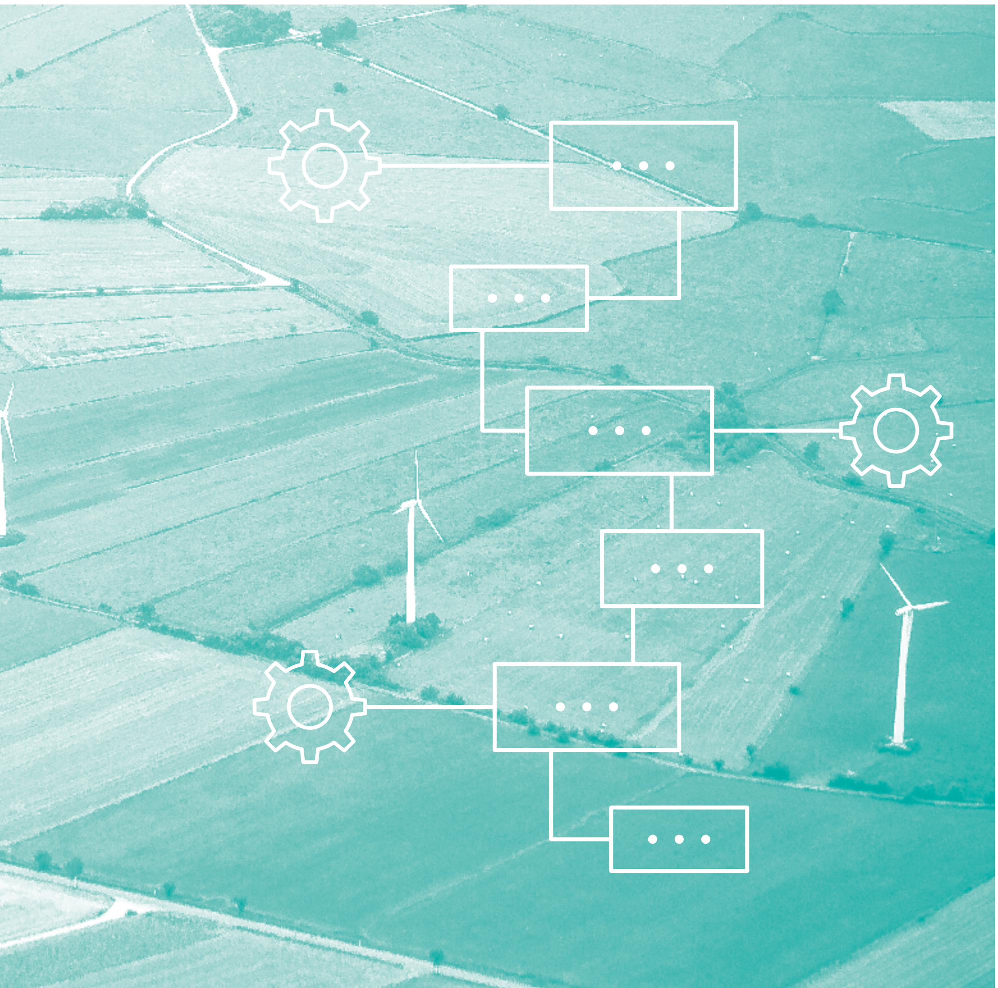
We used our findings to create the enera road map, which shows how enera concepts can be transferred to the whole of Germany. The map illustrates grid regions in which solutions demonstrated in enera can reasonably be implemented, and under which conditions, as well as the challenges that still need to be overcome.

## ACTIVE DISTRIBUTION GRID OPERATIONS IN ALL GRID REGIONS

The project has successfully demonstrated that the enera flex market and smart grid operations work and make sense in the model region. But does the same apply to distribution grid regions with different structures, for example with far lower installed wind power capacities?
In simulations, we investigated the extent to which enera solutions can be implemented and are effective in other locations. In order to make statements on transferability, we needed information on the structure of power grids in other regions; these data are, however, not fully accessible to the public. We therefore determined representative grid regions in Germany and synthetically created distribution grid structures. In the course of this, the depiction of supply obligations and future grid developments was key.
In the representative regions, we simulated active distribution grid operations that use innovative grid operating equipment as well as the local flex market; the simulations also reflected the impact each has upon the other. We were able to depict various courses of development in scenarios for 2030, 2040 and 2050.

On the basis of these simulations, we then assessed the grid regions in which congestion could be resolved through flex markets and the products that play a particularly relevant role in this. It became apparent that expansive grids with a high input of wind power use flexible power from renewable energy generators in particular to resolve congestion. Distribution grids that are not dominated as strongly by one type of plant, on the other hand, also employ other flexibility products.

Our analyses also focused on the extent to which active distribution grid operations can reduce the expansion of these grids. Initial results have shown that conventional grid expansion can be delayed, and even prevented, through grid-friendly congestion resolution – however, to date there is a lack of incentive to do so. The initial findings already indicate key differences, depending on the grid structures observed: in rural areas, conventional grid expansion can be reduced in particular by curtailing renewable energy plants and using regulated distribution transformers, while urban areas can achieve the same primarily by adapting consumption in a grid-friendly manner. →



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## In Berlin households in 2030, the power consumed by electromobility and heating alone will help shift loads of more than 300 megawatts, while the same appliances will merely account for 17 megawatts in the Märkisch-Oderland district.

### HOW PROMISING ARE FLEXIBLE LOADS?

The concept of increasing consumption when the wind and sun generate too much green electricity on the grid has been around for some time. However, until recently the technical and economic potential of grid-friendly consumption had not been clear. The study we conducted for enera has supplied freely accessible data sets on this for the first time, with high temporal and regional resolution.

According to our results, populous counties have the highest technical potential to shift loads. In these regions, cooling and ventilation in trade, commerce and services as well as electromobility and heat applications in private households are most suitable for consuming electricity in a grid-friendly manner. In the 2030 scenario, for example, Berlin was able to shift loads of more than 300 megawatts of power, while the neighbouring Märkisch-Oderland district only managed around 17 megawatts.

If we focus exclusively on the industrial sector, counties with energy-consuming businesses in North Rhine-Westphalia, the Rhine-Neckar region, Bavaria and Saxony in particular have great potential to shift loads. Tapping this potential will require the efforts of both the political and private sectors, for example by reducing the fixed share in electricity costs, introducing time variable grid charges and using more regulated consumer devices.

### THE EFFECT OF ACTIVE DISTRIBUTION GRIDS ON ELECTRICITY MARKETS AND TRANSMISSION GRIDS

German-wide, active distribution grid operations would have an impact on the transmission grids. These become overloaded when generation and consumption hubs are far apart from one another, for example when high quantities of wind power are fed into the north and a lot of electricity is consumed in metropolitan regions and the south. In these cases, grid-friendly transactions on a flex market could ensure that, for example, battery storage systems absorb the generated energy or a biogas plant reduces its power generation in the region ahead of the bottleneck; the region behind the bottleneck would take the opposite approach.

While these effects balance each other out in total, generation and consumption are closer to one another or are in line with current grid capacities. If distribution and transmission grid operators both have coordinated access to the flex market, the market can contribute to relieving distribution as well as transmission grids once it has been implemented throughout Germany, as investigated within the scope of a systems study.

We can also expect the electricity market to benefit from active distribution grid operations that use flex markets. In Germany, wholesale trade leads to the formation of standardised electricity prices. We therefore expanded a model of the electricity market accordingly to verify whether the enera flex market is compatible with this system and can thus be transferred to Germany as a whole. The simulation allowed us to investigate the interdependencies between the flex

#### SOLUTION ELEMENTS

For detailed project reports, please go to the enera project compendium at:
www.projekt-enera.de (German only)

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**The enera road map and enera scenarios**
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market and the established zonal electricity market within a model calculation. The twelve enera scenarios showed that integrating flex markets into the market system can reduce the curtailment of renewable energy. Besides local flexibility markets, the increase in local voltage regulations on distribution grids can also impact transmission grids. In a systems study, we investigated the extent to which interdependencies between regulations on the distribution and transmission grids impact voltage regulation on the transmission grid.

## ROAD MAP FOR ACTIVE GRID OPERATIONS AND FLEX MARKETS

The enera road map incorporates the results of the simulations conducted in Work Package 13 as well as findings from other work packages, focusing on active grid operations and the enera flex market as well as interdependencies between the two. The road map uses future scenarios to illustrate the regions in which, and conditions under which, the solutions demonstrated in the enera project can reasonably be implemented. With the courses of action it recommends, the road map emphasises the challenges that need to be overcome in the course of this. //

"'The things we do today determine the world of tomorrow.'

Marie von Ebner-Eschenbach"

SIRKKA PORADA, RWTH AACHEN UNIVERSITY

Sirkka Porada studied industrial engineering at RWTH Aachen University, specialising in electrical engineering, and is currently writing her doctorate in the same field at the Institute of High Voltage Equipment and Grids, Digitisation and Energy Economics at RWTH Aachen University. Here, her research focuses on energy system operations. She has been involved in the enera project work package "Merging enera and transferring results to Germany" since 2017.

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For more information, please visit: www.sinteg.de/en/

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