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FINAL REPORT

# Data Analysis and Artificial Intelligence in the Electricity Distribution Grid

Opportunities for the future of electricity grids through collaboration between distribution system operators and start-ups

# Legal Information

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# Preface

The energy system is becoming increasingly decentralised and requires greater coordination due to the more prevalent use of renewable energy sources. Grid operators require support in their various tasks due to the resulting increase in complexity at all levels of the electricity grid. Digital systems are needed that can reliably model reality and make this complexity controllable. New methods and innovations, including decision-making tools, must be developed and integrated successively in order to ensure that the electricity system can be planned and operated efficiently and reliably going forward.
A number of experiences we have noted in recent years during various dena projects on the continued development of electricity grids have brought to light the evolving tasks and challenges associated with the electricity grid. This became particularly evident in the following two projects:

- the dena Grid Study III demonstrated the need for convergence in the planning of different infrastructures. Further reflection is needed on the grid itself due to new consumers and more powerful interfaces to heating/cooling, gas or hydrogen grids. Real-time data on the grid status is also becoming increasingly important, as improved utilisation of current capacities may partially reduce or postpone the need for expansion of the power grid. Grid status variables must be monitored during optimised operation close to the designed limits in order to ensure grid security and minimise control interventions.

- The dena Ancillary Services Platform has shed light on the role of innovative digital technologies in the provision of ancillary services. Communication and information sharing between grid levels and operators are vital aspects to leverage potential for efficiency. For instance, Redispatch 2.0, in which smaller power generating plants are used for redispatching, is unthinkable without digital technologies. While the project was still viewed as highly ambitious some time ago, it has since progressed in leaps and bounds – and discussions are even turning to Redispatch 3.0. In addition, the process has demonstrated that mandatory requirements can place defined progress within reach.

These and other digital applications require the collection and meaningful processing of data. It is reasonable to assume that the grid will eventually become virtually impossible to control without the use of innovative technologies and data.

The increasingly complex challenges in the operation of electricity grids are coinciding with the development of new solution methods with some opportunities for disruptive innovation. Artificial intelligence (AI) in particular is becoming more and more widespread due to general growth in the database and increasing availability of computing power. AI unleashes its greatest potential where complex systems and processes can be optimised to reduce costs and generate scalable income. Previous dena projects on digitisation of energy systems have highlighted how AI applications can accelerate the speed of transforming the energy system:

- the EnerKI project demonstrated that the penetration of AI applications in the energy sector is nuanced and geared to specific use cases. The level of technical development – and not just the potential contribution to the energy transition – is extremely high, especially in the cases of forecasts and operational and facility optimisations. Extensive use of AI is expected in grid operation. Important areas of areas of application include, for instance, more precise forecasts of load, predictive planning of feed-in and production as well as optimised operation of the grids themselves.

- The security of AI applications is particularly important when dealing with critical infrastructures such as the electricity grid. The reliability of AI hinges to particular extent on the currency, quantity and quality of data, for example the availability of up to date grid data. But not every AI application is automatically associated with an increased potential for damage in this context, so the demands placed in reliability and traceability also vary. This is evident in the draft of the Artificial Intelligence Act that is currently being discussed at EU level and which adopts a risk-based approach.

- The findings of a dena survey on the use of AI in the energy sector reveal that a large proportion of the management-level respondents attribute significant potential to AI, but believe nevertheless that their own company possesses inadequate expertise – a discrepancy that highlights the immense need for qualification, knowledge building and networking.

The Data4Grid project takes the consistent and important step of combining the topics of digitisation and the electricity grid within a highly practical framework. A mutually beneficial exchange and transfer of knowledge on the development of AI applications in the electricity distribution grid, the necessary framework conditions, strategic decisions in the company and successful implementation emerged from the dialogue between the digital and energy sectors, established actors and start-ups.

We would like to thank the Federal Ministry for Economic Affairs and Climate Protection (BMWK) for enabling us to carry out this project and extend our gratitude also to the representatives from electricity distribution grid operators who actively participated in the project and in some cases invested a great deal of effort. We are thankful to the teams from *umlaut energy GmbH* and *Innoloft* for the strong support they provided to the competition. We deeply appreciate their unwavering commitment to connecting the topics of electricity grids and data analysis/AI and to collaborating on the project to the benefit of everyone involved. Our thanks also go to *Fraunhofer IEE* for preparing the scientific opinion and for using this as a basis to derive several guidelines for implementing new digital technologies in electricity distribution grids. They establish a trustworthy basis and template to build and share knowledge. Last but not least, we would like to thank all the start-ups and development teams that accepted the challenges of obtaining and processing the data during a collaborative work phase lasting several months and who developed valuable concepts. These contributions create a solid foundation for the work of many actors. The teams will undoubtedly establish future partnerships based on these concepts and proven know-how.

Our aim with this report – comprising this Executive Summary, the report on the practical part of the project by *umlaut energy GmbH* and a scientific opinion by *Fraunhofer IEE* – is to provide the sector with useful information on the implementation of innovative solutions for distribution grids. We will continue to engage intensively with the grid operators, the sector as a whole and the digital economy and in doing so drive implementation of the energy transition.

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# Executive Summary

Data analysis and artificial intelligence (AI) in the power grid can not only deliver considerable added value for grid operators and the overall system, but are equally crucial for the successful transformation towards a sustainable energy supply. There are numerous use cases at electricity distribution grid level whose potential has been outlined multiple times, for instance grid status estimates, scenario analyses and predictive maintenance. The importance of data analysis and AI will continue to grow, as they are necessary to ensure the manageability of increasingly complex grid planning, operation and maintenance and to enable efficient processes. Although a large number of methods and technologies are available and proven, they have not yet been put to widespread use.

The Data4Grid project by dena's Future Energy Lab brought together distribution system operators and start-ups to develop practical ways to advance specific use cases for data analysis and AI in the electricity grids. This document summarises their experiences and findings from this collaboration, accompanied by a project report which was prepared by *umlaut energy GmbH* and a scientific opinion by *Fraunhofer IEE*[1]. The project also produced an overview of the current requirements and solutions for grid operators[2] and an **Implementation Guide** for data analysis and AI in the electricity distribution grid.[3]

## Use of data analysis and AI in the distribution grid

The competition held within the project and the collaboration between distribution system operators and teams of data scientists and software developers have shown that significant progress can be achieved in the use of databased solutions and that foundations can be laid for a more widespread roll-out within a short period of time. It took the teams just a few months to develop practicable concepts for three central challenges: to **increase grid transparency**, **forecast the development of electromobility** and improve **consumer forecasts**.

Nonetheless, the following framework conditions must be considered for the use of databased methods and development of applications at the companies:

- **Criticality**
  The electricity grid is a critical infrastructure and is hence subject to strict requirements. In regard to the various processes that may be suitable for the use of innovative data-driven technologies, it is therefore necessary to weigh up where these applications are beneficial or harmless from a security perspective and where they must be implemented according to high security standards.

  Four criteria can be used to assess the criticality of processes in the electricity grid: the system relevance **of a process (e.g. proximity to operations), the** security of information and communications technology (ICT) and data security **(e.g. critical data and information, security vulnerabilities), potential** threshold violations **in the event of process errors or failures (impact on operating resources), and the** damage potential **or outage damage in the event of interruptions or outage of a process (impact on supply and financial loss).**

- **Knowledge and added value**
  Grid operators will only use innovative technologies if they are secure and deliver added value. Companies require sufficient knowledge and competence at various levels in order to come to an appropriate assessment of these aspects, that is, to be in a position to make both strategic decisions and to implement innovative technologies and methods. So far, the deployment of digital technologies has been forestalled by inadequate knowledge and resources, especially in small and medium-sized enterprises. This might eventually lead to a bottleneck in implementing the energy transition.

1 The report by umlaut (2022) and the scientific opinion by Fraunhofer IEE (2022) are published as an appendix to the final report and can be accessed at the following link: https://www.dena.de/newsroom/publikationsdetailansicht/pub/abschlussbericht-datenanalysen-und-kuenstliche-intelligenz-im-stromverteilnetz
2 Overview of requirements and solutions for grid operators: https://future-energy-lab.de/app/uploads/2022/06/220513_dena_FutureEnergyLab_GR_Infografik_Stromverteilnetze_EW7.pdf
3 The findings are published on the Future Energy Lab website: https://future-energy-lab.de/projects/data4grid/

- **Data situation**
  The use of data analysis and AI must always be build on a solid database. At present, data availability and quality are inadequate for the broad application of data-driven solutions, especially in the lower voltage ranges. Moreover, general deficits persist in the collection, storage and processing of data.

  For instance, there is an almost complete lack of real-time data for active or operational management, and the quality of existing data is sometimes inadequate to enable implementation of databased applications. The situation is further compounded by insufficient acceptance of an 'open data mentality' in areas where it would be legally permissible for companies to use shared data.

## Recommended courses of action for grid operators and political decision-makers

**Improve the database**
The first step to prepare for the use of data-driven technologies is to analyse the status quo. Grid operators must then improve the database. The objectives in this case are to ensure the availability of the company's dataset and to enhance its quality for future grid operations and planning, enabling the operators to harness the potential of data-driven solutions and ultimately transform the data into information, knowledge and value.

Long-term benefits can already be achieved with relatively little effort. Initial steps include inspecting and revising the digital grid topology, documenting switch positions, linking the grid operator's current dataset (e.g. SAP, GIS) and integrating external data.

A central repository at the company makes the data more visible, simplifies linking and improves potential uses. Standardised interfaces as well as data models and processes at grid connection points also enable information sharing and the coordinated provision of grid and ancillary services.

**Strengthen data competence, share experience, exploit expertise**
Distribution system operators must build data competence as a basic requirement for improved data quality and the use of new technologies. Data sharing between grid operators can promote knowledge and experience transfer and create added value for small to medium-sized distribution system operators in particular.

Data competence also includes awareness of current legal and regulatory frameworks. For instance, although the General Data Protection Regulation (GDPR) restricts the use of personal data, it often permits pseudonymisation and anonymisation.

Moreover, data pooling can create meaningful synergies for the development of new algorithms. Innovative approaches to AI learning environments such as federated learning enable operators to share the benefits of distributed datasets, without having to disclose them. Both sides can benefit from cooperative agreements between grid operators and start-ups or providers of innovative technologies: innovative companies provide digital skills and novel solutions and approaches, while grid operators deliver valuable real-world data and know-how. Ongoing development of the electricity system can only benefit from connecting these worlds. These cooperative agreements build on appropriate data governance within the companies and the energy sector as a whole.

**Develop the regulatory framework**
Standardisation and certification ease the introduction of AI in the electricity grid, as they engender the necessary trust and security. This must already be factored into research and development so that test procedures and risk assessments can be established and integrated simultaneously. Going forward, these aspects must be actively integrated into the development processes for data-driven applications. Targeted requirements or economic incentives for the provision of datasets (data economy) can also upgrade grid operator databases and, through productive use, increase the efficiency of the overall system.

The general data situation can be improved by encouraging an open data mentality and facilitating uniform access to relevant datasets, such as GIS or geodata, or building and heat cadastres. Switzerland and federal states such as Berlin and North Rhine-Westphalia are setting a good example here.

1

# About the Data4Grid Project

Transforming our energy system towards carbon neutrality will only succeed by incorporating renewable energy sources in the supply systems. Digital technologies are necessary to enable this transformation and to coordinate the increasingly complex and integrated, cross-sectoral energy system of the future.

Distribution system operators (DSOs) are therefore facing a series of challenges that can be better addressed with data analysis and AI. In the Data4Grid project, the Future Energy Lab investigated what is currently possible with today's dataset.

**The project was divided into two parts:**

- The practical part identified use cases where electricity distribution system operators could use data analysis and AI. Three challenges were then defined, which grid operators addressed with teams of data scientists and software developers and for which they built suitable prototypes.
- An opinion was prepared in the scientific part of the project. It investigated what must be considered when using data analysis and AI in the electricity grid as a critical infrastructure, how security can be maintained and, in particular, what can be done to improve the quality of grid operator data.

The practical part of the project was organised as a competition in order to maximise the practicality and specificity of results. Three teams each of data scientists and software developers collaborated with distribution system operators to build solutions to three challenges. They developed scenario analysis concepts for the use of electromobility, for measuring point locations to increase grid transparency and for AI-assisted consumption forecasts based on smart meter data.

The 14 participating distribution system operators, *umlaut energy GmbH* as the competition organiser and the project team at dena's Future Energy Lab initially took current challenges in

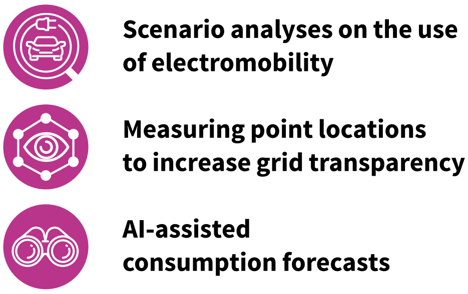



Figure 1: Challenges in the Data4Grid project

the electricity grids to identify potential use cases for distribution grid operators involving data analysis and AI. They then selected three of these use cases. Their main attributes were data availability, feasibility, degree of innovation and added value for the DSOs. In the next step, a public call was initiated with the *Innoloft* platform, inviting interested teams to apply for the challenges. Applications were submitted by 23 teams, who then pitched their concept ideas. Three were selected for each challenge. They collaborated with distribution system operators to develop solutions as a proof of concept during the subsequent processing phase. Prizes were awarded to the best solutions during the SET Hub Open on 4 May 2022.[4]

4 Refer to: https://future-energy-lab.de/news/set-hub-open-2022-im-future-energy-lab/

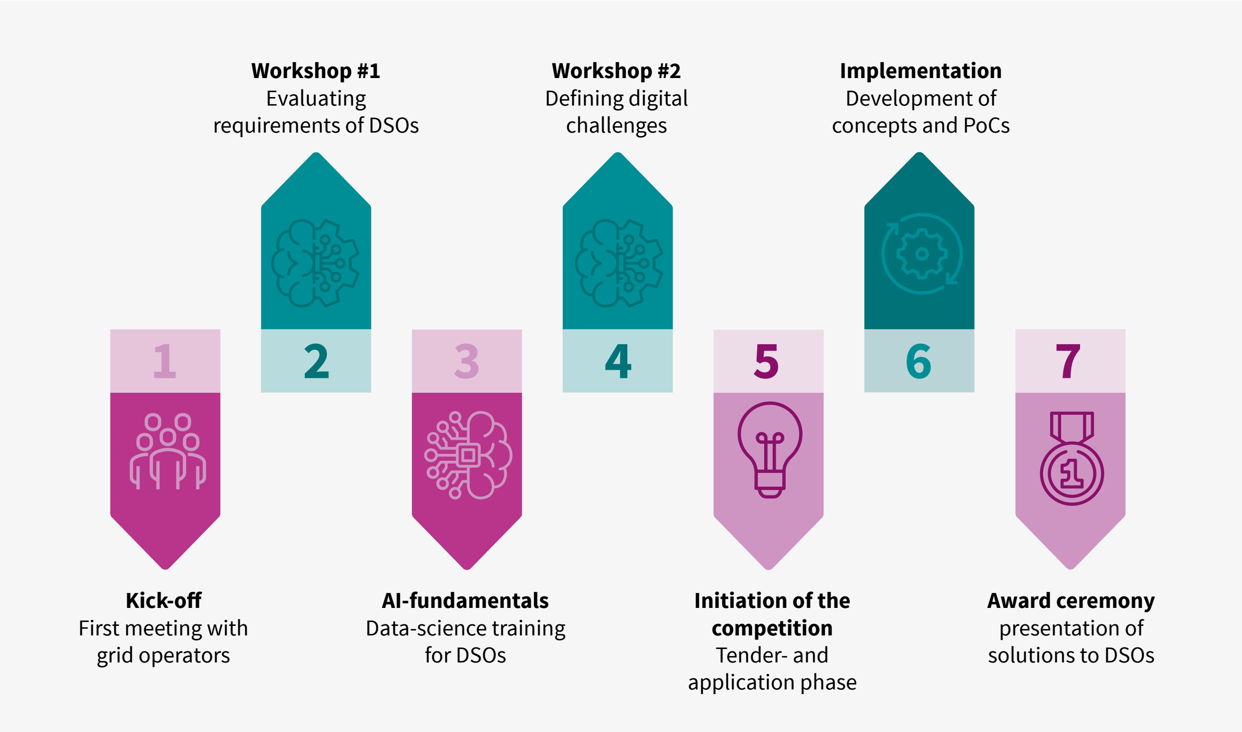



Figure 2: Phases in the practical part of the Data4Grid project

During the scientific part of the project, two workshops and the phase of preparing the opinion were used to discuss which indicators might be suitable to assess process criticality in the electricity grid and how the exploitation and practicality of data may be improved. An Implementation Guide to assist in the integration of data analysis and AI into distribution system operator processes was also developed in this context. It is intended to support grid operators in the implementation of relevant projects. Among other things, the Guide sets out what needs to be considered in the planning and preparation phase and how implementation and sustainable use can be ensured.

This final report summarises the key findings of the project. The report by *umlaut energy GmbH* provides extensive information about the results of the practical project part and the competition, while the opinion by *Fraunhofer IEE* offers detailed insight into the scientific part. An overview of the requirements for distribution system operators, the Implementation Guide and the start-up concepts are published separately on the Future Energy Lab website.[5]

5 Refer to: https://future-energy-lab.de/projekte/data4grid-kuenstliche-intelligenz-im-stromnetz/

## Project participants

### Project management and implementation on behalf of the BMWK

dena
German Energy Agency

### Competition organisation

umlaut

INNOLOFT

### Scientific opinion

Fraunhofer IEE

### Participating distribution system operators

WWNetz Westfalen Weser

e.on

EAM Netz – Ein Unternehmen der EAM Gruppe

enercity netz

WEMAG NETZ GmbH

Stadtwerke Ulm/Neu-Ulm Netze GmbH

energienetze mittelrhein

Netze BW

RNG Rheinische NETZGesellschaft

NETZ HALLE

SWS Stadtwerke Speyer GmbH

Stromnetz Hamburg

EWE netz

Netz Leipzig

### Teams and start-ups admitted to the competition

Localiser

aliunid

OmegaLambdaTec

reto4ki

Fraunhofer IEE

NAECO BLUE

ifesca

enersis climate intelligence

retoflow

# 2

# Upheaval in the Electricity Distribution Grids: Requirements for Grid Operators

Electricity grid operators are entrusted with a vital and complex task for the provision of vital public services: they plan, build, operate and maintain grids, communicate with actors in the energy system and adhere to the rules of the applicable regulatory regime. These requirements are evolving due to the transformation towards a carbon-neutral energy system. After all, the structure of electricity generation and the demand for electricity are both changing radically: the conversion to renewable energy sources means that increasing quantities of decentralised, small-scale generating capacity is connected to the distribution grid. Widespread electrification of the consumption sectors is pushing demand for electricity in general and changing the load profiles. But consumers are also becoming more flexible and controllable,

leading to radical transformation in the function of transmission and distribution grids. Whereas the principal purpose of distribution grids was once to ensure the distribution of electricity generated by central power plants connected to the transmission grid to largely inflexible but relatively uniform consumers, the distribution grids of today collect large amounts of electricity from renewable energy sources such as wind turbines and photovoltaic systems, distribute the electricity at local level and feed surpluses into the transmission grid. New and flexible consumers are being connected at the same time: the number of personal charging points is rising with the propagation of electric cars, while heat pumps are becoming increasingly popular for heat generation and are placing an additional burden on the demand for electricity in the distribution grid. These technologies are sometimes combined with electricity storage systems. Households are therefore becoming prosumers that produce and feed electricity into the grid and are able to switch flexibly between both roles.

This sweeping transformation is also changing the central tasks of grid operators. At distribution grid level in particular, this is increasingly placing new demands on grid operation, grid planning, asset management, project planning and coordination of the various actors. The tasks are becoming more complex and require new processes and technologies.

**An interactive diagram under the following links shows which requirements the transformation places on grid operators:** https://future-energy-lab.de/app/uploads/2022/06/220513_dena_FutureEnergyLab_GR_Infografik_Stromverteilnetze_EW7.pdf

- **New requirements for grid operation**
  Converter-coupled renewable energy systems that are connected to the distribution grid are increasingly required to provide ancillary services due to the decline in conventional generating capacity. The increased volatility of power generation and new consumers lead to greater power flows, higher capacity peaks and more frequent bottlenecks, which must be controlled using methods such as load flow control and congestion management. But this is predicated on improved and current collection and forecasting of the grid status for each node, on short-term forecasting of power generation and consumption, as well as on the management of new grid users. Until now, there has been no need to collect and use this data for the control of grid users at distribution grid level.

- **New requirements for grid planning and development**
  A greater need for expansion emerges at all levels of the grid as the energy transition progresses. This must be done to ensure grid adequacy going forward, i.e. to guarantee sufficient transport capacities in the electricity grid and therefore the security of supply. The expansion must be planned prudently and sustainably and must be coordinated between all levels and with other energy grids for gas, hydrogen and heat. It must consider innovations and new operating concepts, as well as new tasks such as the delivery of ancillary services from the distribution grid.

- **New requirements for asset management and project planning**
  Despite optimisation, fulfilling the extremely high expansion requirements remains a stiff challenge, both in regard to organisational and technical implementation as well as questions of acceptance and financing. Moreover, rising loads on the grids and operating resources demands new maintenance solutions which can be provided with the assistance of digital technologies.

- **New requirements for the organisation and coordination of actors**
  Improved and more transparent coordination is needed due to the sharp rise in the number of producers and consumers, and therefore the actors: secure and efficient communication must be established and the behaviour of grid users orchestrated in a system-friendly manner. This applies to coordination across multiple grid levels – e.g. for Redispatch 2.0 and balancing energy requests – and the integration and control of flexible consumers to the establishment of billing processes. Adding to this are new questions of IT security and the control of possible rectification by grid users.

Solutions for these requirements that either exist today or are currently under development include new planning processes, the expansion of grids and operating resources, optimised grid operation, adaptive control, activation of behaviours that are beneficial to the grid and comprehensive digitisation. Concepts and instruments are being continuously developed and upgraded in this context. Here, digital infrastructure (e.g. measurement and transmission technology) is absolutely necessary to enable the collection, transmission and use of data by AI and other technologies and hence to coordinate the large number of actors.

The Data4Grid project therefore focused on **data-driven solutions for the new requirements placed on grid operators**. The following chapters use the three challenges that the start-ups and data scientists worked on together with distribution system operators to describe and illustrate the use cases for these solutions. They also outline the significant added value that distribution system operators can obtain from digital solutions.

# 3

# Innovative Digital Technologies in the Electricity Grid: Use Cases and Opportunities

There are many areas of application for artificial intelligence within the energy sector. They are spread across all stages of the value chain[6] and can be divided into the clusters of general decision-making, maintenance and safety, as well as sales and consumer service. They include, among other things, forecasts, operational and facility optimisation, planning optimisation, predictive maintenance and security measures. The area in which AI can be used in the energy sector – and therefore the grid business as well – is very broad and presents numerous opportunities. In particular, the areas of forecasting as well as operational and facility optimisation can contribute significantly to the integrated energy transition. Not only are the applications in these areas relatively advanced, they also come with considerable economic potential. What matters now is to leverage this potential in the interests of the energy transition and the electricity grids.[7]

A good database is available as a solid foundation. At the same time, it is necessary to find ways to cope with the large quantities of data that are generated. An extremely wide variety of parameters will have to be monitored – both for planning and in real time – to ensure stable and secure grid operation in the future. In other words: it will be necessary to process and analyse vast quantities of data very quickly. Data management skills will also have to improve due to the increasing complexity of distribution grids, a situation which is compounded by the continuous addition of new producers and consumers as well as the growing requirements. Also compounding the constantly expanding quantity of data from a wide variety of places in the system is the progressive roll-out of smart meters or the rising connectivity of devices and systems (Internet of Things). Data is a future raw material that is not becoming scarcer. Instead, its quantity is growing by the day, especially in the energy system.

Data analysis is tasked with increasing the value of data. It does so by first establishing contextual relationships to create additional information, which is then connected to generate new knowledge. Data analysis draws on a variety of methods in this context: they extend from descriptive analyses that describe connections between historical datasets, to mathematical methods and models that attempt to obtain the most accurate forecasts from pattern analysis, through to prescriptive methods to evaluate alternative scenarios. AI imitates human capacities such as logical thinking, learning, planning and creativity. It collects data, processes the information and uses this as the basis for actions or decisions. With AI, computing is therefore moving away from processing and towards decision-making. It replaces the development and programming of rules in traditional programming with machine learning, a sub-field of AI. This may involve the training of neuronal networks, which learn the rules by themselves. So far, however, 'strong AI' that can cope with any task and is not limited to certain areas of application (e.g. image, speech or pattern recognition, robotics) has not been developed yet. Practically speaking, the distinction between AI and simple data analysis often remains blurred.

## 3.1 Use cases for databased solutions in the electricity grid – overview

A continuously expanding database and improved computing power on the one hand are now available to cope with the increasingly complex challenges on the other. This creates new and beneficial use cases for data-driven solutions, for instance in grid operation or planning and beyond (**refer to Chapter 2**). The grid status, for example, is not well known at the medium- and low-voltage level. But improving visibility by installing extensive

6 Refer to: Deutsche Energie-Agentur – the German Energy Agency (dena, 2020): Künstliche Intelligenz – vom Hype zur energiewirtschaftlichen Realität (https://www.dena.de/newsroom/publikationsdetailansicht/pub/dena-analyse-kuenstliche-intelligenz-vom-hype-zur-energiewirtschaftlichen-realitaet/) and Deutsche Energie-Agentur – the German Energy Agency (dena, 2019): Künstliche Intelligenz für die integrierte Energiewende (https://www.dena.de/newsroom/publikationsdetailansicht/pub/dena-analyse-kuenstliche-intelligenz-fuer-die-integrierte-energiewende/)

7 Refer to: World Economic Forum (2021): Harnessing Artificial Intelligence to Accelerate the Energy Transition. White Paper September 2021 (http://www3.weforum.org/docs/WEF_Harnessing_AI_to_accelerate_the_Energy_Transition_2021.pdf)

technical equipment throughout the intricate and complex grids would be extremely costly. New and intelligent methods can reduce this expenditure by providing a prescriptive recommendation of the ideal amount of measuring infrastructure to install and by optimising processes throughout the electricity grid as a whole.

Additional use cases will become possible and even necessary as the database and system complexity grows. **Table 1** shows examples of use cases in the various areas. The opinion by Fraunhofer IEE in the annex to this report contains a comprehensive list.[8]

| Grid operation |
|---|
| ■ Forecasting and real-time determination of the grid status<br>■ Improving the accuracy of feed-in forecasts<br>■ Production of load time series for different consumer types<br>■ Agent-based operational management<br>■ … |
| **Grid planning and development** |
| ■ More accurate simultaneity calculations for design-relevant load cases<br>■ Optimised positioning of public e-charging points<br>■ Review of grid connection requests<br>■ Creation of scenario analyses for the use of new loads<br>■ … |
| **Asset management and project planning** |
| ■ Monitoring and optimised maintenance of overhead lines for safe operation<br>■ Analysis for the forecasting and early warning of disruptions in substations<br>■ … |
| **Organisation and coordination of the actors** |
| ■ Detection of data manipulation and cyber attacks to ensure ICT security<br>■ Support for the control of flexible loads to the benefit of the grid<br>■ … |

Table 1: Selection of use cases for data analysis and AI in the electricity grid (source: Fraunhofer IEE (2022) and umlaut (2022), own visualisation)

## 3.2 Data analysis and AI in critical processes

Electricity supply and the electricity grid are necessary for public services and hence are classified among the critical infrastructures. It is therefore crucial that security of supply and system stability are guaranteed at all times.[9] Special care must therefore be taken with regard to the introduction of data analysis and AI in processes that may impact the security of supply. A correct assessment of the risks and opportunities associated with automation can only be obtained – and a decision on their introduction reached – by classifying and rating critical processes.

In connection with processes, the term 'critical' points to the potential for significant adverse effects in the event that these processes are discontinued or interrupted. Broadly speaking, a process within the electricity grid can be deemed 'critical' if its disruption would place the supply of electricity to a large area at risk. Processes that directly affect system operation and are therefore essential for general supply can be classified as more critical than processes that affect individual consumers and whose impact on the overall system in the event of an incident would be less severe.

The following indicators can be used to assess the criticality of processes:

- Real-time proximity and immediate impact of the process
- Potential threat to ICT and data security
- Effects on operating resources due to a limit violation
- Damage caused by process outage

**Table 2** presents these indicators and their evaluation in more detail.

8 Refer to Fraunhofer IEE (2022) in the annex to this report
9 Ordinance on the Designation of Critical Infrastructures under the Act on the Federal Office for Information Security (BSI-KritisV)

| When is a process in the electricity grid critical? | Evaluation |
|---|---|
| **Indicator**<br>Evaluation of the **Real-time proximity and immediate impact of** the process<br>■ Is it a planning or operational process?<br>■ Does the process influence direct system operation? | Processes that are closer to operational planning or operations must be rated more critically. They become even more critical if they directly influence operations. |
| **Indicator**<br>Evaluation of **Data and information security**<br>■ Is it a planning or operational process?<br>■ Does the process influence direct system operation? | Evaluation can be based on an ISMS, (service provider) self-disclosures and evaluation of Technical and Organisational Measures (TOMs). |
| **Indicator**<br>Evaluation of **Limit violations** in the event of errors or process outage<br>■ Can the (N-1) criterion be violated?<br>■ Can overloads of the operating resources occur (current and voltage limits)?<br>■ Can other limits be violated (z. e.g. load angle/tripping)? | Differentiation according to the type of limit violation and whether the operating resources affected can withstand temporary or permanent overloads. The process becomes more critical with the number of operating resources that may be affected or destroyed. |
| **Indicator**<br>Evaluation of the damage potential/failure damage in the event of **Interruption or outage of the process**<br>■ How significant is the potential financial loss?<br>■ Might supply interruptions occur (output, number of customers affected, duration → minutes of outage)? | Processes become more critical as the potential damage increases, both financially and in regard to supply interruptions. |

Table 2: Indicators for evaluating the criticality of processes in the electricity grid (source: Fraunhofer IEE (2022), Table 1)

Particularly critical areas can be identified based on the classification outlined in **Table 2**. **System control and operational planning processes**, for instance, must be classified as particularly critical as potential errors have a direct impact. The opportunities to make manual corrections are limited due to the short time periods. It is therefore sensible in this case to leave responsibility initially with the operating staff and to support – but not replace – them with innovative technologies. Optimisation procedures may, for example, suggest recommended courses of action, but will not take charge of the complete grid operation. At present, additional research will be necessary on the databased automation of processes in areas upon which the entire system operation depends.

Automated, data-driven solutions that replace near-real-time processes with high outage damage therefore require particularly stringent examination to identify potential dangers. This applies to implementation, as well as to the available database. It is absolutely vital to guarantee the integrity and security of data throughout the value chain. It follows, therefore, that **ICT security** plays an overarching role. Bulk collection and use of data – especially in smart applications – is associated with databased risks. Aside from possible manipulation, there are also risks during data transmission. Therefore, data transmission should also be classified as a critical process.

## 3.3 Requirements and risks in the use of data analysis and AI

Besides the criticality of processes, data-driven applications and the database used (refer to Training Data) must themselves be examined for potential errors and risks as well.

Although it will be impossible to predict and assess all sources of error with any degree of clarity, key risks in the application of data-driven solutions must nevertheless be thoroughly investigated if they are to be used at relevant points in the electricity grid:

- the quality of results will always **depend on the database**, which must, for this reason, adhere to high standards of accuracy and reliability.
- The **performance capacity** of smart applications and the associated **traceability** of results must be known ('black box' verifiability).

Certain requirements must also be met in order to minimise general risks, especially in the roll-out phase:

- close scrutiny of results and comparisons with findings obtained using conventional methods to ensure accuracy and build appropriate confidence in the application
- redundant operation if possible, as well as intervention options (e.g. a mandatory 'stop button')
- back-up plans for contingency scenarios

While data-driven applications are always associated with requirements for the management of new risks, even the storage and transmission of data can themselves present a risk. There is always the risk that data may be accessed without authorisation, manipulated or destroyed during transmission. Although redundancy can mitigate the risk in the latter case, data transmission always requires security measures. Data security therefore includes protection during the collection, transmission, processing, storage and use of data. The protection objectives in this context are confidentiality (no unauthorised access), integrity (authenticity) and availability of data and systems. Compliance with the protection objectives is vital in order to use data-driven applications and leverage the associated potential.

This acquires even greater importance and criticality against the backdrop of the transformation in the energy sector towards a decentralised and significantly more digitised energy system. The dena report entitled "EnerCrypt – Cyber Innovations for the Secure Energy System of the Future" provides a detailed analysis of this area and discusses potential solutions and opportunities with a focus on innovations in the cyber segment.[10]

## 3.4 Regulatory frameworks

The need to use data-driven solutions is growing across all voltage levels as the energy system and electricity grid become increasingly complex. Also associated with a more interconnected electricity grid are changing demands on grid operation at the lower voltage levels, which must nevertheless satisfy the legal or regulatory requirements.

The legislator has imposed rules in regard to potential attacks on IT systems and the protection of personal data. **Table 3** shows the national laws and regulations that are relevant to electricity grid operation.[11]

| Energy law & IT security |
|---|
| ■ Energy Industry Act (EnWG)<br>■ Act on the Digitisation of the Energy Transition (GDEW)<br>■ Metering Point Operation Act (MsbG)<br>■ IT Security Act 2.0 (IT-SiG 2.0)<br>■ EU Network and Information Security Directive (NIS Directive) |
| **Grid planning and development** |
| ■ General Data Protection Regulation (GDPR)<br>■ Federal Data Protection Act (BDSG) |

Table 3: Overview of national laws and regulations with relevance to electricity grid operation (source: Fraunhofer IEE (2022)

10 The topic of cyber security in an increasingly connected and digital electricity sector is addressed by dena in the Enercrypt and Enercise projects, among others. Moreover, the industry platform Cybersecurity in the Electricity Industry will be established going forward. On behalf of the BMWK, this platform will establish an institutionalised dialogue format with stakeholders from the electricity, digital and cybersecurity industries. Its aim is to play a proactive role in shaping cybersecurity policy and strategy across all areas of relevance to the electricity sector, as well as to identify new challenges and innovations and develop preventative measures at an early stage.

11 This does not include ordinances issued on the basis of the Energy Industry Act.

The energy sector is highly regulated, but only a small number of regulations refer directly to data analysis and AI. Nevertheless, some provisions have already been introduced or are under discussion and development. They includes, above all, the Act on the Digitisation of the Energy Transition (GDEW), which enables in principle the establishment of digital infrastructure with smart grids and, in conjunction with the Metering Point Operation Act (MsbG), defines regulations for data communication with smart meter gateways and sets out requirements for the collection, processing and use of data.

With regard to ICT security, the Catalogue of IT Security Requirements published by the Federal Network Agency (BNetzA) and the Federal Office for Information Security (BSI) demands that grid operators install an information security management system (ISMS), among other things. As set out in the DIN EN ISO/IEC 27001 standard, for instance, grid operators must assess the potential adverse effects of individual processes. The indicators used in this context are similar to those that were presented in **Section 3.2**, but are worded in more general terms.

The General Data Protection Regulation (GDPR) defines the legal framework for the handling of personal data. The regulation prescribes various principles for the processing of this data: transfer, storage and processing are only permitted with the consent of the data subject and processing must always be for a specific purpose.[12]

These principles may therefore present an obstacle to data collection and processing, as the collection of data cannot always be directly linked to the ultimate purpose of its use. In general, personal data can be used in various scenarios, provided it is suitably anonymised and pseudonymised. After all, the added value obtained from data does not always hinge on its direct relation to a particular person. The requirements set out in the GDPR are therefore challenging and associated with the investment of time, but do not constitute an unbridgeable barrier to the use of data-driven applications in the energy sector.[13] It follows, therefore, that there are no evidently insurmountable obstacles to the use of data analysis and AI in the electricity grid in the current legal and regulatory framework.

The Federal Government's AI strategy has taken further important steps towards standardisation and norming.[14] As an integral part of the strategy, the *German Standardization Roadmap AI* includes recommended courses of action in regard to dataset handling, an outcome evaluation of AI applications as well as the development of a security standard and quality criteria. The new edition of the *Standardisation Roadmap AI - Version 2*[15], which will be prepared under the auspices of VDE and DIN by the end of 2022, will address further aspects and, for example, formulate recommended courses of action in the area of energy/environment as well. The process continues to contribute to the regulation of AI in Europe.

Following publication of the Ethical Guidelines for Trustworthy AI[16] and the White Paper on Artificial Intelligence[17], efforts are ongoing at EU level to create harmonised regulations for the use of AI as a uniform framework. Still under discussion, the European Commission's draft regulation on artificial intelligence (AI Act) adopts a risk-based approach. It is based less on a universally valid definition of AI and instead on relevant areas of application. Accordingly, the requirements for transparency, robustness and accuracy, among other things, will only apply to high-risk areas of application, which include the operation of critical infrastructures such as those found in the energy sector.

Furthermore, the regulations governing the economic environment and its incentives have a significant impact on the use of data-driven applications in the operation of electricity grids as a natural monopoly market. It is important to note in this context that the German Incentive Regulation Ordinance, which influences the revenues of grid operators, defines the corresponding economic incentives. Accelerated dissemination of these technologies is possible, for example, by meeting specifications and standards or by offering stronger incentives to shoulder the elevated operating costs associated with the use of these technologies.

12 Cf. Deutsche Energie-Agentur – the German Energy Agency (dena, 2018): Datenschutz und Datensicherheit. Status quo, Herausforderungen und Handlungsbedarf im Rahmen der Digitalisierung der Energiewirtschaft
13 The use cases presented in Table 2, Section 2.3.2, of the Fraunhofer IEE opinion (2022) do not require detailed personal information.
14 Federal Government (2020): Artificial Intelligence Strategy of the German Federal Government. (https://www.bundesregierung.de/breg-de/service/publikationen/strategie-kuenstliche-intelligenz-der-bundesregierung-fortschreibung-2020-1824642)
15 For further information, refer to: https://din.one/display/NRM/Normungsroadmap+KI+Ausgabe+2
16 European Commission (2019): Ethics Guidelines for Trustworthy AI https://op.europa.eu/en/publication-detail/-/publication/d3988569-0434-11ea-8c1f-01aa75ed71a1
17 European Commission (2020): White Paper on Artificial Intelligence (https://ec.europa.eu/info/sites/default/files/commission-white-paper-artificial-intelligence-feb2020_en.pdf)

# 4

# From Theory to Practice

A large number of aspects need to be kept in mind in the gradual incorporation of data analysis and AI. Extensive groundwork and various planning and implementation phases needed to be completed so that data analysis and AI can be put into practice. This chapter starts by providing an overview of these steps and then investigates the issues of data availability and quality.

## 4.1 Implementation guide for data-driven applications in the electricity grid

An Implementation Guide was prepared as part of the scientific opinion by the Fraunhofer IEE. It charts the path from the selection of the use case to regular operation[18] and provides answers to the overarching questions: What must be considered in the planning and preparation phase and which information is relevant? What can be done to ensure implementation and sustainable use?

**1 Decision pathways, feasibility analysis and added value**
Evaluation of basic questions about the application, its feasibility and added value.

**2 Planning**
Detailed planning of the application, e.g. ressources, data, interfaces, processes.

**3 Implementation and validation**
Test of the application and validation during operations.

**4 Commissioning**
Transition to regular operations and training of users.

**5 Maintenance and further development**
Continuous evaluation during operations and improvement of the application.

Figure 3: Steps for implementing digital solutions in the electricity grid

**The Fraunhofer IEE opinion presents the Implementation Guide in detail, together with three specific use cases:**

- **Use case 1:**
  Guideline for the use of neuronal networks to determine the grid status
- **Use case 2:**
  Guideline for AI-based consumption forecasts
- **Use case 3:**
  Guideline for an AI-based early warning system for disruptions in substations

18 Refer to Fraunhofer IEE (2022)

| | |
|---|---|
| **Step 1: Decision pathways, feasibility analysis and added value** | |
| **General** | ■ Which added value and economic benefits does the application deliver? Which AIs can be defined?<br>■ Who is involved at the company and who is responsible (product owner, project director etc.)? Which departments are working together?<br>■ Will implementation be managed internally or with partners/outsourced to third parties? |
| **Data** | ■ Which data and data resolution does the application require?<br>■ Is this data currently available or would this require, for example, the configuration of new measuring points or new sensor technology? |
| **Application/ method** | ■ Do practical examples exist that might be used as a template and permit a reliable assessment of a method's feasibility?<br>■ How would integrating the application impact the affected systems? |
| **External framework** | ■ What is the legal/regulatory framework for the intended use case?<br>■ Which permits must be obtained and which standards complied with? |
| **Step 2: Planning** | |
| **General** | ■ Which resources, headcount and costs must be budgeted? |
| **Data** | ■ Which requirements are placed on the data, and how can the data be made available? |
| **Application/ method** | ■ How will the process proceed, what is the objective and which milestones exist?<br>■ Which method should be used and which risks does this entail? |
| **External framework** | ■ Which legal framework conditions must be taken into account and how does the project impact contractual obligations? |
| **Step 3: Implementation and validation** | |
| **General** | ■ How can validation be carried out and who is responsible? |
| **Data & application/ method** | ■ What else is required for implementation?<br>■ Which training is necessary and who needs to be trained?<br>■ What backup levels need to be created, for instance in the event of data or system interruptions? |
| **Step 4: Commissioning** | |
| **General** | ■ How can the application be integrated into the current systems and operations?<br>■ How can transparency be established at the company and what can be done to improve acceptance and motivation? |
| **Application/ method** | ■ Is redundant operation possible, also to build trust?<br>■ Can input and output data be utilised in real-time operation?<br>■ Do fall-back processes exist for the event data outages, errors or system crashes? |
| **Step 5: Maintenance and further development** | |
| **General** | ■ Have the defined objectives been reached?<br>■ Which experience can be improved with the application? How can the process be made robust to withstand possible errors?<br>■ Are there noticeable changes in the system behaviour? |
| **Data & application/ method** | ■ Are the data quality and the database assured and what could be done to achieve further improvements?<br>■ Is there any data drift and what responses are possible if it occurs?<br>■ What changes affecting the application must be taken into account (e.g. changes in grid topology or load profiles)? |
| **External framework** | ■ Continuous monitoring of the framework conditions that influence the application environment |

Table 4: Overview of key steps for implementation of a use case
(excerpt from the Fraunhofer IEE Implementation Guide (2022), own visualisation)

Applying the main steps set out in the Guide prior to implementation can help to identify the most serious challenges at an early stage and to define abort criteria if necessary. To ensure success, it is particularly important to include all relevant areas of the company and to assemble the necessary expertise during the preliminary planning and implementation process. Moreover, it is conducive to bring in external experts and experienced actors to contribute specific know-how and provide consulting at appropriate points.

## 4.2 Data sources

The use of data-driven applications is always built on a good dataset. There is no universal definition of 'good' in this context, but the expected success of an application will be highly correlated with the available database. Different types of data can be classified based on the frequency with which they change (master or transaction data), their type of use (ex ante/upstream, ex post/downstream or near service data) or how they relate to data protection (personal and non-personal data). These various types of data are associated with a plethora of different sources, transmitting and processing systems, storage requirements and opportunities for use.[19]

Relevant sources for data-driven applications primarily include grid operator data, publicly available data and data from other actors that are not always directly accessible to the public. **Table 5** lists these data sources and types. Data utility can be enhanced by promoting an open data mentality. It became apparent during the project's practical development phase that publicly available datasets (e.g. in Challenge 1: Census data for postcode areas and nationwide information on the number of electric cars) can be a valuable addition.

| Data source | Data types | Publicly available |
|---|---|---|
| **Grid operators** | Asset/operating resource data | No |
| | Data concerning power generation and consumption (e.g. customers' annual consumption, load types<br>power generation in reference installations and metering data etc.) | No |
| | Grid models:<br>■ Parameters of installed operating resources<br>■ Results of power flow and short circuit current calculations<br>■ Switching statuses | Generally no, but in some cases the TSOs' network models are placed online for congestion analysis[20] |
| | Geographic data/GIS data | No |
| **Grid development plans (https://www.netzentwicklungsplan.de/en/)** | Grid development plans with the 2037 and 2045 scenario frameworks | Yes |
| **Deutscher Wetterdienst** | Weather forecasts and additional data on weather conditions | Forecasts are publicly available |
| **renewables.ninja (https://www.renewables.ninja/)** | Historical power generation data and weather conditions | Yes |
| **Open Power System Data (https://open-power-system-data.org/)** | Historical power generation data and weather conditions | Yes |
| **NASA's MERRA-2 (https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/)** | Historical power generation data and weather conditions | Yes |

19 Among others, the following publication takes a detailed look at the types of data that are relevant to the energy sector: Deutsche Energie-Agentur – the German Energy Agency (dena, 2021): Digitale Marktkommunikation für das Energiesystem der Zukunft (https://www.dena.de/newsroom/publikationsdetailansicht/pub/digitale-marktkommunikation-fuer-das-energiesystem-der-zukunft/)

20 Refer, for instance, to Transnet BW's network model for congestion analysis: https://www.transnetbw.de/en/energy-market/congestion-management/congestion

| Data source | Data types | Publicly available |
|---|---|---|
| **ENTSO-E (https://www.entsoe.eu/data/data-portal/)** | Historical consumption data | Yes |
| **Land Registry Office** | Building data (address, geometry, usable space and year of construction etc.) | No |
| **Solar Cadastre** | Solar power potential | Yes |
| **State Geological Survey** | Use of geothermal energy | No |
| **Chimney sweeps** | Boiler data | No |
| **Smart Meter Gateway** | Smart meter data<br>■ Meter readings<br>■ Measurement of electrical variables (current, voltage, active power and frequency etc.) | No |
| **SMARD electricity market data (https://www.smard.de/home)** | Electricity generation, electricity consumption and wholesale prices etc. | Yes |
| **Census data** | Electricity generation, electricity consumption and wholesale prices etc. | Yes |

Table 5: Potential data sources for the application of data-driven solutions (source: Fraunhofer IEE (2022), Table 3)

Linking the data for use is among the most significant challenges, aside from the provision and compilation of data that is relevant to a particular use case. The extremely heterogeneous data is often available in different systems and formats, even within the same company. They might even be, for example, different data models that cannot be linked directly and may therefore require extensive work prior to use. Data analysis can only yield valuable insights if it draws on a sufficiently large collection of data (depending on the use case). An exemplary data space is currently being established within the dena-ENDA (Energy Data Space) – Showcase Redis-X project, bringing together the necessary information for the redispatch use case. Going forward, establishing this kind of data space with suitable data governance will become increasingly important as a basic condition for the use of AI.

## 4.3 Data availability and quality for electricity distribution system operators

Experience acquired from the Data4Grid project has shown that electricity distribution system operators must overcome a variety of challenges in order to obtain a usable and high quality data collection.

Although grid operators can, in principle, draw on significant quantities of data, the first obstacle is to acquire an overview of the data on hand and the systems in which it is located. As shown in **Table 5**, relevant systems at the grid operators' companies include geo-information systems (GIS) and asset databases as well as forecast, process and control systems. And while all this data is certainly available in these systems, its export is no trivial matter. Moreover, the datasets are not always available in structured, accessible and updated databases, but are frequently found in spreadsheet programs.

It is often observed furthermore that data availability and quality are inadequate for broad application of data-driven solutions, especially in the lower voltage ranges (medium- and low-voltage ranges). There is, for instance, a serious lack of real-time data for active or automated system control. Irrespective of the data type, it is reasonable to say that the completeness and quality of data declines successively in the lower voltage ranges of the electricity grid.

There has been no need until now to maintain data in a structured form across all systems and to collect specific data. For instance, the conventional electricity grid had relatively simple frameworks, so it was not necessary to collect, transmit and process real-time grid status data at a wide variety of points, in order to store the information for further use and to link it in shared systems. But the energy transition, with the requirements it places on grid planning and operation, is gradually creating this necessity for many types of data.

Observability and controllability at the lower voltage levels are therefore becoming increasingly relevant as well. It is essential at this point to emphasise the magnitudes involved at the individual grid levels: The high-voltage grid is about 2.5 times larger than the ultra-high voltage grid, the medium-voltage grid is about 14 times larger and the low-voltage grid is over 30 times larger.[21]. So installing the technical equipment at the higher voltage levels therefore involves work on a significantly smaller overall grid than would be the case at the lower levels. It might therefore be purposeful at the lower grid levels to introduce data analysis to support the measuring equipment and hence to implement observability and controllability in a faster and more efficient way.

Data analysis and artificial intelligence can help to optimise observability and controllability at various points. Beyond fundamental data requirements, this also demands human resources and the establishment of know-how among distribution system operators. Aside from the inclusion of internal experts from planning and operations, it is necessary to ensure the availability of essential knowledge in building relevant data structures and linking the 'right' data. This can be handled, for example, by in-house data scientists who amalgamate the relevant data. The numerous and heterogeneous distribution system operators in Germany possess these resources to varying degrees.[22] While larger companies and groups are at an advantage in the process of knowledge building and human resources, it will be necessary to find ways for smaller DSOs and municipal utility companies to address these wide-ranging topics, despite their limited resources.

Larger actors might initially take the lead, allowing smaller grid operators to benefit from their experience. But this would not guarantee implementation in the interests of the overall system. Although the current regulatory regime incentivises efficiency in principle, it does not promise (short-term) industry-wide implementation or the deployment of new concepts. In particular, current mechanisms are hardly suitable to encourage the creation of a usable database which might be expanded and applied to specific grids in the years ahead. Time is of the essence for the achievement of climate policy targets and practical implementation of the energy transition. It is therefore necessary ask what else can be done to promote the implementation of data-driven solutions.

Dialogue between grid operators and throughout the sector will be particularly important here. Approaches such as federated learning provide fresh opportunities for inter-organisational collaboration. Federated learning describes a machine learning environment in which many participants collaboratively train a global AI model that is orchestrated by a central server, while the training data remains decentralised. This kind of application is therefore of considerable interest and relevance to the increasingly decentralised energy sector.[23] If applicable, institutionalised dialogue would encourage knowledge and experience transfer and might help smaller grid operators in particular to establish know-how and implement initial use cases. It would be advantageous to share procedures or even to connect data on a universal scale to create valuable synergies, especially if it is reasonable to assume that not all of the actors will possess sufficient data for data-driven solutions or these solutions will be improved by adding meaningful information.

This will requires fundamental data work throughout the sector. Even a reasonable initial outlay may produce long-term benefits, for example if companies review and revise their own digital grid topology, document switch positions and link in-house data with the addition of external data, if necessary. The fact that data exchange has a value in its own right may stimulate the willingness to ensure that datasets are adequately prepared and then shared with other actors (keyword: data economy)[24]. Here, too, data spaces with suitable data governance – such as the aforementioned data space in the dena-ENDA project – may offer a potential solution going forward.

Furthermore, it is already necessary to create greater convergence across all levels of the electricity grid to ensure coordinated delivery of grid and ancillary services. The creation or expansion of standardised interfaces, data models and processes at grid nodes is a vital aspect if grid operators are to share information. Irrespective, the changes precipitated by the energy transition require relevant actors to engage in dialogue and coordinate their actions. This foundation must now be built upon and the preconditions fulfilled to make digital technologies ready to face the growing and foreseeable challenges.

21 Refer in this regard to the Federal Ministry for Economic Affairs and Climate Protection (BMWK) (2022): Ein Stromnetz für die Energiewende. (https://www.bmwk.de/Redaktion/DE/Dossier/netze-und-netzausbau.html, last retrieved on 23/06/2022)

22 There is only a small number of large distribution system operators in Germany that cover large grid areas, and very many small grid operators. In total, over 800 grid system operators are listed in the Federal Network Agency's core market data register.

23 Refer to the dena "Energieeffiziente KI" project for an investigation of how federated learning promotes energy efficiency: https://future-energy-lab.de/projects/energieeffiziente-ki/

24 Deutsche Energie-Agentur – the German Energy Agency (dena, 2022b): Die Datenökonomie in der Energiewirtschaft https://www.dena.de/newsroom/meldungen/2022/dena-analyse-datenoekonomie-in-der-energiewirtschaft/)

5

# New Alliances: Data Scientists and Grid Operators

The significant changes in requirements for distribution system operators necessitate the use of databased solutions in the distribution grids and makes them profitable for the energy system. Although the database remains limited in places and despite the relative paucity of experience with databased solutions, considerable progress can already be achieved and the foundation laid for more widespread application. This was demonstrated by the competition held within the project and the collaboration between distribution system operators and teams of data scientists and software developers. It took the teams just a few months to develop practicable concepts for three central challenges: to increase grid transparency, forecast the development of electromobility and improve consumer forecasts on the basis of smart meter data.

## 5.1 Relevant databased use cases in the distribution grids

The collaboration within the project elucidated that grid operators, working with data scientists and software developers, can already develop feasible concepts on the basis of available data and with reasonable effort.
In particular, the following use cases for databased solutions can deliver real added value for distribution system operators today and in the near future:

| Application field | Use cases |
|---|---|
| **System management** | **Improved transparency in the grids**<br>The precise load, consumption and grid status will usually be unknown in low-voltage grids. Aside from a lack of installed measuring technology, unregistered consumers (e.g. wall boxes) impede exact knowledge of the various parameters.<br>The intention going forward is to significantly increase the transparency of low-voltage grids in order to support system management. A metering concept that uses a minimum number of measuring points to enable secure system management reduces the need for measuring technology to be installed throughout the grid. The use of AI and data analysis can help to determine optimum sensor positions, identify unknown consumers and detect grid congestion, thus permitting conclusions on measures to expand the power grid. |
| **Grid planning** | **Scenario analyses on the use of e-mobility**<br>Distribution system operators in the lowest voltage ranges in particular are having to cope with a change in peaks in demand due to the upsurge in electromobility. Although the number of electric cars is rising overall, it is difficult to predict the extent to which nationwide sales figures can be transferred to individual municipalities or grid areas and hence to the need for grid expansion. Scenario analyses can alleviate this situation: individual forecasts of load requirements on the distribution grid can be calculated and incorporated into expansion planning based on information concerning the ramp-up of e-mobility and wall box owners in individual grid areas. |
| **System management and grid planning** | **Real-time grid calculation and forecasting**<br>Decentralised feeders and new high-load consumers present challenges for grid operators when calculating the grid status. But awareness of the current grid status is of vital importance for potential automation of congestion management going forward. In future, the roll-out of smart meters will yield sufficient data to carry out real-time grid calculations and forecasting based on AI. These detailed load flow analyses will be used to automate system management and achieve progress in cost-efficient expansion of the power grid. |

| Application field | Use cases |
|---|---|
| Asset management | **AI-assisted status evaluation of operating resources**<br>To ensure cost-efficient maintenance of operating resources, the intervals between scheduled maintenance should be as long as possible, without risking that grid operations are impaired by a defect. This is why preventative maintenance is currently performed at times that are based on historical values. But predictive maintenance will become possible as the quantity of available data from the operation of grid components increases. In this case, data is collected about mechanical or electrical operating resources and then analysed with AI or statistical models to assess their current status. Doing so allows grid operators to optimise their maintenance intervals and hence to save costs on material and personnel. |
| System management | **Beneficial management of low-voltage grids**<br>Managing low-voltage grids in a beneficial manner enables efficient operation of electricity grids and can reduce the need for grid expansion. In the long term, evaluation of GIS and measurement data might enable an AI to perform independent grid interventions and hence prevent congestion at an early stage. Not only would this kind of system help to make expansion of the power grid efficient, it would also accelerate the integration of renewable energy sources and high-load consumers. |
| Grid connection | **Grid connection tests for renewable energy sources and e-mobility**<br>Requests for the installation of charging points are becoming more frequent with the rise in the number of electric cars. A similar trend can be observed in the number of decentralised feeders from the area of renewable energy sources. Processing these applications and conducting the grid compatibility test – which is still performed manually – are time-consuming, use up significant resources and present personnel challenges for grid operators. A digital customer interface that incorporates an AI-based grid compatibility test or optimised determination of suitable grid connection points promises to enable the processing of these applications with less resource expenditure. |

Table 6: Practical use cases for databased methods in the operation of distribution grids

## 5.2 Criteria for the implementation of data-based methods

The question of whether using one of the above solutions makes sense for individual distribution system operators depends on a number of factors. Three evaluation criteria – **data availability, added value** and **feasibility** – provide a suitable mechanism to determine whether implementation would already be purposeful or whether other steps should initially be taken, for instance database improvements.

- **Data availability:** The availability of sufficient, high-quality data is essential for the targeted application of data analysis and other procedures. Here, it is necessary to evaluate which data the company holds or can prepare or obtain on short notice. Publicly available data also exists that can be taken to supplement relevant models.
- **Added value:** Aside from data availability, the added value of implementing a use case based on the current dataset must also be clear. The strategic decision on resource deployment becomes easier, depending on the precision with which this question can be answered.
- **Feasibility:** Human and time resources, a willingness to change and technical skills are crucial factors in the implementation of new, databased solutions. These conditions must be sufficiently available to achieve a project objective and to generate added value.

## 5.3 Practical testing: Insights from three Data4Grid prototypes

The start-up competition organised within the project demonstrated that collaborative work by start-ups and distribution system operators yielded profitable concepts in a very short time. However, it also illustrated that data availability and quality still pose the greatest challenges. The potential of databased methods can be harnessed to better effect going forward by establishing greater data competence (**refer to Section 4.3**).

**More detailed information about the competition is available in the umlaut report and on the** Future Energy Lab website.

The following profiles summarise the key findings of the three use cases, namely increased grid transparency, trend forecasts for electromobility and improved consumption forecasts.

Challenge

1

# Scenario analyses on the use of electromobility

## Motivation

Electric vehicles account for an increasing share of the market. The accompanying demand for electricity are changing the load behaviour, demanding a response from electricity grid operators. In particular, the implied dynamics lead to greater complexity in grid planning and are currently presenting grid operators with challenges. Forecasts are therefore needed on the temporal and spatial penetration of charging connections for electric cars in the distribution grids in order to continue promoting the expansion of electromobility, while concurrently assuring long-term grid stability.

Aside from the gradual development of public charging infrastructure – which is comparatively transparent for grid operators – the demand for privately owned wall boxes at regional level is a relevant factor that is hard to predict. The increasing installation of wall boxes is leading to a rise in the amount of data about their owners and the penetration of e-mobility in each region. Data analysis using AI and other methods simplify the search for indicators of wall box installations and thus help to forecast the ramp-up in charging infrastructure for personal use.

Netze BW

Sponsors & data providers

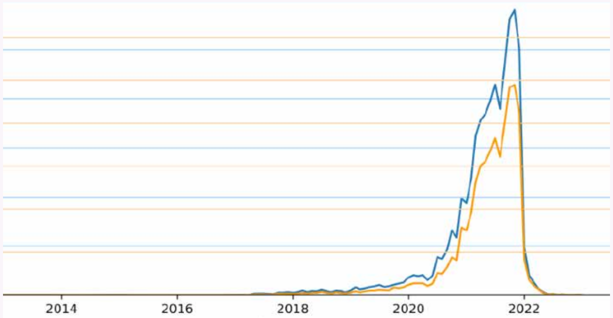
## Objectives

The defined objective of this Challenge was to apply a bottom-up approach to consolidate data that would enable forecasts of wall box installations at postcode level. Once finished, distribution system operators can use the solutions to create a ramp-up curve to deduce trends in the installation of privately-owned charging points and the resulting load requirements for the grid until the year 2050.

## Data

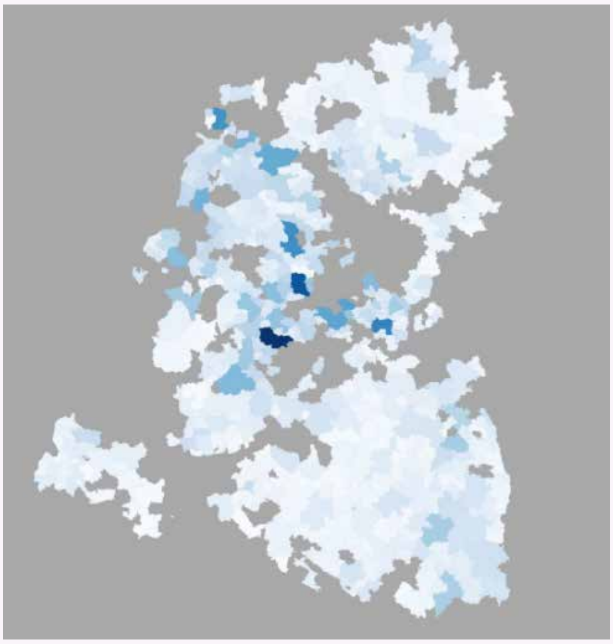
The teams were given data from the Netze BW grid area to develop their models. This data contained details about wall box purchases, building types of EV owners and, in compliance with the GDPR requirements, also postcodes to enable geographic use of the data. In addition, the data also specified the installed charging capacity and the number of fitted charging points.

The teams were allowed to use other datasets during processing, provided they were obtained as open source. They were therefore able to process census data for the relevant postcode areas and nationwide information on the number of electric cars and wall boxes.




Ramp-up in installed capacity (blue) and number of charging points (yellow)

All teams took the opportunity to use additional data sources in order to find information of relevance to the issue at hand. Data from the most recent census and electromobility studies, for instance by NOW, proved useful.



Distribution of wall boxes

## Results

The common features of all the team results are that statistical regression is sufficient for this dataset and that machine learning methods are not required. But there are differences in the assumptions concerning the ramp-up of electromobility. The analyses were used to calculate scenarios with various parameters for the share of electric cars and personal wall boxes.

Grid operators can calculate both the temporal and spatial penetration of electromobility in their grid area based on the geo-referenced forecasts for the installation of new wall boxes per month. These results can also be visualised by digital tools (refer to the diagram on the next page).

During development of their models, all teams stated that additional data about the wall box owners would be extremely helpful to improve the ramp-up curve. They cited information about installed solar power systems and more precise locational data as examples. However, it was not possible to share this information with the participating teams due to strict data protection requirements.

### OmegaLambdaTec

The OmegaLambdaTec team applied a combined top-down and bottom-up approach to produce the forecast. It incorporates both national information about the ramp-up of e-mobility, as well as regional data from Netze BW. Logistical regression showing the number of new wall box installations was selected as the modelling method. A variety of scenarios can be calculated and visualised, depending on the parameter settings.

### Localiser

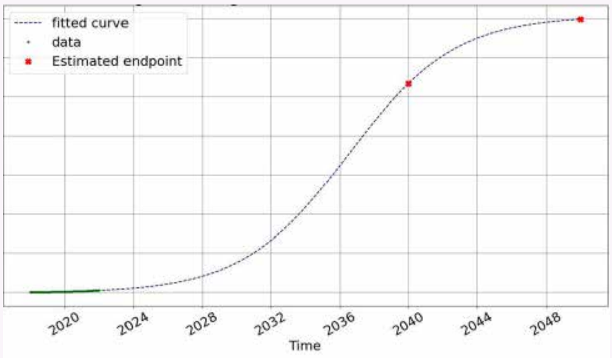
Localiser also expanded the database, e.g. with census or GIS data, after thorough analysis of the available wall box data. They then applied statistical methods of data analysis to perform a geo-referenced extrapolation of wall box installations on the compiled dataset. This builds on an availability factor of privately-owned charging points per building type, which permits various scenarios.

### aliunid

After analysing and expanding the data set, aliunid grouped the included postcode areas into three clusters according to the speed at which electromobility was developing. This was used as a basis to prepare forecasts up to the year 2050, again based on logical regression. The assumptions with relevance to the model include, for instance, the share of e-mobility in the transport sector for the years 2040/2050.

## Insights

All data was provided by Netze BW, so validation was only possible for a single grid region. A further step must therefore be performed in order to review the extent to which the results are transferable. The teams are also confident that they will achieve greater model precision if data that is collected in the future is used continuously to further develop the forecasts.
During development of their models, all teams stated that additional data about the wall box owners would be extremely helpful to improve the ramp-up curve. They cited information about installed solar power systems and more precise locational data as examples. However, it was not possible to share this information with the participating teams due to strict data protection requirements.




Example of a predicted ramp-up curve

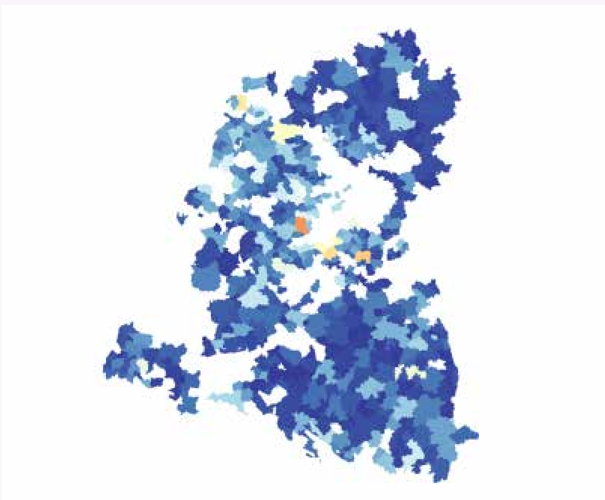
## Outlook

The competition has shown that important insights can be obtained for the development of wall boxes, even with a limited dataset. The bottom-up approach gives grid operators the opportunity to improve the precision of their grid planning with regard to electromobility and to estimate future load profiles.
In order to implement the findings, grid operators should review their datasets and determine how they can add relevant data. Ongoing dialogue between grid operators would appear purposeful, as smaller grid operators in particular do not possess the quantities of data that are required for accurate forecasts.
In order for grid operators to generate added value during operationalisation, it is important to pay close attention to defining realistic parameters and to continuously adapting the models to new findings in the area of electromobility. Visualisation in the form of a dashboard enhances acceptance and assists in the decision-making process.

The Challenge shows grid operators how data analysis can be put to use in the area of e-mobility and emphasises the relevance of data collection as a basis for accurate forecasting models in the growth market of privately-owned charging infrastructure.

| First Place | Second Place | Third Place |
|---|---|---|
| OmegaLambdaTec | Localiser | aliunid |

Results



Forecast – installed wall boxes in 2050

Challenge

2

# Evaluation of relevant measuring points to increase grid transparency

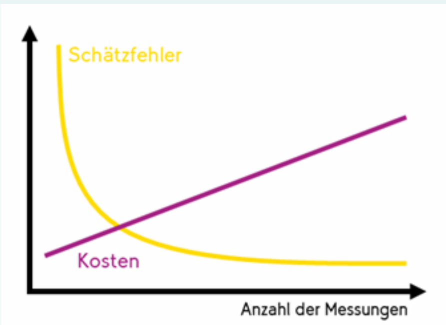
## Motivation

The challenges associated with secure grid operation are becoming increasingly significant as the energy transition progresses. Electricity generation is becoming more decentralised, and household consumption and peak loads at certain times are growing with the electrification of the mobility and heating sectors. It is therefore important for distribution system operators to be aware of their current grid status so that they can implement suitable measures to ensure grid stability, if necessary. A focus on cost efficiency will, however, lead to a conflict of objectives between a high level of grid transparency and the expenditure required for measuring technology.

## Objectives

Here, data-driven solutions provide the opportunity to develop optimised metering concepts and reduce the amount of measuring technology required, while at the same time improving grid security. The question arises for grid operators as to the number of measurements – and their local distribution – that are needed to obtain sufficiently accurate transparency for a grid section.

In this Challenge, the participating teams were asked to develop a concept based on current measuring stations that would support the decision-making process for the installation of new sensor technology.




Costs-Estimation Error-Conflict of Objectives

## Data

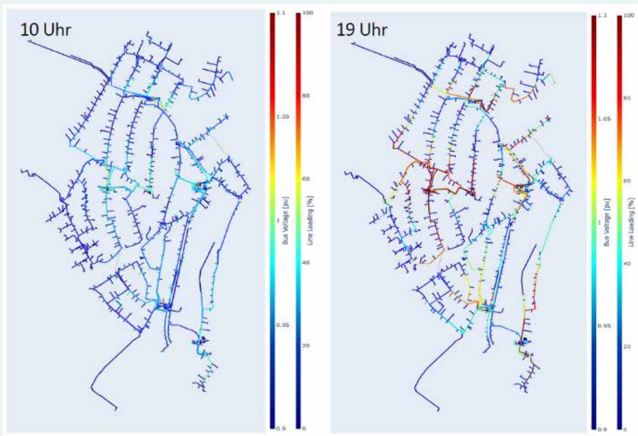
A Challenge according to the open innovation approach was agreed with the sponsors due to the limited availability of data. This did not focus on analysing a dataset and instead on the search for ways to obtain high grid transparency, taking into account the small number of measuring stations.

EAM Netz provided a dataset containing urban and rural transformer areas in order to validate the concepts. Information for these areas on feeders, consumers and current measured values from local grid stations was extracted this data.

Sponsors & data providers

## Results

In a first step, the teams performed exploratory data analysis to examine the available dataset in more detail. The pandapower tool was used to calculate and visualise initial grid simulations. The diagram below shows an example of grid load compared over the course of a day. The red grid edges indicate congestion. Findings obtained from the data analysis yielded information about load behaviour in the grid sections and provided a foundation for the team concepts outlined in the following.




Visualisation of the grid load

The variance between the results shows that grid operators will be unable to resolve the challenge of metering point optimisation using standard procedures:

### reto4ki

The retoflow GmbH team applies an iterative method to perform network simulations with a constantly increasing number of measuring points. The estimation error is determined in each case using a neural network with bidirectional training and compared with the requirements of the grid operators. The position and quantity of measuring technology can be determined on the basis of the findings.

### enersis

The enersis concept builds on cluster analyses. Their purpose is to detect similarities between local grid stations so that only a sample of transformers need to be equipped with measuring technology. A dynamic factor will be used to map future repercussions of electrification in the areas of mobility and heat, thus ensuring that measuring point recommendations can be used as a sustainable concept.

### OmegaLambdaTec

In the first step, the OmegaLambdaTec team simulated scenarios for future loads in the distribution grid. They were used to detect the risk of overload in specific lines and cables. Correlation analysis was then applied to determine the optimum measuring points. Grid operators can use input parameters to define the required grid transparency and in response obtain suitable sensor recommendations.

## Insights

The findings clearly emphasised how databased solutions can help grid operators to select the right measuring points. However, the developed concepts still need to be validated in other grid areas.

These models are susceptible to imprecise recommendations due to the high dimensional feature space and the low quantity of data that is otherwise used in AI applications. Grid operators should review this aspect in regard to their own database when transferring the models into practice.

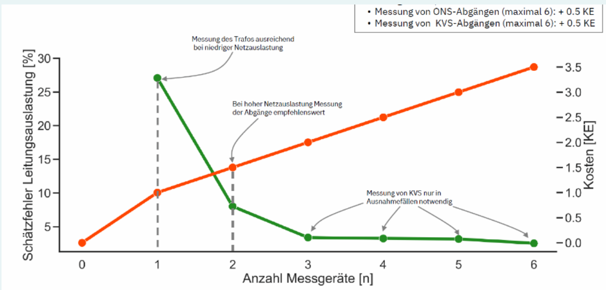
Specific parameters must be selected for the individual grid operators during operationalisation. Variations in grid topology and sector coupling momentum should be taken into account. All teams noted that grid operators must ask themselves during implementation which certainty the grid concept must exhibit in regard to potential estimation errors. Dialogue with start-ups emphasised the importance of defining a clear objective for AI projects, ideally as a measurable variable.

| First Place | Second Place | Third Place |
|---|---|---|
| reto4ki | enersis climate intelligence | OmegaLambdaTec |

Results

## Outlook

The Data4Grid project provided grid operators with three separate concepts for positioning measuring points in the distribution grid. The results promise optimisation of grid transparency, while still adhering to budget restrictions. In view of the current regulatory regime, this Challenge enables grid operators to generate directly measurable added value in their planning.




Results for the EAMN grid area in Fauleborn

All of the teams visualised the grid and therefore achieved the objective of modelling a decision-making tool. This provides grid planners with an overview of grid sections that are at risk of overload and in which areas additional measuring equipment might help to obtain valuable information. The diagram on the right shows a possible minimisation of the estimation error (in green) in a grid area in which a smaller number of measuring devices are already installed.

In view of the results obtained by the teams, grid operators should make efforts to implement the concepts in their own areas of the grid. Models to assist in the decision-making process can be developed, despite the paucity of available data, so that an early move would promise more efficient grid planning, in addition to increased grid transparency.

Challenge

# 3

# AI-assisted consumption forecasts based on smart meter data

## Motivation

It will become essential in the electricity grid of the future to obtain accurate predictions of the electricity consumption associated with households, businesses, charging points for electric cars and other consumers. Only then will it be possible to guarantee a stable grid status, despite fluctuating feed-in. The volume of available data is rising steadily with the roll-out of smart meters, providing a potentially strong basis for load forecasts in the distribution grids going forward. In particular, the data granularity promises significant knowledge acquisition, which, combined with data analysis methods, might lay the foundation for continued automation of grid operation.

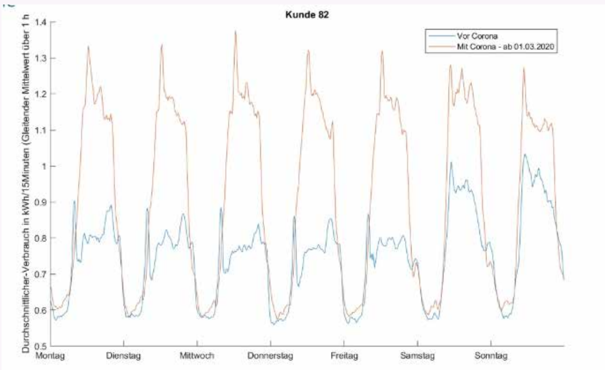
## Objectives

In this Challenge, the teams were asked to analyse smart meter datasets from grid operators and to derive consumption forecasts on this basis. The first step was to form the available data into clusters containing measurements with similar levels of consumption.
On this basis, the second step involved calculating 1-day forecasts for individual smart meters, the clusters and the whole portfolio. As part of the Data Science Challenge, the teams were then rated according to the deviation between their forecasts and the real values from the test dataset.

## Data

Stromnetz Hamburg and enercity Netz provided consumption data to create the forecasts in this Challenge. In total, the teams received information from 438 smart meters, including partial classification into the German Association of Energy and Water Industries (BDEW) clusters. A few days from the dataset were withheld from the teams in order to evaluate their models based on this real test data. The diagram below visualises the enercity dataset, in which a perpendicular line represents one day of smart meter readings. While the left section shows the different times when the devices were put into operation, the yellow lines on the right side represent the days that were withheld from the teams in order to evaluate their models.

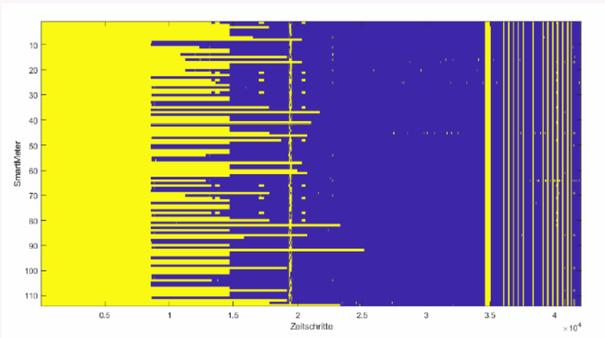
Sponsors & data providers




Consumption comparison for before and after the COVID-19 pandemic

## Results

The teams from Fraunhofer IEE and NAECO Blue based their selection of suitable clusters on seasons and days of the week. By contrast, the ifesca team assigned the individual time series to known standard load profiles published by the German Association of Energy and Water Industries (BDEW). For the second step, consumption forecasting, the teams and sponsors agreed on clusters obtained with the latter method in order to obtain a standardised evaluation.




Availability of smart meter readings (enercity)

The informational value of smart meter readings was demonstrated in the data analysis carried out by all teams at the beginning. One example is the comparison of recorded consumption one week before and after the onset of the COVID-19 pandemic (refer to the diagram above). It is clearly noticeable that private electricity consumption rose during the periods in which people were working from home (red line). Although changes, especially the load peaks, yield valuable information for distribution system operators, it can only be made visible through the use of smart meters.

## Fraunhofer IEE

The team from Fraunhofer IEE used various machine learning methods such as decision trees or neuronal networks in order to produce their forecasts. The final forecast builds on a combination of two models to compensate for gaps in the measured values. The neuronal network method is viewed as particularly suitable to recognise the complex relationships.

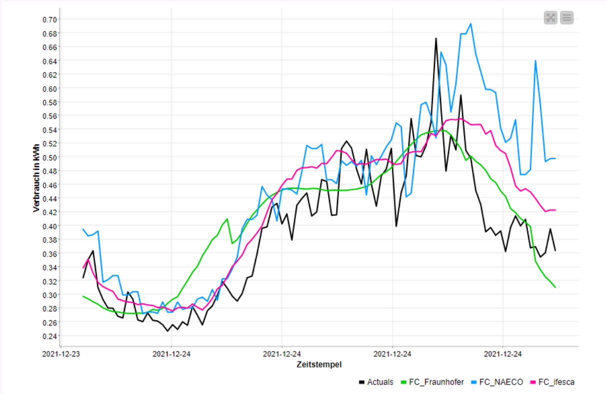
## ifesca

The ifesca team built their approach around a gradient boosting regressor, which requires little training and is not particularly susceptible to overfitting with training data, which makes it more suitable for use in practice. Several regressor levels are used in the final model, in which each level possesses a different forecasting focus.

## NAECO Blue

NAECO Blue also trained different models, including neuronal networks, statistical methods and regressors. The results differed, depending on the dataset. The statistical model outperformed the machine learning methods with limited data, but the boosting regressors were otherwise chosen as the best model.

A comparison of the forecasts produced by the individual teams demonstrates that there are two possible modelling approaches (refer to the diagram on the right). These are the prediction of determined values or the replication of real consumption including short-term fluctuations. The forecast deviations measured in the test dataset indicate that the averaged approach seems to yield better results. However, the grid operators stated that peak loads are particularly important for grid calculations, so the second approach offers advantages as well.




Consumption forecast over the course of the day in kWh

## Insights

Although the team forecasts delivered good results with low deviations from the real data, expanding the dataset remains a core factor for optimising the models. It will therefore be necessary to observe during smart meter roll-out whether the AI models are able to identify peak loads, which are difficult to forecast, as the volume of data increases.

The teams were barely able to investigate exogenous influences, although they promise significant potential in regard to the predictability of consumption. However, any combination of smart meter data and other consumer information requires critical analysis from a data protection perspective, as preserving the anonymity of users is imperative.

With regard to AI modelling, this Challenge emphasised the relevance of selecting the right evaluation metric in order to achieve the stated objective. Although the chosen root-mean-squared error enables comparability of results, it also favours consumption averaging, whereas grid operators are interested in peak loads. This case stands as an example of the challenges that must be anticipated during the implementation of AI projects.

## Outlook

Two factors are relevant to grid operators with a view to the increased prevalence of smart meters in the electricity grid. Firstly, the necessary databased systems should be designed to enable scaling to large data quantities. Computing time in particular must be taken into account for operationalisation. Secondly, grid operators may ask themselves to what extent the standard load profiles need to be changed or extended, as the team evaluations indicate that shifts in peak loads or even new peaks compared to the standard load profiles are already occurring.

| First Place | Second Place | Third Place |
|---|---|---|
| Fraunhofer IEE | ifesca | NAECO BLUE |

Results

The Challenge demonstrated that the use of smart meters presents considerable potential for grid operators and that the associated use cases should be implemented at an early stage. Aside from data protection aspects, the requirements linked to clearly defined objectives must be factored in prior to implementation.

# Table of figures



# List of tables

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# List of abbreviations

| | |
|---|---|
| **BDSG** | Federal Data Protection Act |
| **BMWK** | Federal Ministry for Economic Affairs and Climate Protection |
| **BNetzA** | Federal Network Agency |
| **BSI** | Federal Office for Information Security |
| **DIN** | Deutsches Institut für Normung, German Standardization Institute |
| **GDPR** | General Data Protection Regulation |
| **EnWG** | German Energy Industry Act |
| **GDEW** | Act on the Digitisation of the Energy Transition |
| **GIS** | Geoinformation system |
| **ICT** | Information and communications technology |
| **ISMS** | Information security management system |
| **IT-SiG** | IT Security Act |
| **AI** | Artificial intelligence |
| **KPI** | Key performance indicator |
| **MsbG** | Metering Point Operation Act |
| **NIS Directive** | EU Network and Information Security Directive |
| **TOM** | Technical and organisational measures |
| **TSO** | Transmission system operator |
| **VDE** | Association for Electrical, Electronic & Information Technologies |
| **DSO** | Distribution system operator |

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