

ip  **INNOVATIVE PROJECTS**
for the German wind market

The following pages are dedicated to companies whose new products, processes or methods ensure the continued development of the wind industry.



An excerpt of the
BWE Industry Report
'Wind Industry in
Germany 2025'

Automated performance analysis for wind projects

4cast Horizon offers automated, precise performance analysis that accompanies your projects efficiently and successfully from planning to implementation.

The successful planning of wind farms depends largely on the ability to accurately predict the potential yield of a site in the early stages. With 4cast Horizon, our innovative solution for automated performance analysis, we ensure that planners and developers have the tools to make informed decisions quickly and efficiently.

4cast Horizon uses proprietary analytics software built on a highly scalable, cloud-based infrastructure. This solution makes it possible to process extensive data sources such as turbine specifications, park layouts and meteorological data

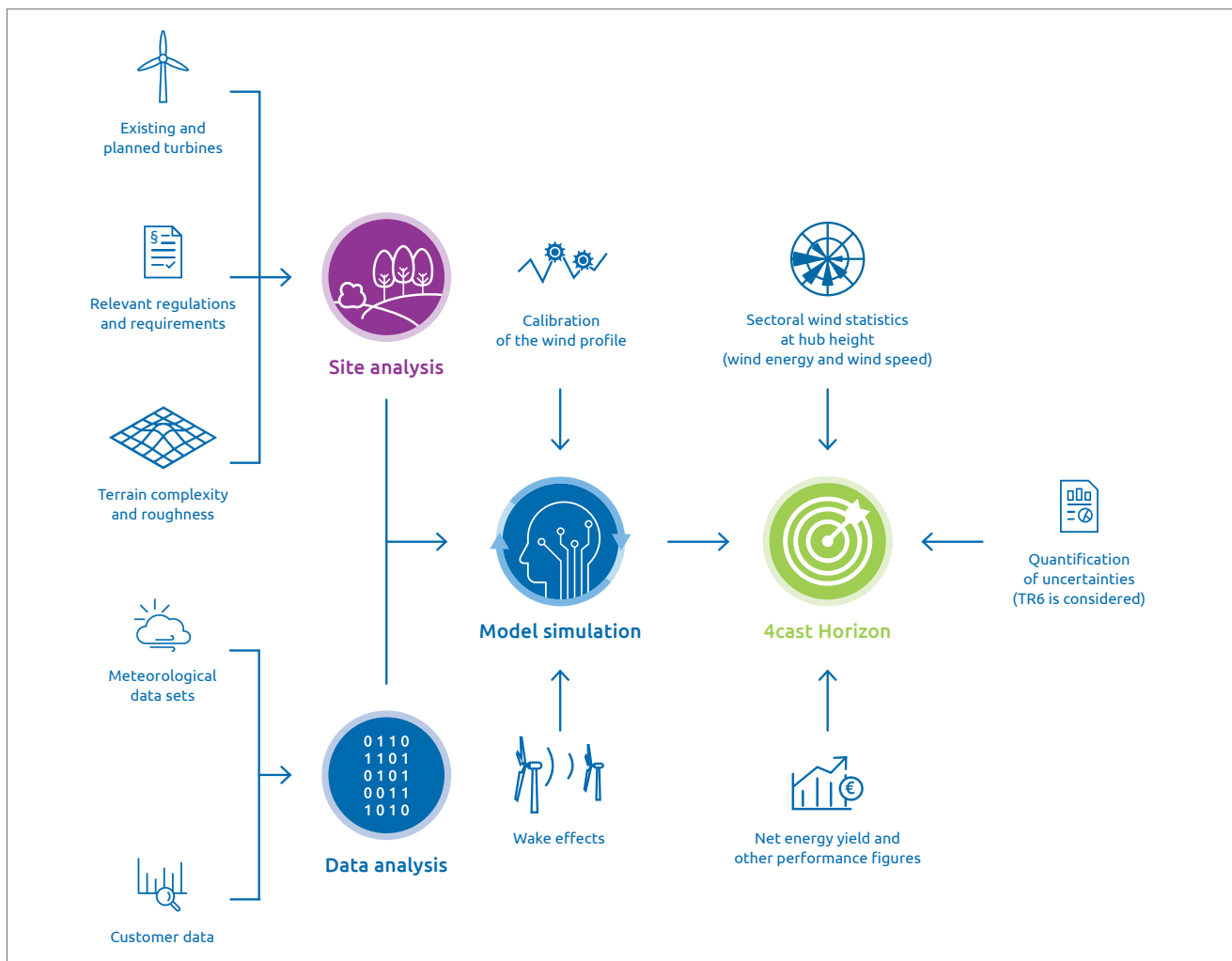
sets and create precise yield forecasts. By automating individual process steps, you not only save time and resources, but also receive reliable results that help you plan your projects with maximum efficiency.

A particular advantage of 4cast Horizon is its ability to calculate and compare a variety of scenarios. This is extremely useful when it comes to evaluating different site options or analyzing the impact of changes in project constraints. Our forecasts take into account not only the layout of the farm and wake effects, but also the roughness of the terrain and the mutual influences of the wind turbines. This en-

ables us to provide you with detailed net energy yields that take into account technical losses and environmental constraints.

In addition to providing yield forecasts, we also offer historical time series of energy yields and wind data. This information enables you to better understand the wind patterns and fluctuations at a location and to plan your projects even more precisely. We also offer combined yield forecasts for the simultaneous use of photovoltaic and wind energy, which is particularly beneficial for optimal grid utilization.





Process flow with 4cast Horizon

Project status and goals:

4cast Horizon is already being used successfully by planners and developers and is undergoing continuous development. Our goal is to further expand the service and integrate additional functionalities to offer our customers even more flexibility and precision. Drastically reducing processing time is our biggest focus and is constantly being improved by driving forward automation.

Contact and networking opportunities:

We invite interested companies and professionals to network with us and work together to optimize 4cast Horizon. For a conversation write to us at hello@4-cast.de or scan this QR code directly:



Project overview

Initiator	4Cast GmbH & Co. KG
Status	start of the project May 2024, continuous development
Location	Worldwide
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Web	4-cast.de



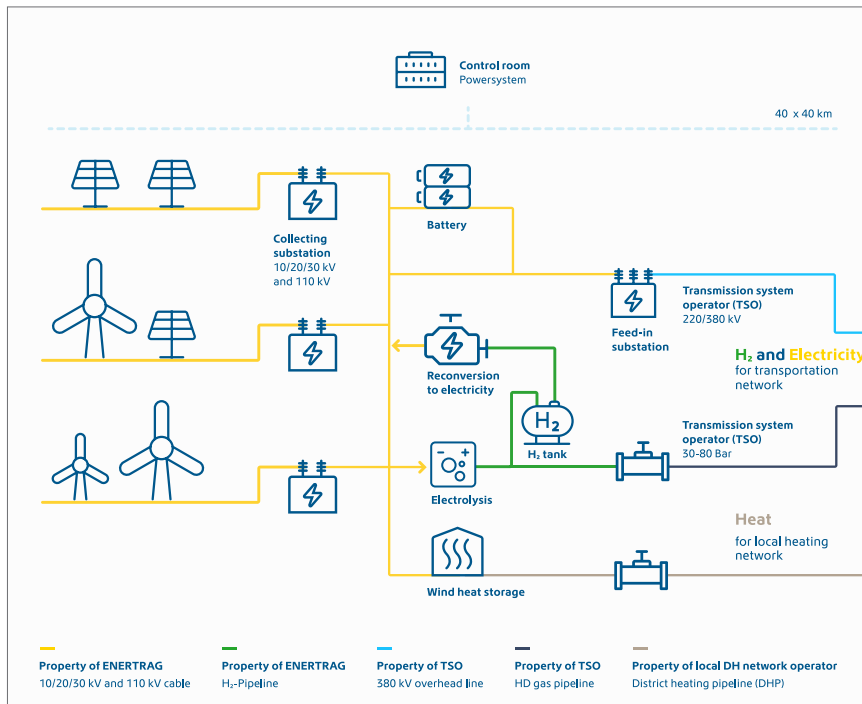
Conclusion:

4cast Horizon offers you fast and precise yield forecasts that ensure the success of your wind projects. With our solution, you can make informed decisions and optimize your investments for maximum yields.

Are you interested in the project and want to know how your community or your business can benefit from it? Contact us. Our contact can be found in the **business directory on page 146.** ▶

The ENERTRAG Verbundkraftwerk® – The Prototype for Clean Energy Supply

The ENERTRAG Verbundkraftwerk® provides energy as reliably as conventional power plants – only cleaner and more sustainable.



The energy flow in the ENERTRAG Verbundkraftwerk®

→ Conversion and storage

Surplus energy is stored, for example in batteries, with the help of an electrolyzer as green hydrogen or in wind heat storage systems. In contrast to other energy producers, ENERTRAG does not shut down its wind power and photovoltaic systems during periods of darkness. In the event of bottlenecks in the electricity grid, the stored green hydrogen can be converted back into electricity.

→ Control centre

The control centre is the central monitoring and control unit of the ENERTRAG Verbundkraftwerk®. All systems are directly connected to it via control lines. From the control room, a team continuously monitors the operation of the entire combined power plant and its components. This includes energy generation, conversion, distribution and grid connection.

Principle

ENERTRAG Verbundkraftwerk® are directly connected energy plants, i.e. without a public grid. These produce electricity from wind and solar energy, which flows primarily into the transmission grid. The surplus electricity is stored, for example in a battery, as green hydrogen or in the ENERTRAG Verbundkraftwerk®. The storage units supply the electricity sector when too little wind and solar power can be produced.

Components

→ Primary energy from wind and sun

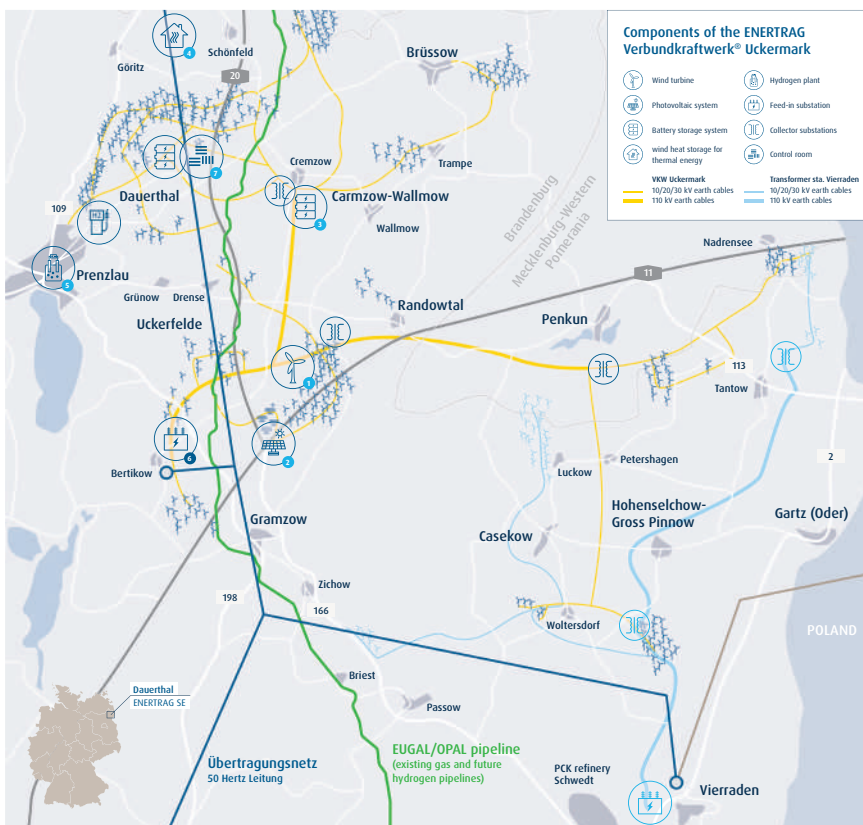
The ENERTRAG Verbundkraftwerk® generates large quantities of sustainable electricity from wind and solar energy.

→ Network infrastructure

The electricity is collected in hybrid form in local grids, forwarded to the central substation via substations within the area of the ENERTRAG Verbundkraftwerk® and fed into the transmission grid there as a priority. Hydrogen pipelines and heat pipes can also be part of the local interconnected power plant grid infrastructure.

→ Utilization

The electricity is fed into transmission grid as scheduled electricity via a single large substation so that households and industry can utilize it. The ENERTRAG Verbundkraftwerk® also guarantees all the necessary system services, such as black start capability, peak load coverage and the provision of balancing energy. The surplus electricity is stored as green hydrogen, for example, flows into the future hydrogen grid and can also be used by industry. Green hydrogen can also be further refined into hydrogen derivatives such as ammonia or methanol. Further, surplus electricity can be used for local heat supply.



The ENERTRAG Integrated Power Plant® Uckermark at a glance: Already a reality, the Uckermark plant generates clean electricity, green hydrogen, and heat over an area of 40 x 40 kilometres.

Important to know

The different and fluctuating generation patterns of wind energy and photovoltaic systems balance each other out in the ENERTRAG Verbundkraftwerk®. This enables a constant, predictable and demand-oriented power supply.

Conclusion

The ENERTRAG Verbundkraftwerk® can fully replace conventional power plants.

From top to bottom:
 Wind turbine General Electric (GE) 5.5/158/5500 (Windfeld Falkenwalde),
 PV plants Kreuz Uckermark,
 Alkaline Electrolyzer (AEL) Wittenhof



Under Construction: The Hydrogen Analysis Laboratory of ENERTRAG Operation



Preparations are in full swing for a state-of-the-art hydrogen analysis laboratory in Prenzlau, located next to the existing hydrogen filling station. The lab is scheduled to launch in early 2025. Initially, it will serve the hydrogen projects “Heidekrautbahn” and “Industriepark Osterweddingen” and will gradually expand to serve other customers. The lab’s goal is to certify hydrogen purity in line with the strict requirements of DIN ISO 14687, ensuring the best possible product quality. Hydrogen sample bottles will be rinsed with hydrogen 6.0 and provided by ENERTRAG Operation, filled by the customer, and returned for analysis. Customers will receive an analysis report. The lab has the capacity to conduct several hundred analyses per year. ENERTRAG, which has been producing green hydrogen since 2011, aims to integrate the analysis process into its own value chain.

Project overview

Initiator	ENERTRAG SE
Key Figures	<ul style="list-style-type: none"> • 622 MW wind power capacity • 600 km of ENERTRAG owned earth cables • 560 kW electrolysis • 22 MW battery storage • 24 MW solar power capacity
Location	Uckermark



Are you interested in the project and want to know how your community or your business can benefit from it? Contact us. Our contact can be found in the **business directory on page 168.** ▶

Software for the Energy Transition

The Landwind Group and node.energy are joining forces to optimize municipal participation in renewable energy and are relying on innovative software solutions.

At a time when the energy transition is more than just a buzzword, innovative solutions are needed to meet the challenges of the green transformation. The Landwind Group, an established company in the renewable energy sector, and node.energy, a pioneer in software development for the energy transition, have teamed up to improve the efficiency and management of renewable energy installations.

Landwind, a family-run company with a history spanning over 250 years, is not only a pioneer in implementing the energy transition but also a model for sustainability, regionality, and citizen

participation. Operating renewable energy installations comes with great responsibility, but it also demands high efficiency in management and compliance with regulatory requirements.

This is where node.energy comes in. As a leading provider of software solutions for renewable energy, node.energy offers a SaaS solution called opti.node, a digital platform for professional operators and commercial managers of energy facilities. With opti.node, projects can be comprehensively evaluated, optimized, and managed efficiently, enabling the development of profitable business models from renewable energy sources.

A key concern for Landwind was managing the § 6 EEG contracts for municipal participation, including the generation of credit notes for municipalities and the reimbursement process with grid operators. This complex task required a legally compliant and automated solution to stay on top of energy industry and contractual obligations while reducing administrative effort.

By implementing the opti.node module for the automated execution of § 6 EEG, this challenge was successfully addressed. The module covers all tasks related to municipal participation and gives Landwind a comprehensive overview of the necessary credit notes and reimbursement applications.



Commercial operations management with the opti.node Cockpit



Construction site assembly at Windpark Gevensleben

Evi Wehr-Paulus from Landwind summarizes: “The significant effort caused by regulatory requirements would have been nearly impossible to manage without the solution from node.energy. Manually evaluating all the required data would have consumed too much labor and potential errors cannot be overlooked. With the § 6 EEG solution, we can work more efficiently and get all billing-related data at the push of a button.”

Phillip Micke, Customer Success Manager at node.energy, also highlights the importance of this partnership: “After our discussion, Landwind shared that without our solution, managing the workload due to the massive regulatory requirements might have been too overwhelming. The appreciation for our solution makes us really proud.”

The partnership between Landwind and node.energy shows how the intelligent integration of technology and industry expertise can successfully tackle the challenges of the energy transition. By utilizing opti.node, professional operators of renewable energy installations, such as Landwind, not only benefit from efficiency gains but also contribute to the energy transition and develop profitable business models. Moreover, municipal participation increases regional acceptance as it supports the expansion of schools, kindergartens, and other local projects.



Rotor blade assembly



Machine house assembly

“The collaboration with node.energy enables us to efficiently manage regulatory requirements and make optimal use of our resources.”

Evi Wehr-Paulus, Landwind

Project overview

Initiator	Landwind Group • node.energy
Implementation	11/2023
Key Figures:	500 GWh of electricity generation per year
Status	Operational



Are you interested in the project and want to know how your community or your business can benefit from it? Contact us. Our contact can be found in the business directory on page 190 (node.energy) and on page 257 (Landwind-Gruppe). ▶

Conclusion

The collaboration between Landwind and node.energy demonstrates how innovative software solutions can improve the efficiency of managing renewable energy installations. This not only contributes to the energy transition but also promotes regional acceptance through municipal participation.

With innovation against corrosion

Rain, waves, salty spray – nature takes its toll on wind turbines at sea and on land. Sooner or later, corrosion also creeps in, literally eating away at the metal structures. But an innovative approach promises to overcome this challenge with corrosion in the long term.



It's a common sight on the coast: grey sky stretches across rough sea, in the distance, the huge blades of offshore wind turbines seemingly do their work in silence. If you were to drive out to them, you could feel the harsh environment up close: sea air, salt water, strong wind and UV radiation – a combination that has a merciless effect on the turbine components and their painted surfaces. This results in fine cracks and flaking of the paint,

especially on the metal surface of the wind turbines. The exposed areas quickly become the victim of corrosion.

A battle against time begins: due to the favourable environment, corrosion eats into the material structures and spreads. Planned and unplanned downtimes are inevitable – to the detriment of economic efficiency. Conventional solutions may provide some assistance, but they quickly

reach their limits. Painting work at sea is sometimes like a game of chance with the weather conditions: Humidity, temperature and wind must harmonize ideally – even during the drying phases. A change in the weather can result in days of unbudgeted delays, costs and loss of earnings.

But where there are challenges, innovation is not far away – and with it a promising corrosion protection technology that is

Transparent PMMA (Acrylate) layer
UV stability

PVC functional film
Color: RAL 7035 (light grey) or RAL 1023 (traffic yellow)

Adhesive
with corrosion protection property

Protective liner
will be released when applied

Can be applied directly to the surface without primer

RENOLIT CP Advanced
Corrosion Protection Film - Onshore & Offshore
Certified and tested according to
BAW standard (DIN EN ISO 12944-9 CX)



currently being used in a pilot project on a North Sea transformer platform. It is a high-performance film called RENOLIT CP Advanced that fundamentally changes the fight against corrosion. The innovation lies in its ingenious structure: a high adhesive layer thickness ensures reliable adhesion, even on rough, uneven surfaces. After cleaning and removing corrosion, the film can be applied directly – without primer, as this is already integrated, as is the anti-corrosion effect.

But innovation also means efficiency: as a one-step solution, the film provides immediate protection without drying times. Therefore, this concept significantly reduces the dependency not only on the weather, but also on the amount of work involved: under normal conditions, it takes just ten minutes to protect 1 m² of surface with the film – a potential saving of 1–4 hours/m² compared to conventional painting work. And the constant thickness of the film also means a much more even and more effective corrosion protection as a result. The ecological benefits also speak in favour of this innovation: no volatile organic compounds (VOCs) as with conventional paintwork – no paint or other substances that could drip off into the sea.

The durability is also outstanding: several years of field tests in Helgoland demonstrate the film’s resistance to UV radiation and extreme weather conditions. Underlining this benefit are a Xenon test of over 15,000 hours in accordance with ISO 4892-2, and the long-term corrosion protection of over 10 years which is certified according to BAW standard (tested in accordance with DIN EN ISO 12944-9 CX, the highest corrosivity category).

Conclusion

The RENOLIT CP Advanced corrosion protection film has been specially developed for application on onshore and offshore wind turbines. For an industry whose success depends largely on the longevity and reliability of its wind turbines, this innovation is a significant step towards more efficient and cost-effective maintenance strategies. Nature may show its harsh side, but technological progress will enable the wind industry to face it even better in the future.

Project overview

Initiator	RENOLIT SE
Implementation	RENOLIT SE and WP Energy GmbH
Figures, data, facts	RENOLIT SE has been on the market for more than 75 years and employs around 5,000 people at more than 30 production sites and sales units in over 20 countries.
Status	completed



Rely on it.

Are you interested in the project and want to know how your community or your business can benefit from it? Contact us. Our contact can be found in the **business directory on page 136**. ▶

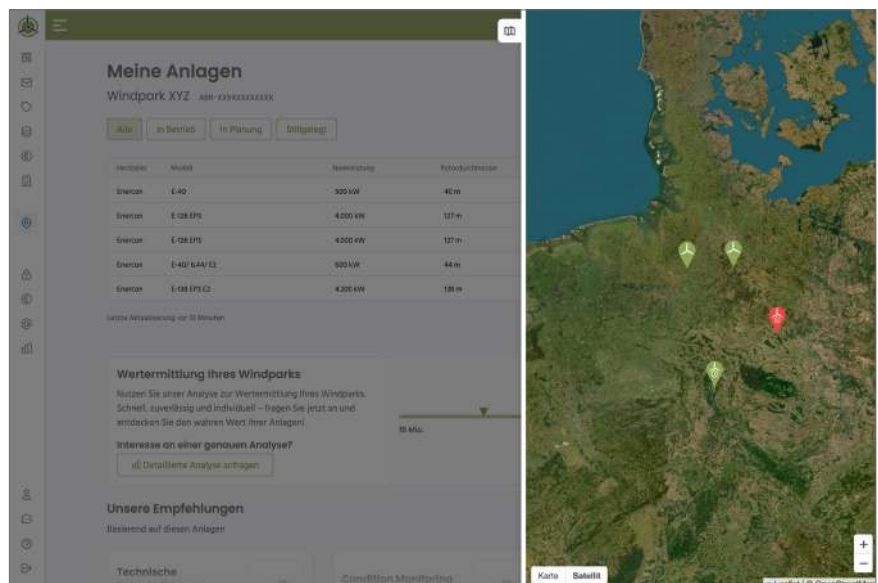
Windpark Cockpit: Digitalizing Wind Farm Management and Marketing

The Windpark Cockpit on wind-turbine.com enables innovative management, evaluation, and marketing of wind farm assets—digitally and efficiently.

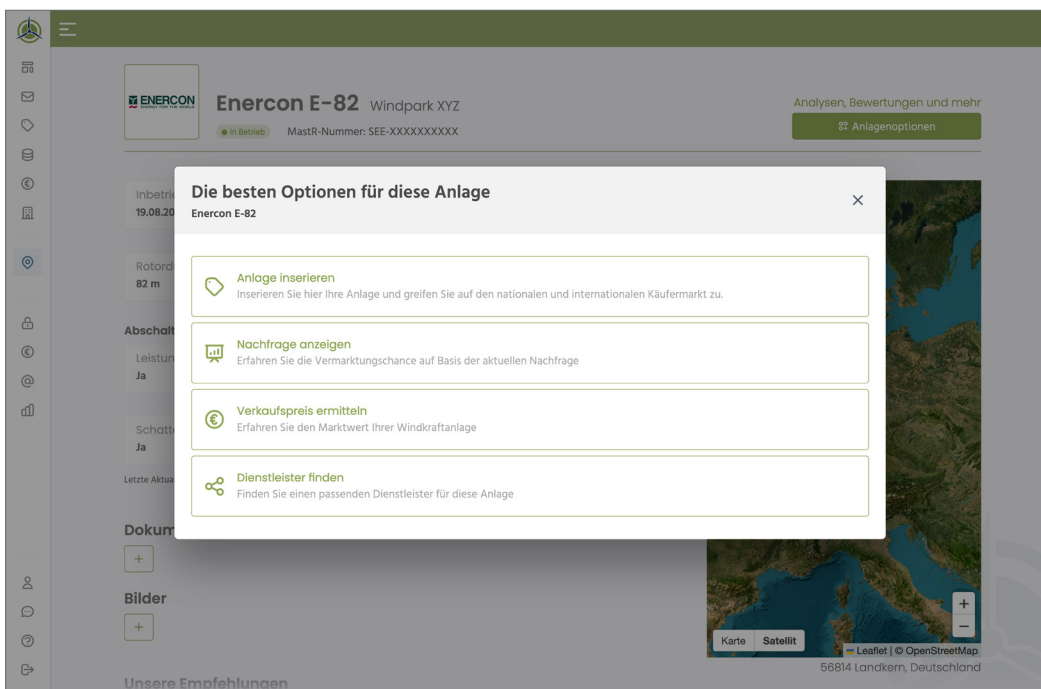


The Windpark Cockpit

The Windpark Cockpit is a specialised application within the global marketplace wind-turbine.com for existing and new wind farms. It is designed to streamline the management of wind energy assets for operators, managers and service providers, offering a centralised and digital platform. The tool leverages comprehensive market movement data and expert knowledge to enable effective commercialisation of one's own portfolio. The platform's core features include a marketing assessment, ongoing operational forecasts at the new location, potential lease income projections, and a matchmaking service that directly connects users with an international, verified market of buyers and service providers.



Overview of Wind Turbines



Tools and Applications

DMS – the foundation for secure and transparent transactions

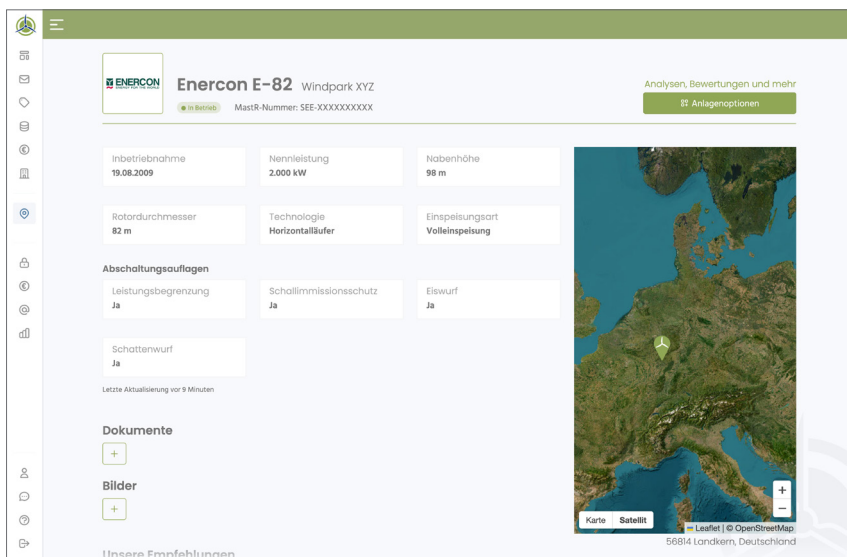
In addition to these existing features, wind-turbine.com plans to introduce a data document management system (DMS). This system will guarantee the secure transmission and storage of data, while also providing a transparent and efficient basis for the transaction process when selling assets to buyers and sellers.

The Windpark Cockpit is currently in its beta version and invites users to actively participate. Input from industry professionals is vital to ensure the tool is continually improved and meets the needs of the sector. The input of industry experts and organisations, such as the German Wind Energy Association, is invaluable in this regard.

Conclusion

The Windpark Cockpit provides an efficient, transparent and secure sales process for wind assets on a digital and independent platform in collaboration with innovative partners.

Overview of Turbine Types



Project overview

Initiator	wind-turbine.com GmbH
Figures, data, facts	Marketplace: 11 billion in trading volume since 2011, 16,000 registered users from over 190 countries
Status	Windpark Cockpit: BETA phase



Are you interested in the project and want to know how your community or your business can benefit from it? Contact us. Our contact can be found in the **business directory on page 221**. ▶

RESEARCH IN GERMANY

Insight into the industry of tomorrow

Germany occupies an outstanding position in international wind energy research. The following pages present some research results of industry-related science, which can provide you with valuable insights into the latest technology trends.

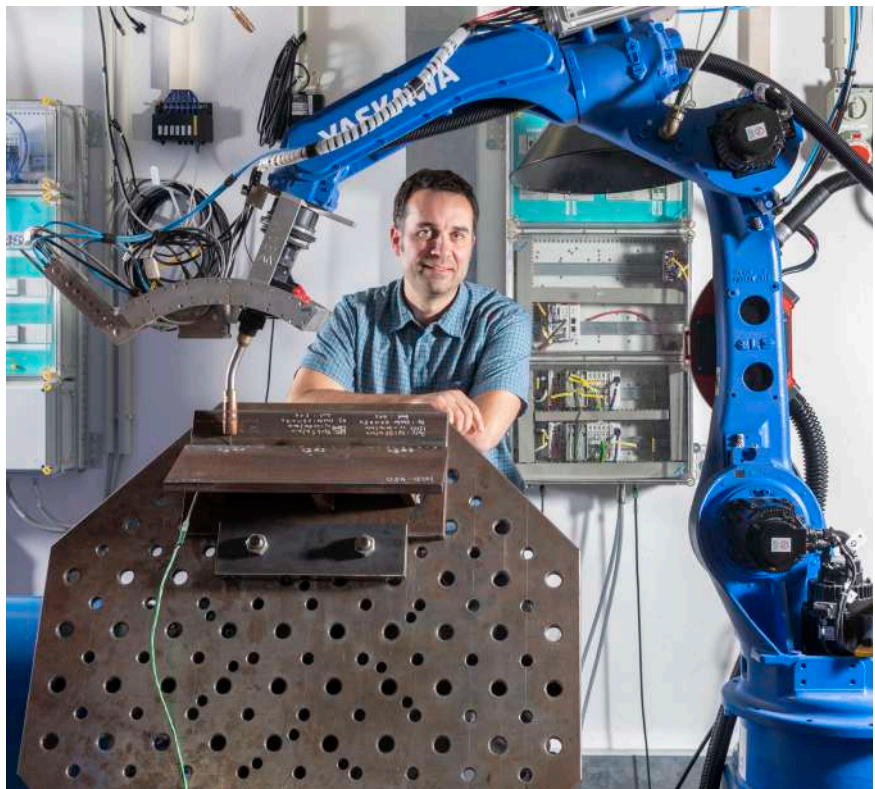
Smart Welding Technology Saves CO₂ in Offshore Wind Construction

The Federal Institute for Materials Research and Testing (BAM) is developing automated welding techniques to reduce CO₂ emissions during the construction of wind turbines.

For offshore wind turbines, a large steel pile, known as a monopile, is typically used as the support structure. These monopiles require up to 2,000 tons of steel to be welded together, resulting in a substantial CO₂ footprint. In contrast, the more light-weight „jacket“ foundations have a significantly lower carbon footprint since they require much less steel. However, welding these structures presents a challenge.

Potential Savings of 100,000 Tons of CO₂

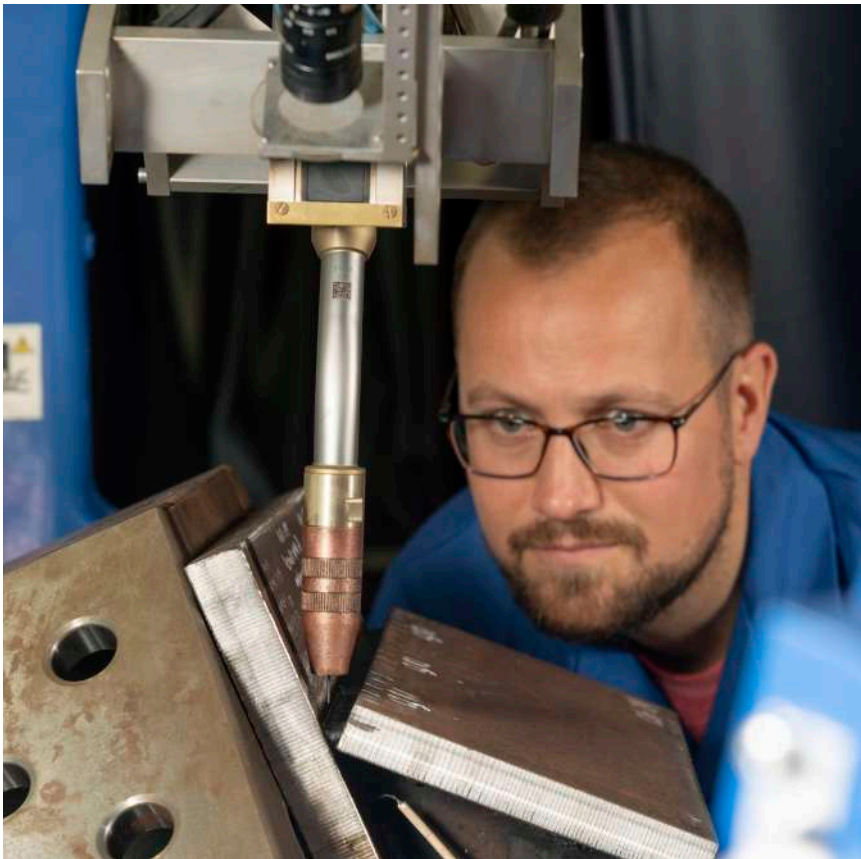
The main difficulty lies in the complex welds required. For safety reasons, jacket foundations use very thick steel plates. According to Andreas Pittner from BAM, „Automated welding processes, which produce weld with higher fatigue resistance, could improve the strength of jackets. As a result, pipes with thinner walls could be used, significantly reducing the amount of steel needed.“ For a wind farm with 100 turbines, this would mean a reduction of over 100,000 tons of CO₂ compared to monopile foundations.



Andreas Pittner aims to enable CO₂ savings in wind turbine construction through smart welding techniques.

“Through automated welding processes, the construction of a wind farm with 100 turbines offers the potential to reduce CO₂ emissions by over 100,000 tons.”

Dr.-Ing. Andreas Pittner (BAM)



The robot creates more precise welds than a human ever could, allowing for steel savings – and thus CO₂ reductions.

Fast Technology Transfer to Industry

Currently, the welds for jacket foundations still pose a challenge for automated manufacturing. The collaborative project „SmartWeld,“ led by Andreas Pittner, is addressing these issues. „We aim to enable the use of lightweight construction techniques through the full digitization of the entire production and inspection process,“ said Pittner. „We are intentionally working under industry-like conditions to ensure a fast technology transfer to the economy.“

Conclusion

The rapid expansion of offshore wind energy is crucial for Germany and the EU to meet their climate targets. Many tons of CO₂ could be saved during the construction of wind turbines. BAM is researching how to intelligently combine lightweight design principles with digitized quality control to achieve these savings.

Project overview

Status	Ongoing
Location	Berlin
Federal Institute for Materials Research and Testing (BAM) Department of Welding Manufacturing Processes	

Dr.-Ing. Andreas Pittner

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Related content: welding in offshore lightweight construction, see also next page.

New Welding Alloys for Gigantic Wind Turbines

The Federal Institute for Materials Research and Testing (BAM) is paving the way for lightweight construction in offshore installations with innovative welding alloys.



Precise manufacturing of the samples on a 5-axis portal.

To make offshore wind turbines even more powerful, they must be equipped with longer rotor blades, which in turn requires taller towers. To economically and technically realize these gigantic structures, switching to lightweight construction with modern high-strength steels is essential – otherwise, their weight would be too great. This switch could also save up to 20 % of the steel used.

Welds as a Weak Point

So far, welds have been considered a weak point in the transition to lightweight construction. Offshore wind towers are subjected to immense loads, causing cyclic, oscillating stresses on the material. Unfortunately, the fatigue strength of modern high-strength steels is compromised by the welding process.

Special Alloys Strengthen Welds

BAM, in collaboration with the Fraunhofer Institute for Mechanics of Materials (IWM), is testing special alloys that are designed to reinforce welds. „These special alloys form a structure during cooling that reduces residual stresses in the material, stabilizes the weld, and increases its fatigue strength,“ explains Arne Kromm, welding technology expert at BAM and head of the project. The goal is to enable the industry to safely process these welding consumables, while also integrating these findings into industry standards.

“The innovative use of special alloys allows the lifespan of welded high-strength steels to be extended.”

*Dr.-Ing. Arne Kromm,
BAM welding technology expert.*

Top: Welded sample with test seam.
Bottom: Fatigue fracture at the weld seam transition; the dot pattern is used for deformation measurement.



Project overview

Status	Ongoing
Location	Berlin

Federal Institute for Materials Research and Testing (BAM)
Department of Weld Mechanics

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The project is funded by the Federal Ministry for Economic Affairs and Climate Action based on a decision of the German Bundestag.



Conclusion

The results are not only relevant for the wind industry but also for mechanical engineering, automotive, and steel construction sectors, helping to fully exploit the lightweight potential of high-strength steels. Moreover, the findings impact the design of the large specialized cranes needed to erect these even more massive wind turbines.

Life Extension through Monitoring

The Federal Institute for Materials Research and Testing (BAM) aims to make a monitoring system ready for practical use to optimize the operation of wind turbines.



Recording the stresses of the steel tower by measuring the strains using strain gauges



Measuring the vibrations of the tower induced by wind loading using biaxial acceleration sensors



Central measuring station at tower base for recording and transmitting of all monitoring data

As wind energy continues to expand, the focus is increasingly on extending the operational lifespan of existing turbines. BAM is developing a new monitoring system in a collaborative project that aims to ensure existing wind turbines can be safely used beyond their originally planned lifespan, allowing them to contribute more to the energy transition.

Vibrations Can Lead to Cracks

Wind turbines are currently designed for a lifespan of about 20 years. The towers, particularly those made of prestressed

concrete in onshore installations, are constantly subjected to vibrations. These stresses can lead to fatigue and cracks. BAM has extensively researched how such damage can be detected using ultrasound and acoustic emission measurements. In collaboration with partners from academia and industry, these methods are now being further developed so that wind turbines can be more efficiently monitored on-site.

Using Turbines Beyond 20 Years

The goal is to develop a monitoring concept based on a pilot plant in Brandenburg, which can later be applied efficiently and economically in wind farms. The project, funded by the Federal Ministry for Economic Affairs and Climate Action, also includes participation from the Technical University of Dresden, Leibniz University Hannover, RWTH Aachen University, and several industry partners.

Conclusion

BAM is developing a new monitoring system in a collaborative project to make it practical for use, enabling the continuous monitoring of existing wind turbines and allowing them to be safely operated beyond their originally planned lifespan of 20 years.

“Our goal is to continuously monitor the condition of the towers. This allows for better maintenance planning and ensures that the potential of existing wind turbines is fully utilized – ideally even beyond their intended lifespan of 20 years.”

Dr.-Ing. Marc Thiele (BAM), expert in concrete fatigue

Project overview

Status	Ongoing
Location	Berlin

Federal Institute for Materials Research and Testing (BAM)
Department of Structural Engineering

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NearWake and SysDamp

Research impulses from DLR for wind energy

Since 2023, the German Aerospace Center (DLR) operated the Krummendeich Research Wind Farm, known as WiValdi, a unique testing infrastructure developed in collaboration with partners from the Wind Energy Research Alliance (DLR, ForWind, Fraunhofer Institute IWES) with funding from the federal government and the state of Lower Saxony. Currently, groundbreaking projects are underway to advance the wind energy sector.

NearWake

Under the leadership of Enercon / WRD, DLR is working together with the University of Oldenburg (ForWind), the Technical University of Munich, and the Center for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW). The project is developing innovative wake models to provide a more accurate representation of the near wake of wind turbines. This allows turbines to be positioned more closely and designed more efficiently. The optimized



Drone fleet measuring the wake in front of the wind turbine OPUS 2

arrangement also enables an increase in the energy production of wind farms. Extensive measurement campaigns have recorded the wake using a specially designed setup consisting of three measuring masts and a gondola-based lidar on the first wind turbine, OPUS 1. Additionally, a fleet of small drones, flying between 50 and 200 meters from the rotor blades of the second wind turbine, OPUS 2, measured the near wake. The collected data serves as a basis to validate these wake models and compare them to the complex conditions on-site.



Gondola-mounted lidar on the wind turbine OPUS 1

SysDamp

Led by DLR, the SysDamp project is developing innovative methods for determining damping, in collaboration with WRD, SPEKTRA, and Leibniz University Hannover (ForWind). Accurate determination of damping allows for better estimation of loads on the turbines, thus extending their lifespan.

Conclusion

The projects NearWake and SysDamp, funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK), demonstrate the importance of research and development in the wind energy sector. With new models and methods, wind farms can be operated more efficiently, reducing the cost of energy generation.

Project overview

Status	Ongoing
Location	Krummendeich, Braunschweig, Göttingen

German Aerospace Center (DLR)

Wind Energy Experiments

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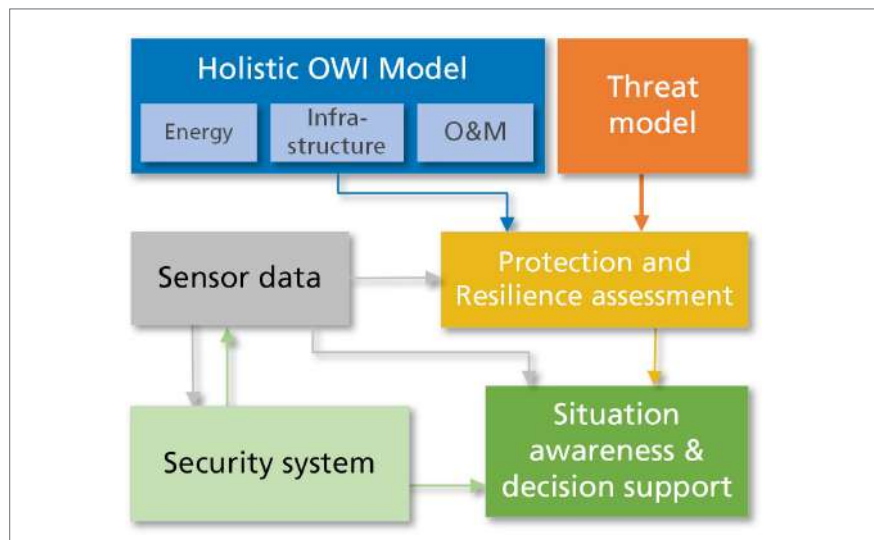
Secure and Resilient Offshore Wind Energy

The German Aerospace Center (DLR) is researching solutions for the physical protection of offshore wind energy infrastructures.

Offshore wind energy is becoming increasingly important for energy supply security, with many offshore wind farms now classified as critical infrastructure. Recent events indicate that hybrid threats are also on the rise in maritime environments. These threats involve the coordinated use of methods such as sabotage and disinformation, aiming to destabilize states and organizations without escalating into open conflict.

Protection and Resilience

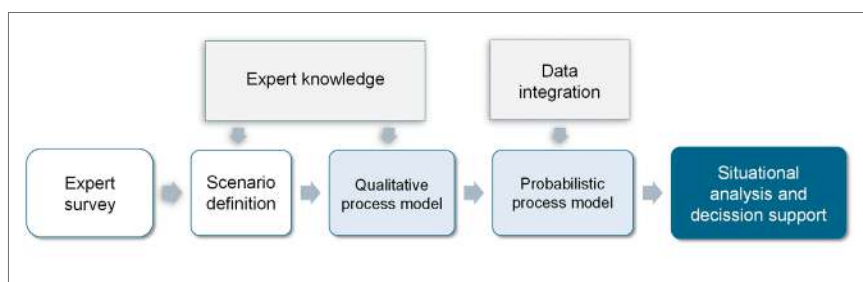
In the „ARROWS“ project, the DLR Institute for the Protection of Maritime Infrastructures is investigating how to enhance the physical protection and resilience of offshore wind energy infrastructures (OWI). The institute is developing a holistic simulation model that considers the electrical system, maintenance and operational processes, as well as the infrastructure components. In parallel, probabilistic models of physical threats are being created, incorporating expert knowledge.



Model-based design of a protection system for offshore wind infrastructures (OWI). Source: DLR

Based on these models, DLR is exploring methods to assess the protection and resilience of OWI against physical threats. The analysis also takes into account the influence of surveillance sensors. These methods not only help develop effective

security systems to protect OWI but also enable the evaluation of current security levels and support informed decision-making for operational management.



Methodological approach to data-driven risk and threat analysis, incorporating expert knowledge. Source: DLR

Conclusion

The ARROWS project addresses hybrid threats to offshore wind farms, which are increasingly targeted as critical infrastructure. By using a holistic simulation model and probabilistic threat analyses, effective methods to enhance the protection and resilience of these infrastructures are being developed.

Project overview

Status	To be completed in 2025
Location	Bremerhaven

German Aerospace Center (DLR)
Institute for the Protection of Maritime Infrastructures

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ADVENTURE: Anomaly Detection for Wind Turbine Efficiency

The goal of the ADVENTURE project was to further develop an early fault detection system for monitoring the operation of wind turbines to reduce downtimes and increase efficiency.

As wind turbines continue to expand in the context of the energy transition, maintaining these systems becomes increasingly complex and labor-intensive. Offshore wind turbines in particular present optimization potential due to their challenging accessibility and the complexity of potential failures. Early detection of impending issues before they become critical can significantly improve maintenance efficiency. Many failures are signaled by abnormal behavior, often well before they lead to a downtime.

In the BMWK-funded [ADVENTURE](#) project, a software architecture was developed to implement an early fault detection system. Building on prior work from the ModernWindABS project, the system uses advanced autoencoder methods to detect anomalies. These methods learn the normal behavior of wind turbines based on historical data and identify deviations from this normal behavior during operation as anomalies. As anomalies occur more frequently within short intervals, the 'criticality' of the wind turbine rises.

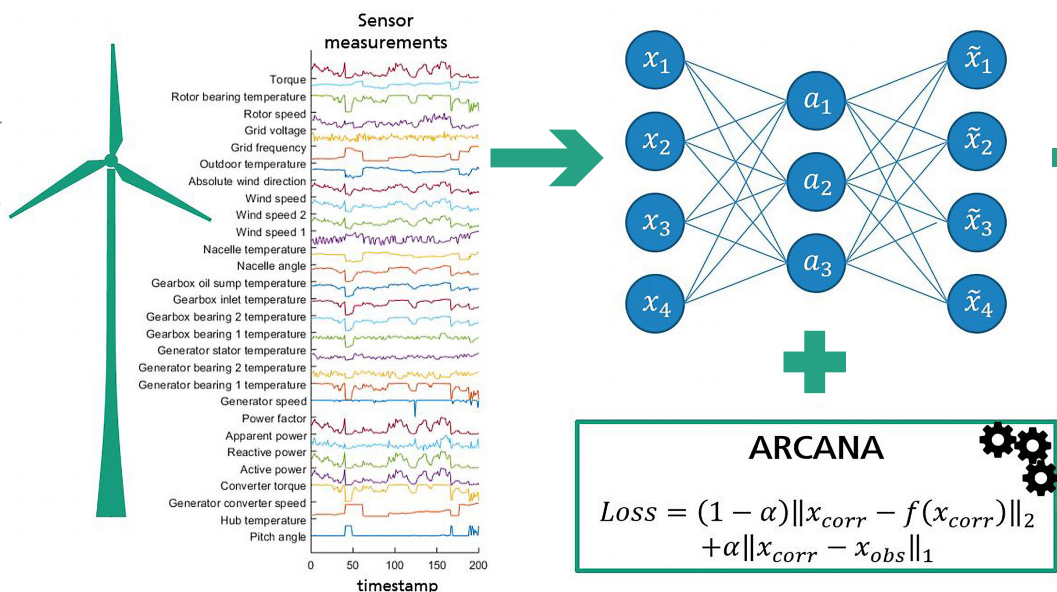
A high criticality indicates the potential for operationally relevant faults. Because anomalies are characterized by deviations

from normal behavior, the system can detect a wide variety of fault types.

The system was further enhanced by integrating ARCANA, a root cause analysis method that allows for a more [in-depth investigation](#) of identified anomalies and helps pinpoint potential causes. For ease of access and understanding by wind farm operators, the results are displayed through a prototype web interface.

The system was iteratively evaluated and validated in close collaboration with the project partners. Insights gained from real wind turbine data provided a foundation for further research in

Schematic representation of the anomaly detection system developed in the ADVENTURE project. The sensor data from a wind turbine are fed into the model (depicted as a neural network). The ARCANA method enables the identification of the cause of a detected anomaly. Without this method, all sensor values are classified as abnormal, although in this case only one sensor value deviates from normal behavior.





“Automated early fault detection systems can enhance the efficiency of renewable energies.”

Cyriana Roelofs, Project Lead

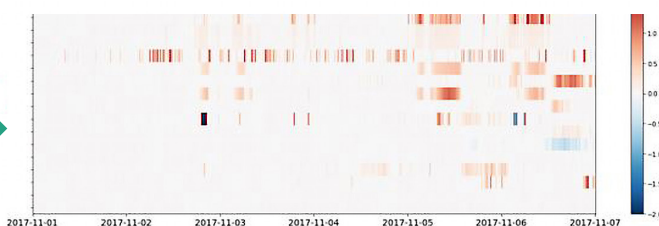
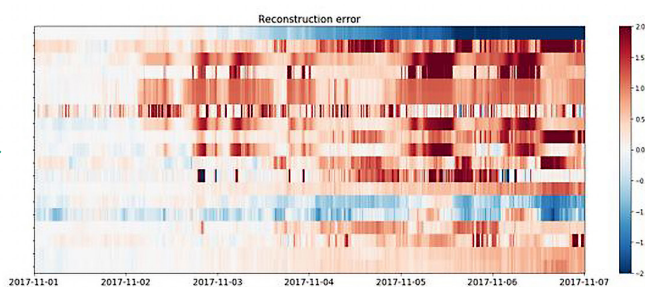
areas such as model robustness, transparency, and transferability. [Transfer learning](#), for example, enables already trained machine learning models to be applied to new, similar tasks. This approach proved particularly useful in addressing issues such as limited data availability for new or long-idle turbines, potentially reducing the computational costs for model training and reducing data storage and collection costs.

A groundbreaking result of the ADVENTURE project is the release of a benchmark dataset that includes examples of wind turbine faults and different forms of normal behavior.

This dataset is the most comprehensive and detailed public resource for comparing early fault detection systems for wind turbines and is available on Zenodo.org under the search term ‘Care2Compare.’

Conclusion

The software architecture developed in the ADVENTURE project provides a solid foundation for the operational and continuous automated monitoring of wind turbines. Its scalability and adaptability make it well-positioned for future commercialization.



Project overview

Status	Completed
Location	Kassel

Fraunhofer IEE

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Optimized Yield in Offshore Wind Farms

In the C²-Wakes project, Fraunhofer IWES, RWE, ForWind and Helmholtz-Zentrum Hereon are investigating reduction options of large-scale wake effects.

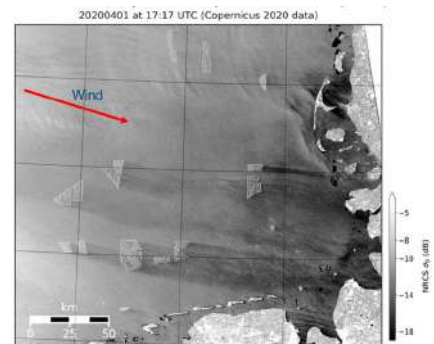


Scanning Lidar device on the nacelle of a wind turbine at RWE's offshore wind farm Amrumbank West. © Jörg Schneemann [2024]

Improved methods for optimized wind farm yields

In large wind farm clusters wakes with lower wind speeds and higher turbulence can develop downstream of the turbines. Improved modeling and measurement of the wakes allows optimized site selection and resource planning for future offshore wind farms. Thus, the project team is collecting data via a comprehensive scanning lidar measurement campaign in RWE's Amrumbank West offshore wind farm. The devices installed on the nacelles measure the flow fields downstream of the wind turbines. Using the acquired data, the scientists analyze how the wind speeds within the wind farm and large-scale wake effects behind the wind farm evolve and whether and how these can be influenced.

As the areas available for offshore wind farm development in the German Bight are limited, efficient utilization of this space is required to maximize the benefit of offshore wind. Therefore, offshore wind farms are often installed in groups known as clusters. In the Controlled Cluster Wakes research project, "C²-Wakes" for short, the Fraunhofer Institute for Wind Energy Systems IWES investigates together with its project partners RWE, ForWind (University of Oldenburg – Institute of Physics), and Helmholtz-Zentrum Hereon how the planning and operation of large offshore wind farms and wind farm clusters can be improved to increase the overall yield by the reduction of wake losses.



Radar image showing wakes behind offshore wind farms in the German Bight. © Copernicus Sentinel data [2020]

Project overview

Status	May 2023 – April 2026
Location	German Bight

Fraunhofer Institute for
Wind Energy Systems IWES

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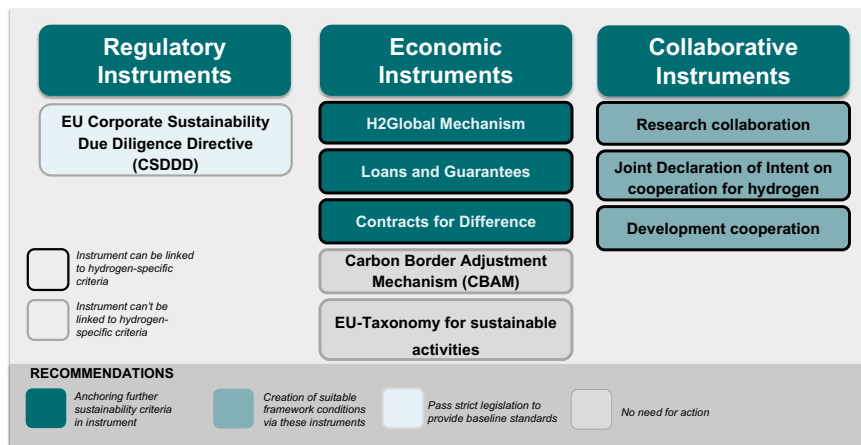


Conclusion

In addition to scientific publications, the results of the C²-Wakes project will also be made available to industry and planning authorities in the form of recommendations for action and open-source software tools such as the FOXES wind farm planning software.

Green Hydrogen Needs Sustainability Criteria

A short study by the Wuppertal Institute outlines sustainability goals, criteria, and possible political instruments for hydrogen imports.



Researchers examined how sustainability criteria could be implemented in the analyzed political instruments. Source: Wuppertal Institute.

Green hydrogen is considered a key element for a climate-neutral future. To achieve climate protection goals, Germany will rely heavily on importing green hydrogen. But how can environmental and social standards be maintained during production abroad? And what can policymakers do about it? The short study “Political Instruments to Ensure the Sustainability of Hydrogen Imports” by the Wuppertal Institute provides answers. Researchers examined which policy instruments are suitable for embedding various sustainability criteria for hydrogen imports, as outlined in the hydrogen import strategy released in July 2024.

However, the sustainability of imports cannot be guaranteed by a single policy instrument. Therefore, the short study, published in March 2024, recommends to establish a unified framework for sustainable hydrogen imports as soon as possible to ensure that market players adhere to sustainability criteria and avoid investment uncertainties. Sustainability goals for hydrogen imports must be translated into measurable criteria and verification processes. Although Germany’s Supply Chain Due Diligence Act and the EU’s supply chain directive provide important safeguards, they are not sufficient. International cooperation can play a key role in

developing sustainability criteria for hydrogen projects together with local partners. Economic instruments are suitable for embedding sustainability criteria early on and for using the German and European markets to set global standards.

Project overview

Status	Completed
Location	Wuppertal

Wuppertal Institute for Climate, Environment and Energy gGmbH

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Conclusion

A sustainable hydrogen economy can only be achieved through a coordinated interplay of different policy instruments. Early action and clear sustainability criteria are essential in order to achieve the climate targets and at the same time to ensure social and ecological standards.

