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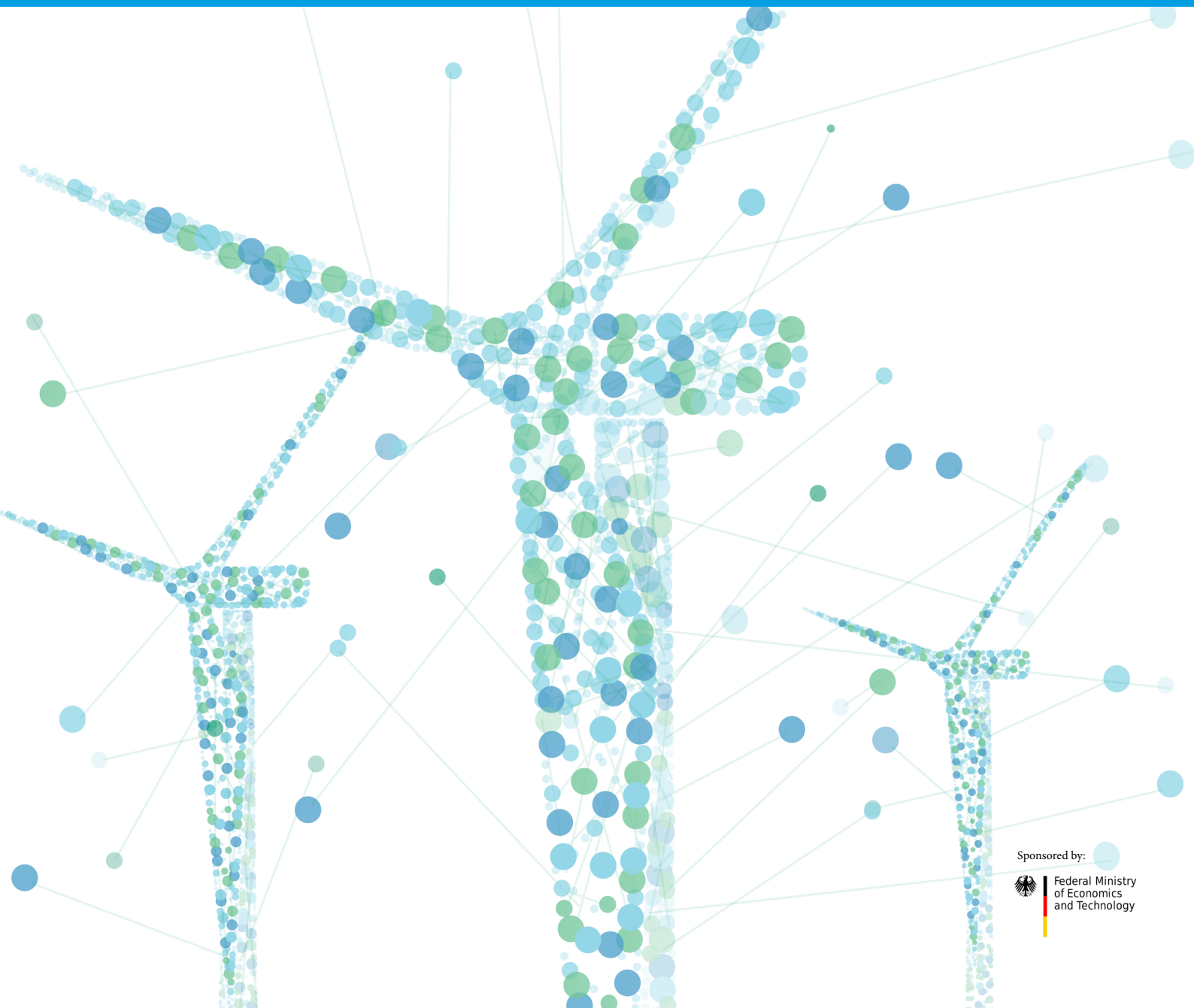
PREDICTIVE MAINTENANCE FOR WIND TURBINES ENERGY DATA SPACE WHITEPAPER



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Content

The data of the wind energy industry

Digitalization in the wind industry 4
Secure data exchange in business ecosystems 8
A model for new data spaces: Silicon Economy 8
Data sovereignty: International Data Space Initiative 10

Creating a data ecosystem for the wind energy industry

Predictive maintenance for wind turbines – a use case for International Data Spaces 14
Practical challenges 18
Vision of an ENERGY DATA SPACE for wind farms 22
Added value of an ENERGY DATA SPACE 26
Digital sovereignty 26
Federal data management 28
Simple data linking 30
Protection of Confidence 32
Secure data supply chain 34
Data Governance 36

Call for Action

Opportunities for participation and cooperation 38
Contact 40

The data of the wind energy industry

Digitalization in the wind industry

Volker Berkhout, Emanuel Skubowius

The generation of electricity from wind energy is the technology with the lowest electricity generation costs among the renewable energy sources. Worldwide, there is an installed wind power capacity of more than 600 GW. Annual additions around the world comprised 50 GW and above over the past five years. The trend shows that the importance of wind energy will continue to increase.

Wind turbines are technologically complex due to a number of technologies they include like the fluid-mechanical effect of the airflow on the rotor, the mechanical transmission of the torque via shafts and the gearbox to the generator, the electromagnetic generation of voltage and the adaption to the requirements of the power grid. During the design process, the intercorrelated systems are modeled in detail using digital components and material properties and load simulations are optimized.

Extensive sensor technology is installed on the wind turbines to control and monitor their operation. In offshore wind farms, several hundred sensors continuously provide data on temperatures, pressures, speeds, accelerations, forces, moments,

The data of the wind energy industry

Digitalization in the wind industry

voltages, environmental conditions and other physical data of the turbine. Large amounts of data are also generated during the planning, production, installation and maintenance of wind turbines. Dealing with “Big Data” or rather combining it to optimize operations requires the use of new methods for data processing and a corresponding data infrastructure.

Furthermore, the integration of wind power into the energy system is also data-intensive. Generation is dependent on wind conditions, which in turn are predicted from weather models that heavily rely on data and computers. Feed-in must consider both technical data at several voltage levels of the power grid and economic data from the electricity market.

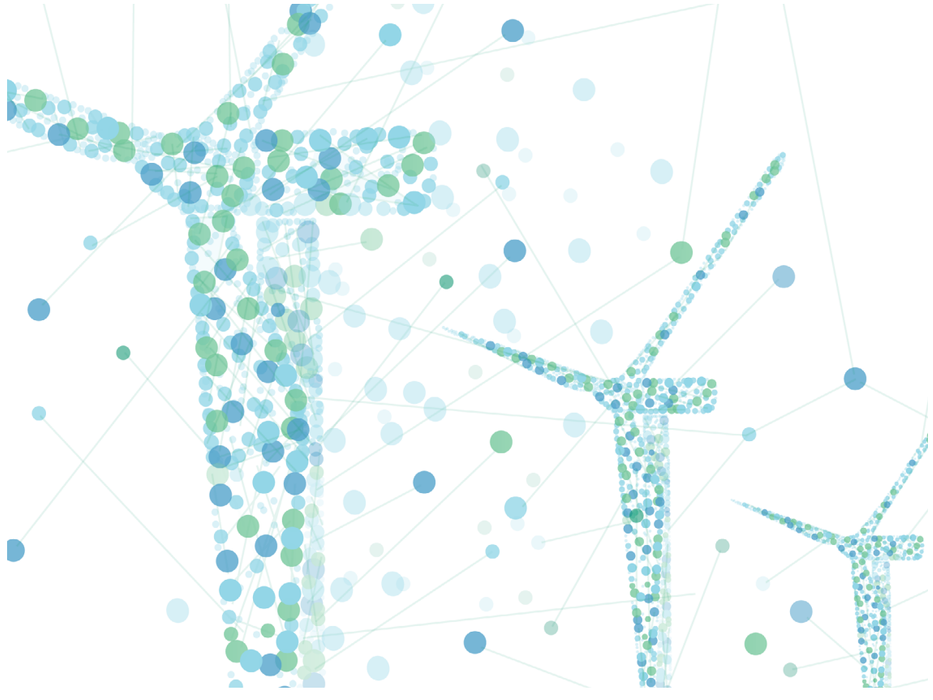
When operating the wind farm, it is important to avoid unplanned outages, since in addition to the costs of repair, the operators miss out in revenue as long as the turbines are at standstill. Predictive maintenance should therefore use the extensive data from the turbine and its environmental conditions to detect anomalies in operation and incipient failures. In this way, the risk of failure can be reduced and operations can be managed more efficiently.

Another advantage poses the possibly longer service life of the systems.

As part of digitalization, it should be possibe for digital applications to use all data generated in the future during the lifecycle. In addition to clear rules on rights of data usage, this also requires industry-wide agreements on the use of standards and data formats. Based on the definition of IEC 61400-25, further agreements are necessary so that new application developments do not have to be individually adapted to particular companies, but can be used industry-wide. Important advances in this regard are the “Recommended practices” of IEAwind Task 33[1] for handling maintenance data and the RDS-PP[2] and ZEUS[3] standards. In the IEAwind Task 43, further issues relating the digitalization of wind energy are being discussed and coordinated internationally.

The rule is: the more and higher quality the data, the more opportunities and the better results. Also, and especially in the wind industry, data is the commodity for more efficient processes and better-informed decisions.

The data of the wind energy industry
Digitalization in the wind industry



A model for new data spaces: Silicon Economy

Dealing with data is a success factor in almost all industries. Whether projects on digitalization, Industry 4.0 implementations or applications of artificial intelligence, they are all data-driven. The potential for optimization based on data analysis is enormous. A large number of new business models are already based on data. Anyone who wants to increase this potential must be able to link data sources and create suitable applications from them. The use of third-party data via a standardized data exchange provides a decisive resource of data. Algorithms, technologies using artificial intelligence or even platforms are already leveraging the initial potential resulting from the use and analysis of data. The ability to share data efficiently and confidently enables a further push of these developments. Standardized and secure data exchange for data value creation is the basis for new cooperation and collaborative data usage concepts. Virtual data rooms are being created to network the numerous market participants. The formation of such data ecosystems can be described, for instance, in terms of the so-called Silicon Economy, a guiding principle for the shift towards new types of cooperation in global, digital ecosystems. In this context, the

The data of the wind energy industry

Secure data exchange in business ecosystems

aim is to build business ecosystems that are more efficient, open and flexible in their use of data as compared to today's inflexible business relationships, without disregarding data ownership whilst ensuring sovereignty over data. The availability, transparency and access to data under data sovereignty are central prerequisites and driving forces of innovations and new data-based business models or services.

A digital infrastructure for autonomously acting and highly dynamic data value creation networks only prospers due to the involvement and use of data. The infrastructure enables the interconnection of data source and data user on digital data marketplaces. This virtual infrastructure includes brokers, automated negotiations or mechanisms for control and trust. The overall object is the formation of new digital business models that would not be possible without the exchange or trade of data sets. The wind industry also benefits from an open and digital domain-specific ecosystem. These correlations will be explained in more detail in the second section of this paper based on the vision and concept of the Silicon Economy.

The data of the wind energy industry

Secure data exchange in business ecosystems

Data sovereignty: International Data Space Initiative

Data sharing under data sovereignty is of great importance for democratized data ecosystems. It is central to preserve self-determination over the data of the individuals participating in the data exchange. Thus, data sovereignty is part of the German government's Digital Strategy 2025.

The International Data Space (IDS) initiative aims to establish virtual data spaces for cross-company collaboration and standardized data trading. The focus of this pre-commercial project is the development of a scalable and secure architecture for such a data room while using modern IT technologies. At the same time, maintaining sovereignty over data is a top priority. Since 2015, numerous projects have not only used the reference architecture as a core component, but also developed various software designs, e.g. different connectors.

In parallel, the International Data Space Association (IDSA e.V) pushes the transfer to, in the meantime, more than 100 companies and organizations. Further follow-up research projects together with the association have ever since specified the architecture, interfaces, but also sample code for an open, secure data ecosystem

The data of the wind energy industry

Secure data exchange in business ecosystems

with trustworthy partners. The IDSA's specification provides the foundation for data ecosystems and marketplaces that guarantee data privacy and security, equal opportunity through a federated design, and ensure data sovereignty for the creator of the data and trust between participants. Therefore, the association forms the strategic link between the creation of data in the Internet of Things on the one hand and the use of this data in machine learning (ML) and artificial intelligence (AI) algorithms on the other. The reference architecture model of IDS places the user at the center and is based on strong data ethics principles to ensure trustworthiness in ecosystems and sovereignty over data in the digital age as most important values.

IDS defines a reference architecture that supports the sovereign exchange and sharing of data between partners regardless of their size and financial strength. It thus meets the needs of both large as well as small and medium-sized enterprises (SMEs). Data can now be harnessed as an economic asset and be incorporated into innovative business models.

To minimize entry barriers, IDSA wants to lower the cost of sharing and exchanging data. As a result, the financial risk for

engaging with new data-driven business models is lowered and companies are more willing to invest in the data economy.

IDS enables partners of the ecosystem to define software-readable contracts associated with the data. These contracts are based on rules for usage tracking such as duration of usage, data sharing, etc. In addition, the purpose and cost of data use can be specified. IDS-certified software enables modeling, configuration, monitoring, and enforcement of the rules and policies specified in data contracts. For instance, sensitive data can be made available for calculations with the certainty that it cannot be read or used in any other way.

The data of the wind energy industry

Secure data exchange in business ecosystems

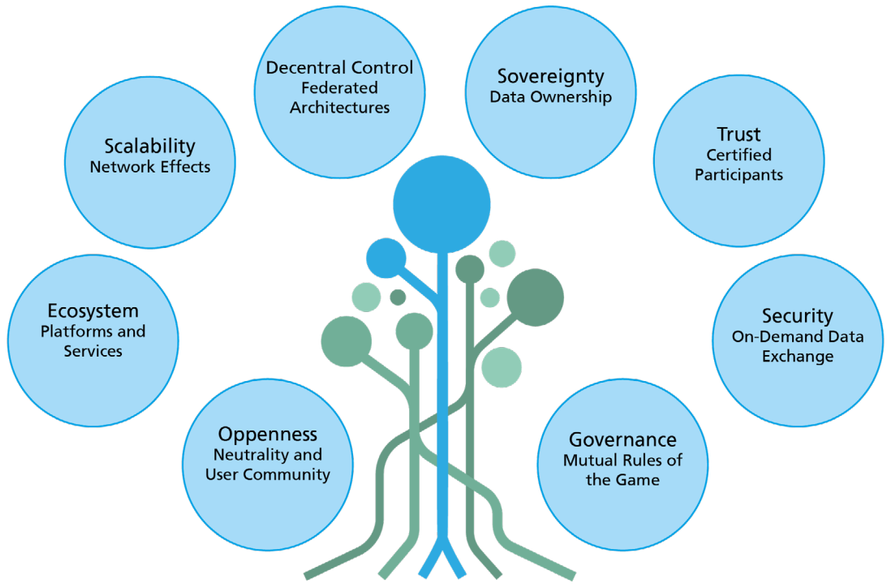


Figure 1: Strategic requirements of the International Data Spaces Initiative

Creating a data ecosystem for the wind energy industry
Predictive maintenance for wind turbines – a use case for International Data Spaces

The example of predictive maintenance procedures for wind turbines is a good illustration of the advantages of data exchange and the formation of data ecosystems. Predictive maintenance as a data-based service is particularly relevant for wind farm operators and their service providers. The object of this approach is to reduce unplanned downtime and optimize maintenance activities.

Starting point is an anomaly detection software that is trained to recognize the normal behavior in SCADA and CMS data of a wind turbine using techniques of machine learning based on a learning data set. Situations with large deviations from normal behavior can then be identified as potential fault patterns. The trained AI is able to evaluate the data of a wind turbine and to infer the fault-causing component through correction calculations. The more and better-quality data there is to be considered, the better results the AI delivers.

Particularly on the part of the wind farm operators, there is great interest in early fault detection, as this can shorten maintenance periods, minimize failure, and increase technical availability. Furthermore, the evaluation of this data is also interesting for the manufacturer of wind turbines as they may promote product development and design the turbines more efficiently and more resistant to faults. The same applies to component suppliers. In addition,

Creating a data ecosystem for the wind energy industry
Predictive maintenance for wind turbines – a use case for International Data Spaces

there are other interest groups that can benefit from access to such data, for example appraisers. Another potential is that anomaly detection data and results are assessed by experts for specific components or types of equipment. Enriched by their expert knowledge, the identification of the fault or the prediction of possible damage is complemented. In the context of a data economy, new business relationships between stakeholders can thus emerge and new business models by developed along the usual business processes around operation and maintenance. The various functionalities in the business process are performed by different participants in the data ecosystem.

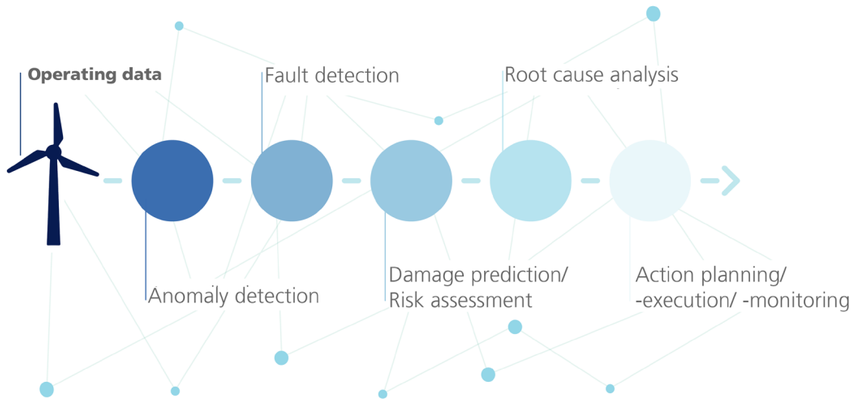


Figure 2: Data value chain for predictive maintenance in the wind energy industry

Creating a data ecosystem for the wind energy industry
Predictive maintenance for wind turbines – a use case for International Data Spaces

When analyzing possible input data, different data sources need to be taken into consideration. Apart from the operating data of the wind turbines, additional sensor technology often provides relevant information. External data, such as weather data, must be taken into account, as must the results of the functionalities themselves. For example, wind turbine manufacturer could use simulation models to predict conditions of turbine and components or service life based on detected anomalies.
It would be interesting if such a service could be retrieved in an automated and anonymized way and if it could be integrated into entire data value chains.

Creating a data ecosystem for the wind energy industry
Practical challenges

Everyone wants to use data, but who owns the data?

Wind turbine manufacturers or manufacturers of individual components have a great interest in the operating data of its turbines. The permanent recording of the operational states enables to ensure the availability and operational safety of both the individual components and the entire machine. But also operators or project planners of the wind turbines use the acquisition of production data for a more efficient operation. The quite simple and at the same time typical configuration of an industrial business relationship raises some questions:

- Who owns the data?
- What is the value of the data?
- How can data be monetized?
- Who is responsible for the quality of the data and which standards and exchange formats are applied?
- Who may access the data and for what purpose?

Certainly, these questions can be clarified with high manual effort. For this purpose, bilateral contracts are drafted to handle the data. As long as the value chain is known and manageable and the advantage is clearly defined, this is the common approach.

The more data the better

The more data is shared, the more data sources there are, the more actors are involved, or the more dynamic business relationships are, the less economical it

Creating a data ecosystem for the wind energy industry
Practical challenges

is to handle data in this way. Big data will not be available through bilateral contracts. However, scaling is relevant for modern data-based services. Especially AI-based software solutions become better or more accurate with a larger amount of high-quality data.

Challenges: Insecurities, dependencies, power and influence

The objective is to leverage the enormous potential of data. Collaborative approaches are promising, but often avoided by companies. There are many reasons for this, for example one's own advantage in the collaboration may not be certain or the potential benefit does not compare to the effort. Although data sharing can generate new and advantageous business models, it often results in unused data volumes instead. Data is generated, but hardly used. If neither data ownership nor data value are clear, or one fears dependencies and loss of influence, sharing does not occur.

Approach: Creation of an Energy Data Space based on the International Data Spaces initiative

Resolving the conflicts of collaborative use and the associated questions concerning data sovereignty of industrial data is what drives International Data Spaces. It enables scalable contracts and provides the appropriate technical architecture and software components to reduce implementation effort and thus investment risk.

Creating a data ecosystem for the wind energy industry
Practical challenges

Why the wind energy industry? Why now?

Wind turbines are similar worldwide in their design and function. This homogeneity in the technical side makes it a promising application area for standardization. This is especially true at the data level. This aspect is essential for a shared data space because the greatest potential lies in scaling data-based services. At the same time, there is little willingness to standardize, especially on the part of manufacturers. They see in utilizing e.g. operational data their own business model and therefore enforce monopolistic structures. The full potential of data is only unlocked by combining different data sources and services based on them. To resolve the conflicts around data usage and for establishing collaboration in data ecosystems in the wind industry, secure, i.e trustworthy, infrastructures and independence are needed. In IDS, the participants themselves define the rules regarding authentication, access control and usage control. In particular, it enables the description, negotiation, and enforcement of usage policies by attaching them to data assets as metadata. In doing so, IDS creates a networked and provider-neutral data infrastructure. Each company decides for itself where its data is stored and by whom and for what purpose it may be processed. Therefore, the terms of use and obligation on the handling of the data desired by the Data Owner must be taken into consideration by the

Creating a data ecosystem for the wind energy industry
Practical challenges

Data Consumer. B2B data marketplaces and the ability to monetize the data through data value creation, are also provided. Brokers required for this purpose or the tracking via distributed ledger technologies facilitate or secure data exchange and create incentives for even more data exchange. Such a basic infrastructure is the catalyst for data-based services not yet known.

Creating a data ecosystem for the wind energy industry
Vision of an ENERGY DATA SPACE for wind farms

Modern software applications are data intensive. The basic willingness to exchange data is growing, especially if the use of the data for a specific purpose can be enforced. The motivation encompasses new business models involving data-based services. In many scenarios, there is no alternative to this trend because new requirements and competition are pushing it. In the future, the requirements for coordination with grid, storage and flexibility systems in the power grid will also increase. Automated data exchange will therefore become mandatory.

In the course of this, it is all the more important as a competitor to define the own role in dealing with data, and in a data ecosystem. The company's own strategic orientation is very closely linked to existing and new data-based business models. The need for data exchange and requirements regarding data sovereignty arise from the company's own use cases, as do the necessary business partners in a data ecosystem. The vision of an Energy Data Space is one of a purpose-built, domain-specific and prosperous data ecosystem.

Following the overall picture of a Silicon Economy, it combines the data level of operational and turbine data with digital platforms and cloud technologies. Everything is networked and interoperable. Different participants, services, and data assets are found and dynamically used via brokers. The actual infrastructure for data exchange under

Creating a data ecosystem for the wind energy industry
Vision of an ENERGY DATA SPACE for wind farms

data sovereignty is the networking through IDS connectors in the middle of the big picture. IDS connectors are the connection points for communication between wind turbines, wind farms but also all other services, cloud services, platforms and actors. All applications for data processing and especially for enforcing data sovereignty can be implemented in them.

SILICON ECONOMY
Wind Energy Data Space

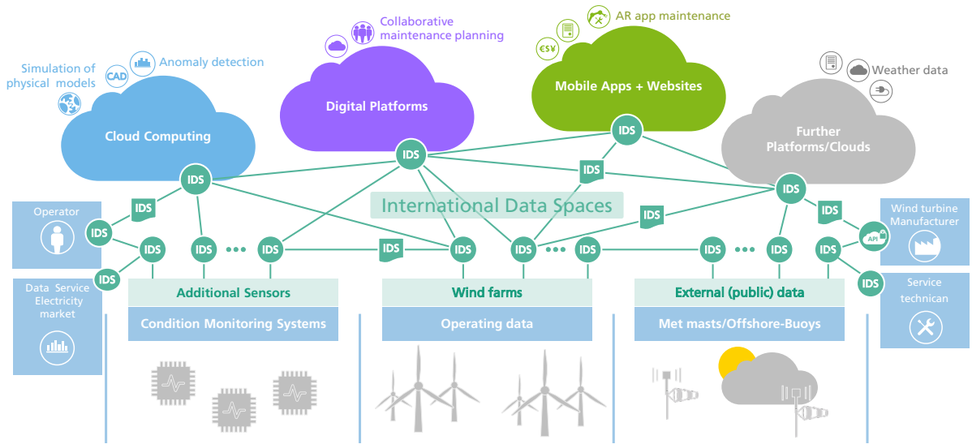


Figure 3: An energy data space for the wind energy industry based on the Silicon model Economy

Creating a data ecosystem for the wind energy industry
Vision of an ENERGY DATA SPACE for wind farms

For such an Energy Data Space it is not necessary to start from scratch. The domain-specific implementation is significantly supported by the use of the IDS reference architecture and the IDS software components. The premise here is to link the various stakeholders of the wind energy domain via a secure data space with data sources and cloud services, while ensuring data sovereignty and security.

A trustworthy infrastructure for the secure exchange of data between distributed actors is the basis for innovative data-driven business models in the operation and maintenance of wind turbines. The use of data can be controlled through the architecture and the proposed tools, such as certification, in a way that is transparent, compliant with data protection and in the interest of all stakeholders. Based on this, modern algorithms can further use the data for new services.

Creating a data ecosystem for the wind energy industry
Added value of an ENERGY DATA SPACE

Digital sovereignty

Initial situation/ challenge

„Digital sovereignty is the ability of a natural or legal person to exercise exclusive self-determination with respect to the asset of data.“ [1]

Ownership and usage rights for wind turbine data are negotiated and contractually agreed upon between the manufacturer and operator as part of the procurement process. The contracts rarely define individual data assets, but are generalized, i.e. concerning many data sets and static. The terms of use for data assets are negotiated individually. Confidentiality and data security are important motives for most operators. The effort required to negotiate additional data uses is high. What is more, operators are sometimes uncertain about which uses are permitted under the agreements with the manufacturer.

Approach

The International Data Spaces initiative defines the preservation of digital sovereignty as a central core requirement for a data space. In this context, the owner of the data should be able to maintain sovereignty over his data despite data exchange and data trading. The data owner himself determines the terms of use for his data and „attaches“ them to the data assets as metadata. An Energy Data Space based on the architecture of the IDS enables specific use of the data, hence enabling new data-based business models. Among others, the following groundwork can be used:

- A standardized „vocabulary“ for describing data usage policies.
- The International Data Spaces Association‘s legal task force to clarify legal issues.
- Automated contract negotiations concerning data usage.
- Control mechanisms such as a digital certificate confirming participants and technical certification.
- Identity provider.

Creating a data ecosystem for the wind energy industry
Added value of an ENERGY DATA SPACE

Creating a data ecosystem for the wind energy industry
Added value of an ENERGY DATA SPACE

Creating a data ecosystem for the wind energy industry
Added value of an ENERGY DATA SPACE

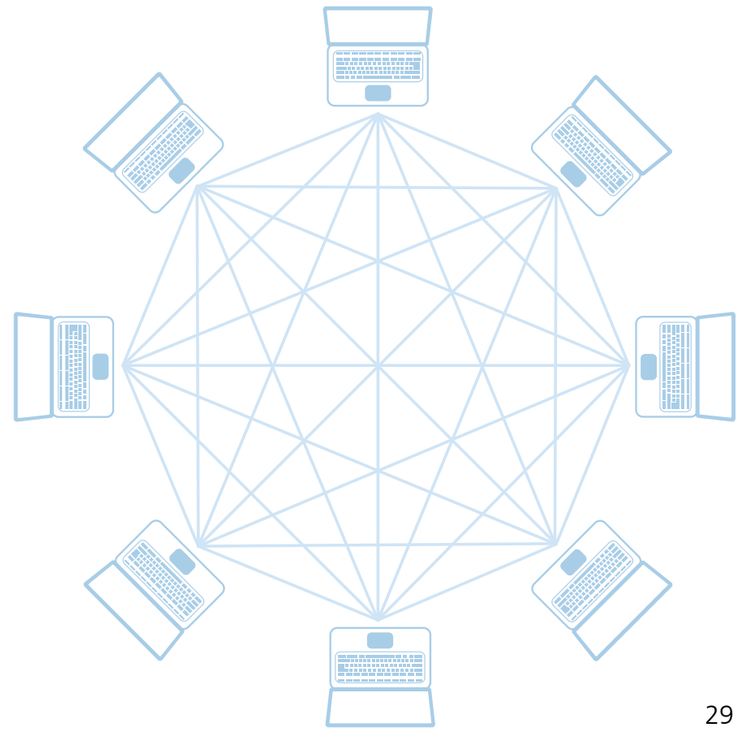
Federal data management

Initial situation/ challenge

The data is usually held by the data owner. In some cases, data is held in IT systems of service providers for operational management systems, condition management systems or in ERP systems. This data is available in a decentralized manner, but usually neither standardized nor accessible. The use of cross-company data usually means a high setup effort and is therefore a barrier and cost factor for new data-based services. Digital platforms offer data-based services at lower cost, but they often use and store customer data centrally. Digital sovereignty is rarely maintained here.

Approach

The reference architecture of the International Data Space enables decentralized data storage. IDS standardizes the metadata and the data exchange protocol in terms of security and data sovereignty. As a result, IDS encourages and supports the building of domain-specific vocabularies and metadata vocabularies to provide context between data. This already reduces significant effort. IDS did not solve the major obstacle of standardization of potentially usable data (semantic integration). However, decentralization is the basic principle of IDS. This enables connectors to be used for event-driven updates of data into the ERP, for example. In the bilateral exchange of data, the use of IDS developments initially increases the effort. However, in the creation of data ecosystems, the initial effort is paid back. IDS standard components then reduce costs, for example, in trust building, connectivity or certification.



Creating a data ecosystem for the wind energy industry
Added value of an ENERGY DATA SPACE

Creating a data ecosystem for the wind energy industry
Added value of an ENERGY DATA SPACE

Simple data linking

Initial situation/ challenge

Operational data is collected and used throughout the industry in accordance with IEC standard 61400-25. Standards for additional measurement data from operation, for component identification or maintenance information are available (RDS-PP, ZEUS) but are still in an early stage of implementation. Still, much important information is available in free texts. Ontologies for the wind energy sector, which are intended to make relationships between terms usable in an automated way, have been described in initial research projects.

In the wind energy industry, much important information from operations and maintenance is not yet accessible for automatic processing. Therefore, data linking currently still requires considerable manual effort. Data assets that are described in a standardized way for specific applications do not yet exist. Furthermore, each additional use requires a new linkage to the corresponding data sources. Data flows are therefore implemented individually.

Approach

For easy data linking, it is crucial that the data is described in vocabularies. Methods of computational linguistics, AI, image recognition, information extraction from unstructured texts or filtering of documents can be used here to make information usable for the computer. This can also be done automatically. For example, IDS connectors can be used to implement the methods mentioned and to filter out information from free text. The information model of the IDS also enables a metadata description. Through the described data assets, IDS facilitates the linking of data sources. Linked data concepts and common vocabularies provide preparatory work for the integration of data between participants. In this context, a technical vocabulary is the basis for data exchange.

To take advantage of these opportunities, measures for managing a company's data are usually required to prepare data sets and processes for future uses.

Creating a data ecosystem for the wind energy industry
Added value of an ENERGY DATA SPACE

Protection of Confidence

Initial situation/ challenge

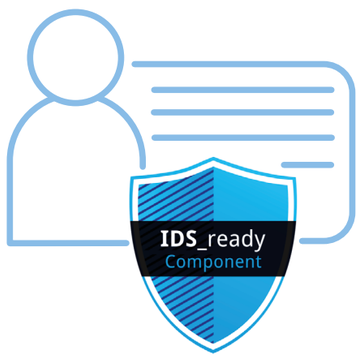
The use of certifications or procedures for the secure identification of partners for data exchange are negotiated individually by the legal and IT departments of the respective companies. In the case of large companies, central decision rules may be in place. Individually agreed rules must be translated into corresponding program code for data flows and applications. This entails additional development and cost effort and leads to the issue of trust building in particular being identified as a major obstacle for data sharing and exchange. Legal coordination to reach consensus is possible, but often takes a very long time and leads to slower implementation times for data-based service ideas, resulting in some of them being no longer economical.

Approach

The topic of trust protection is another strategic requirement for which IDS offers solutions. The initiative provides for certification authorities that certify both subscribers and software, and issue digital certificates for this purpose. The International Data Spaces Association regularly coordinates the assessment procedures and process with potential certifiers. Identity providers are already provided for authentication and identification in data exchange.

Creating a data ecosystem for the wind energy industry
Added value of an ENERGY DATA SPACE

As a working group within the association there is also a legal task force that deals with legal issues and e.g. develops and provides standard clauses for data use agreements. At the moment, a primary field of research is automated negotiations of IDS contracts in order to reduce the coordination and negotiation effort involved in the actual use of data. Therefore, it is probable that in the future not all data usage conditions of a data exchange will have to be negotiated individually and manually. The standardized rules for describing data usage conditions, data exchange and usage control in IDS simplify legal reconciliations, especially if they are agreed and accepted industry-wide.



Creating a data ecosystem for the wind energy industry
Added value of an ENERGY DATA SPACE

Secure data supply chain

Initial situation/ challenge

At the moment, measures for security only concern the identification of the remote station and the transmission of data in terms of encryption. Data owners currently have no way of checking whether their data is actually being used by the respective partner only for the agreed purposes. Unilateral withdrawal of data is not possible. Business models based on renting out the data are therefore insecure. Particularly sensitive data, for example on the design of components, could be used very beneficially for wind turbine and load monitoring. However, this data is only provided by manufacturers or suppliers in exceptional cases.

Accordingly, a high level of trust is required. A truly secure supply chain therefore requires not only identification, authentication, end-to-end encryption, but also the enforcement of defined conditions for data usage.

Approach

The approach of International Data Spaces addresses both access control and usage control. All current security mechanisms such as PKI or TLS encryption can be implemented. When using IDS connectors already developed and provided as open source software, these security technologies are already included. In addition, IDS offers a decentralized identity management.

Creating a data ecosystem for the wind energy industry
Added value of an ENERGY DATA SPACE

Various federated identity providers can already be used. The exchange of data along the entire data value chain thus achieves the highest level of security. To enforce usage control, various technologies (MYDATA, LUCON, IND²UCE, Degree) are proposed in the IDS and have already been implemented in various connectors.

Creating a data ecosystem for the wind energy industry
Added value of an ENERGY DATA SPACE

Creating a data ecosystem for the wind energy industry
Added value of an ENERGY DATA SPACE

Data Governance

Initial situation/ challenge

With growing data processing, data governance plays an increasingly important role in maintaining control and transparency over one's data. It defines rules and processes for handling data. The transfer of an internal data governance strategy and its principles can inhibit data sharing. For example, the wind turbine purchase contracts include rules on the use of data. Many operators cite these data use rights as a barrier to sharing with other digital services. Rules for data sharing are negotiated individually in each case. In this context, the ownership of data involved is often unclear or it is contractually regulated in such a way that the sharing of information is not possible. In particular, manufacturers see opportunities for adding value to their existing service business in the analysis of operational data. At the same time, a restrictive handling of data for third parties ensures the consolidation of their own competitive position in the O&M business. As a result, data sharing is inhibited.

Approach

Sharing data holds great potential, especially in the wind energy industry, and enables new data-based services and optimizations to be developed. In IDS, data provenance (data origin and traceability) simplifies the implementation of data governance principles. For example, a clearing house provides a blockchain-based solution to generate returns from data usage. If, for example, the wind farm operator offers its operating data, it is possible to realize a share in the revenue from the use of the data by means of a data usage condition. Claiming one's share of the data value creation is supported legally and technically.

Call for action

Opportunities for participation and cooperation

The initiative International Data Spaces offers a reference architecture and open source software components for decentralized data exchange with the premise of data sovereignty. The demonstrated anomaly detection on wind turbine operational data is just one example of a multitude of possibilities for new data-based services in the wind energy industry.

Currently, Fraunhofer IEE is pushing projects for digitalization in the wind energy industry with the help of the IDS architecture. Through existing research programs, there are various opportunities for companies to work on jointly defined use cases in research and development projects.

Now is the right time for an industry-specific discussion of common challenges and to validate IDS's approach. Fraunhofer IEE is your contact regarding the ecosystem of wind energy in the Energy Data Space and coordinates the implementation of further use cases, also in the adjoining areas of power grids and sector coupling.

The IDS reference architecture and the software components are constantly being further developed in numerous projects, also on an international level. For instance, a European-funded consortium is pursuing data exchange for offshore wind turbines using IDS connectors[5].

The non-profit International Data Spaces Association brings together companies, research institutions, associations and initiatives in several working groups.

Call for action

Opportunities for participation and cooperation

In this context arises the opportunity to actively help shape the International Data Spaces and learn from other industry communities. Networking is beneficial, but does not succeed on its own. Market participants are therefore called upon to define their role in data ecosystems and participate in shaping them.

Call for action

Contact IDS

The International Data Spaces Associaton e.V. is a non-profit user association with more than 100 members from industry, research, associations and initiatives. It organizes the exchange of experience between science and industry and creates opportunities for all interested parties to participate.

International Data Spaces e. V.
Fraunhofer Forum
Anna-Louisa-Karsch-Straße 2
10178 Berlin, Germany

Email:
info@internationaldataspaces.org

Website:
www.internationaldataspaces.org

INTERNATIONAL DATA SPACES ASSOCIATION

Call for action

Contact wind energy sector

Authors

Emanuel Skubowius
Fraunhofer Institute for Material Flow and Logistics, IML
Phone number .: +49 231 9743-632
Email: emanuel.skubowius@iml.fraunhofer.de

Volker Berkhout
Fraunhofer Institute for Energy Economics and
Energy System Technology, IEE
Phone number .: +49 561 7294-477
Email: volker.berkhout@iee.fraunhofer.de

Call for action

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Call for action

Projectinformation

Project number: 0324128
Project partner: ABO Wind AG, Bachmann electronic GmbH, Fördergesellschaft Windenergie und andere Erneuerbare Energien (FGW) e.V., Fraunhofer IML, Global Tech I Offshore Wind GmbH, Industrial Data Space e.V., Steag Energy Services GmbH, Trianel Windkraftwerk Borkum GmbH & Co. KG

Whitepaper as part of the ModernWindABS project,

Modern methods for new applications in the operation and service of wind energy systems in the information flow of Industry 4.0

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Project management: Fraunhofer IEE, Volker Berkhout