Applications and platforms in digitalisation of wind farm O&M – community feedback and survey results

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Abstract. Achieving performance optimisation and cost savings by advanced data analysis techniques and improved digital communication is a significant focus of wind farm operators and research organisations often framed under the terms IoT or Industry 4.0. Within the research project ‘ModernWindABS’, Fraunhofer IEE has conducted a twofold approach to identify new applications using modern methods that will innovate operation and maintenance processes. Based on a systematic structure of O&M processes and mathematic methods, innovative applications were identified and evaluated in expert workshops. Separately a survey among wind industry professionals with the focus on innovative applications through digital platforms has been conducted in partnership with German industry associations. From both approaches, applications, that enable failure risk monitoring, turn out as the highest priorities from the professionals consulted. Additionally, the survey results yield insights on participants’ expectations on benefits and financial contribution per organisational role and preferences regarding the platform setup and points out gaps between these expectations and current platform service designs. It further identifies the main barriers to the broader use of platforms, of which organisational and legal obstacles seem to outweigh technical problems.

1. Motivation

In the age of digitalization, operation and maintenance (O&M) services will benefit from innovative applications that are being developed and are evolving throughout the industry at a rapid pace. These applications make use of the data, that is provided by the wind farm’s supervisory control and data acquisition (SCADA), condition monitoring (CMS) and structural health monitoring (SHM) systems itself and applies software algorithms from an ever-increasing toolbox powered by the dynamic development of machine learning and computing capacities to provide insights that were not available to this point. Turbine and farm data may also be enriched with additional data sources, such as environmental or market data.

At the same time, software applications are increasingly being distributed through digital platforms. While this is obvious for the consumer sector with platforms such as Play Store or App Store in place, this development is also beginning to reshape the business-to-business software market and, thus, correspondingly the wind energy industry. Totaro [1] provided an initial overview of a digital services app store for the wind industry, combining the type of application and digital platform providers. Additionally research on future needs for data management has been built up. The FAIR-principle has been proposed to ensure that data especially in the scientific sector is findable, accessible, interoperable and reusable [2]. As further building blocks for digital platforms the European Energy Research Alliance Joint Programme Wind Energy has proposed taxonomies for metadata [3] to support machine-
readability of data sets and thus optimizing process workflows. Furthermore, ontologies for the wind sector have been suggested [4]. Currently, a new IEAwind Task 43 is being set up for international collaboration on the digitalization of wind energy [5].

The Fraunhofer IEE picked up on these developments within the research project ModernWindABS and took a twofold approach: On the one hand, we developed and sketched out ideas for possible near-future applications based on a structured approach to O&M processes and on the other hand we surveyed German industry experts on their take and expectations on the potential applications and benefits from digital platforms in the wind energy sector.

2. Development of ideas for innovative applications in wind energy O&M

2.1. The OECD has defined innovation as ‘the implementation of a new or significantly improved product (good or service), or process, […] in business practices […]’” [6]. The relevance of the implementation or commercialisation of new products or processes has also been underlined by Edison et al. [7]. Innovations based on information and communication technology in industrial processes are often summarized with the term ‘Industry 4.0’. However, there is no clear scientific consensus of a definition of the term Industry 4.0 but it is well characterised by Hermann [8] with the design principles technical assistance, interconnections, information transparency and decentralized decisions. We therefore approached innovative applications as the combination of the implementation of a modern method of information technologies to an existing process that is required for the current operation and maintenance of wind farms. The objective of the approach was to develop ideas for applications that improve the current operation and maintenance processes of wind farms. A process model was developed and combined with a structure of modern methods to achieve this objective.

2.2. Process structure. The process model aimed at identifying main and sub-processes in operation and maintenance of wind farms. Therefore, different information from the maintenance standard DIN 31051 [9], the RDS-PP [10] component structure and processes of service providers were used. The model, as shown in figure 1, contains two main processes – operation and maintenance. The next level of the operational process was determined according to the processes of several service providers. The sub-level of the operation process was divided into business management and technical management. The maintenance process was segmented into inspection, service, repair and improvement according to DIN 31051. As these processes are highly specific for the different sub-systems and components of a wind turbine we suggest to use the reference designation system for wind power plant (RDS-PP) for the further breakdown of maintenance processes with a functional system hierarchy complimentary to the process tree structure.
2.3. Method structure. We considered the general classification systems on mathematical and information technology areas, specifically the Mathematical Subject Classification (MSC) [11] provided by Zentralblatt Mathematik and the American Mathematical Society in the 2010 version and the Computing Classification Scheme (CCS) by the Association for Computing Machinery [12].

We preferred the MSC over the CCS as the focus and detail on the methods for data processing are more granular. At the same time, the CCS also covers several technological aspects of computing. The MSC span across three hierarchical levels with a total number of 6198 single entries categorized into 63 top-level domains. Top-level categories for applied mathematics were chosen from these, which are summarized in figure 2 as probability and statistical analysis, physical modelling and other, which is basically operations research and mathematical programming. The sub methods of probability and statistical analysis are segmented into probability theory and stochastic processes, statistics, numerical analysis and computer science. The mechanics of particles and systems, mechanics of deformable solids and fluid mechanics were matched with the main method of physical modelling.

Figure 1: Structure of O&M processes using standards DIN 31051 [9] and the reference designation system for wind power plants (RDS-PP) [10]
2.4. **Process-Method-Workshops.** The process and method structure were combined in a matrix shown in figure 3. The sub-processes represent the rows and the method sub-categories represent the columns of the matrix. Each cell of the matrix would depict a different method-process combination as a possibility for innovative applications. In-house workshops were held to identify ideas for applications for the various cells of the matrix structure for each method category. Ideas were created in two to three small teams of two experts. A process expert and a method expert explored ideas on what kind of process and the corresponding challenges might be supported by which methodological approach. The method categories ‘mechanics of particles’ and ‘mechanics of deformable solids’ were merged in one workshop to accommodate scheduling and personal resource issues.

Altogether, seven workshops took place. Within the workshops, brainstorming sessions were performed with at least two process- and two method-experts. The aim of the brainstorming sessions was to develop and document ideas for applications of modern methods in wind farm O&M. The results of the seven workshops were collected and evaluated. In total, 83 ideas have been developed. Figure 3 shows the breakdown into the process-method combination. The series of workshops created ideas for application in every method group. For each main process there are ideas for innovation. However, the number of ideas is exceptionally high for the technical management, which comprises the remote monitoring of wind farm operation, includes highly data-intensive processes and is therefore well suited for the modern data processing approaches. Most ideas were created in the combination of this process with approaches from computer sciences, in most cases of artificial intelligence methods.

![Figure 2: Structure of modern methods for application in wind O&M based on MSC2010 categories [11](image)](image)
2.5. External Workshop. The total of 83 ideas was clustered into 20 topics and publicly presented at an industry workshop in November 2019 at the Fraunhofer IEE in Kassel. A number of 30 participants from the wind industry and research organizations discussed the ideas. Based on a questionnaire all topics where rated and prioritized during the workshop. Participants were asked to choose and rank the five most relevant issues from their perspective. We applied a simple linear scoring mechanism for the evaluation weighing the top priority with five and the fifth priority with one. The results of the survey were evaluated and are shown in Figure 4.

Anomaly detection for early failure prediction and technical degradation modelling based on lifetime indicators turn out to be both of outstanding interest to participants from industry and research. After these top runners, there is also a high interest in digital assistance functions for reporting of service activities, the optimization of maintenance operations with methods from operations research and the use of mechanical models from digital twins, which would support load and fatigue calculations of turbines in operation. This ranking provides an insight into the priority of topics of professionals in the O&M sector of the wind industry. It does not give information on the size of potential economic benefits.

![Figure 3: Process-method-matrix for in-house workshops with numbers of ideas developed](image-url)
3. **Survey on digital platforms in wind energy**

In a parallel effort, we conducted an online survey on potential applications and benefits from digital platforms in the wind energy sector. The invitations to participate in the survey were distributed through the leading German industry associations ‘Fördergesellschaft Windenergie und andere Dezentrale Energien e.V. (FGW)’, the advisory board on wind farm operations of the German Wind Energy Association (BWE) and to wind industry contacts of Fraunhofer IEE. A total of 380 wind professionals were invited to take part in the survey.

The survey was online from August 21st to October 15th, 2018. A total of 39 participants filled out the survey entirely, which is a response rate of 10%. For six questionnaires that were left incomplete, the information from the sub-questions was included in the evaluation. Operators and plant managers...
form the largest block with 15 respondents. Furthermore, several answers come from research institutions and turbine manufacturers and component suppliers. The full breakdown of responses by roles can be seen in figure 5. Two-thirds of the respondents rated themselves as experts in the wind industry, just under a further third as experienced and only one participant classified himself as a beginner, underlining that the answers are based on substantial experience in the industry.

The majority of those surveyed belonged to the technical sector or the research and development department, followed by the IT and software sector of the companies. Furthermore, a significant part of the respondents said they belonged to middle management; another part belonged to executive management or corporate management. The results describe the assessments of the participants and show their interests and focal points. The number and characteristics of responses do not allow for representative conclusions for the wind industry. Therefore the results are provided as descriptive statistics.

The survey focused on the assessment of selected functionalities, the connection of resources and systems, the use of existing standards and other framework conditions for the use of digital platforms and their financing. Figure 6 provides an overview of the survey’s findings. The details are outlined in the subsections below.

![Figure 6: Summary of survey results on digital platforms in operation and management of wind farms](image)

3.1. Application and integration of functionalities and systems. The survey provided a list of 24 selected features that are listed in [13] and were to be rated in terms of estimated added value and status of internal application. These two results were combined into a mid-term potential where added value is perceived, but no plans to put these functionalities into practices existed. Similar to the findings from the industry expert workshop, the highest mid-term potential is expected in the monitoring of failure risks and, more specifically, in the determination of the remaining useful life at the component level. Next are service support systems, which include requirements planning and logistics for spare parts and remote support for service technicians. Within forecasting, icing and curtailment forecasts show the highest mid-term potential. Performance monitoring at component level is the leading position in the yield optimization block.

When developing digital platforms in organisations, the focus is clearly on providing access to information to its employees. Around 40% of those surveyed stated that their own employees are already connected and using a platform as resource. Looking to the future, the most significant medium-term potential concerns the integration of employees from external service providers to provide information
and to optimize data flows into a platform or into the companies itself. In terms of resources, potential was also often seen in the connection of spare parts. Information about raw materials and supplies on a platform also represents a recognizable added value for the survey participants. Regarding the aspects of IT-systems, linking the condition and structural health monitoring systems to a digital platform has turned out as the most significant mid-term potential. There is also the expectation that added value can be created by integrating information from document management systems (DMS) and enterprise resource planning (ERP).

The availability and the use of standards is the enabler for interconnection in the industry 4.0 [8] and a critical factor in the benefits and success of digital platforms. The choice of standards was derived from the IEAwind recommended practices on wind farm data and reliability assessment [14] and were complimented with additional potentially relevant standards. The participants unanimously agreed on the added value of using standards. While the IEC standards 61400-25 and -26 have the highest relevance in the field, more maintenance-oriented data standards, such as the global service protocol, the ZEUS state-cause-event-key based on the Technical Guideline TR7 ‘Operation and Maintenance of Power Plants for Renewable Energies’ by the FGW [15] or a standard on lifecycle documentation [16], were rated beneficial, but are commonly yet to be put into practice.

Further details and figures on findings on applications, systems and standards have been documented in a summary of survey results [13].

3.2. Benefits and financing of digital platform usage. When asked to assess whether the use of digital platforms would yield benefits or losses to specific roles, a majority of participants stated for each role that they would expect the particular group to benefit. The results are shown in figure 7. Nine in ten participants expect operators and maintenance service providers to benefit. The consensus gradually declines but remains at 50% even for authorities, which are least perceived as benefitting from platform use. Losses are being mentioned only sporadically. About 10% of the participants expect adverse effects on manufacturers and software providers.

![Figure 7: Assessment of the impact of the use of digital platforms for roles in the wind industry](image-url)
The development and operation of digital platforms need funding. The survey participants were also asked who should bear these development and operational expenditures. The answer options included development cost only, operating costs only, development and operating cost, neither and the option unable to assess.

The answers, as shown in figure 8, demonstrate that the majority of the participants wanted all players to participate in the financing of a digital platform and that this should relate to both development and operational cost. When looking at individual roles, authorities, research institutions and industry associations are increasingly mentioned in the area of development financing. Furthermore, authorities and research institutions are the roles that are most frequently mentioned not to be involved in the funding at all, with a third of respondents choosing this option. The main share of financing operations is expected from operators, maintenance service providers and direct marketers.

When combining the results from the question on the benefit from digital platforms for specific roles with the item on the kind of funding contribution expected from these roles, it becomes apparent that the assessment of the financial participation correlates with the expected added value for a specific user group as can be seen in figure 9. The general notion of respondents is that those who can derive a large benefit from the use of digital platforms should also make an equal contribution to the funding. Industry associations and research institutions are outliers in this analysis. They are expected to benefit strongly, while a financial contribution is less frequently expected. As these institutions are mainly financed through membership fees and public funding with a business model that focuses less on profits but instead builds on reallocation, this might explain that outlying position.
3.3. **App-Store operation.** A central element on a digital platform is the app store. In the case of a platform setup that is open for third-party app developers, which is vital to 73% of respondents, the app store operator manages which applications are made available to the platform participants and is responsible for checking the quality of the applications offered. It also is a central position for revenue streams generated through the marketing of applications. The survey therefore also asked for actors who are considered suitable for that position.

The survey shows that research institutions and IT- and software companies are preferred in the position of an app-store operator with 80% respectively 77% of respondents deem these actors suited (see figure 10). The third role that is being seen as suited by a majority of participants are industry associations (63%). Behind, there are operators, maintenance service providers and turbine manufacturers (OEM), basically the main actors of the wind value chain. They are perceived as suitable app-store operators by around 40% of respondents.
If these results are considered together with the previously shown expected financial contribution, which in turn correlates with the benefit of using a common digital platform, clusters of complementary user groups and possible app-store operators become apparent in figure 11.

Research institutions, IT and software providers and industry associations are most frequently named as suitable app-store operators. The main industry players – operators, maintenance providers and turbine manufacturers – are expected to benefit from platform usage by most of the respondents. However, they are less seen in the governing position on the platform. This group of actors may be described as the main user group. Additionally, there is another user group that may be characterized by low suitability for app-store operation and lower funding contribution to the platform that forms a complementary user group consisting of providers for related processes and services.

![Figure 11: Funding contribution and suitability as an app-store operator on a digital platform](image)

3.4. **Obstacles and barriers for platform adaptation.** The survey also addressed possible obstacles and barriers to increased use of digital platforms. One question asked for legal aspects that are inhibiting the adoption and use of digital platforms and another question asked for operational issues. The results are shown in figure 12.

In terms of legal aspects, data usage right resulting from the contractually agreed terms is the primary concern that is inhibiting more widespread adoption. Further issues of high importance are requirements for data protection and IT security. From the operational perspective, the highest share of participants finds the availability of applications to be inhibiting. There is also a significant concern of dependence on individual platform operators known as the vendor lock-in effect. However, this finding is based on a smaller total number of responses, as this option has been skipped by several participants. Based on absolute numbers, the quality and availability of data have been mentioned as inhibiting factors.
4. Discussion

Two different approaches with nearly disjunct industry expert groups were used to determine and prioritize the main functionalities for future digital applications. The combination of the systematic approach with a structured process and method analysis and expert workshops and the online survey approach with the assessment of given functionalities based on literature, identify technologies for monitoring failures risks of top priority to the industry. This includes anomaly detection from turbine data as well as remaining useful lifetime calculation and the identification of parameters describing the technical lifetime consumption.

Furthermore, the findings show that there is a high interest in further service support systems and performance optimization applications that are becoming possible with digital means. The potential benefits are being perceived, not only for OEMs and operators, but for all kinds of organisational roles in the wind energy value chain.

The survey is also one of the first to show empirical findings on industry professionals’ expectations on setup and finance of a digital platform. While numerous platform services have entered the market and are currently under development, there has been little scientific research and debate on the business model of a digital platform. One of the few publications on that is Andrew [17] pointing out that two-sided platforms may be favourable, e.g., for lifetime extension analytics.

However, the outcome of the survey indicates that the participants’ mindset on the platform business model shows a strong correlation between benefit and funding: if an organisation benefits from the platform, it is also expected to contribute to development and operational cost. While this is at first glance a common-sense approach, recent digital platform business models, especially in the business-to-consumer sector, have instead applied two- or multi-sided platform models for monetization.

Based on the analysis of funding contribution and the suitability to act as an app-store operator, three user groups have been identified: main users, complimentary users, and trusted gatekeepers. Considering that rather neutral organisations are preferred as app-store operators, the consequences for business
models have to be thoroughly investigated. Current services on the market are often not in line with these preferences, where major platform services are provided as additional services from turbine manufacturing companies.

Finally, as these findings are based on an expert elicitation and survey approach, some caveat should be noted. As already mentioned, the survey was open to all recipients of the invitation mails by the industry associations. So the results are descriptive statistics, and there might be biases in the respondent groups. One bias is that participants had a strong focus on the German market. Another bias might arise from using internal industrial contacts in addition to the industry associations. Thus the view of people who have already worked with research institutions may be overrepresented in the findings. Besides, it needs to be underlined that the prioritization in both the workshop approach and the online survey builds on individual personal assessment. Financial estimates on the possible benefits of suggested application would add relevant information for prioritization but would be very sensitive to underlying assumptions at the same time.

5. Conclusion
The research has shown that the use of digital platforms is generally perceived as beneficial to all actors in the wind industry. Priorities in applications for operation and maintenance have turned out in two separate approaches to be failure risk monitoring technologies like anomaly detection or remaining useful life calculation and service support and assistance functions.

For more widespread adoption of platform usage, legal and non-legal obstacles need to be overcome. Among these are data quality and availability as the primary technical issues. However, legal and organisational barriers like data usage rights, data protection, and vendor lock-in concerns are of equal or even higher concern and might be even more challenging to overcome as they often depend on long term contractual conditions.

Besides, the discussion of business model related questions implies that there are gaps between the expectations from industry professionals with services currently offered and the latest business models addressing multi-sided markets. These leave much space for innovation that will lead not only to new applications, but it may also be a basis to rethink the setup of digital platforms in the wind industry for faster and broader adoption.

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