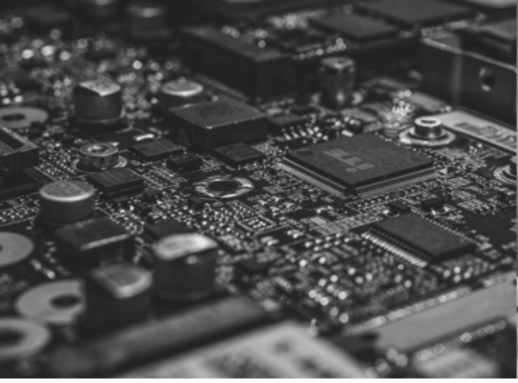
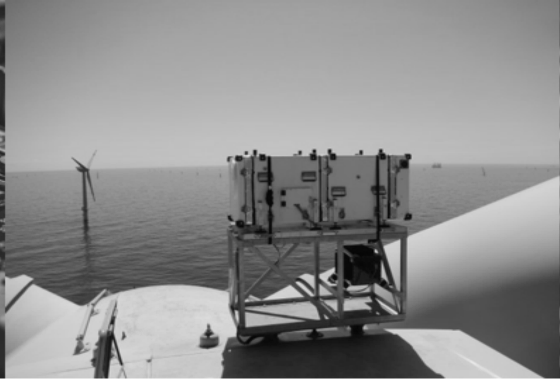


IEA Wind Task 32 Workshop Minutes

WS16: Digitalisation of Wind Lidar

Authors: Andrew Clifton, Ines Würth, David Schlipf

What will digitalisation mean for wind lidar, and how can digitalised wind lidar be integrated with the digitalised wind energy business?

Wind energy and many other users of wind lidar are going digital, leveraging decades of developments in programming, more reliable communications, and the internet of things. This digital transformation will lead to new ways of working, new opportunities, and new business ideas. But it will also mean that wind lidar will change as well. Together, the wind energy industry and wind lidar will undergo digitalisation.

This workshop used a combination of presentations, group work, and discussions to explore what digitalisation might mean for wind lidar hardware, software, users, and stakeholders.

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The presence of a person's name or an organisation's name in this document (e.g., in the list of participants in Table 8) should not be taken to imply that that person or organisation agrees with any of the opinions set out here. Similarly, the use of any brand names or trade marks does not constitute an endorsement.

Attribution

The workshop ran under modified Chatham House rules. Specifically, participants are free to use information from the discussion, but are not allowed to reveal who made any comment. Material presented by the three invited speakers (listed in "Digitalisation in Practice") may be attributed.

1 Agenda

Time	Activity
14:00	Introduction
14:20	What is digitalisation? • How the common lidar data format improved our data processing (Ines Würth, SWE) • The Smart Lidar Concept - New Opportunities for the Lidar Community (David Schlipf) • Modularising wind lidar (Andy Clifton)
15:00	Working groups: user stories for different wind lidar scenarios
16:00	Sharing results
16:45	Close

2 Introduction: what is digitalisation?

Wind lidar is an inherently digital measurement device in that the results of the measurement are digital signals (radial wind speed, wind vector, etc.). Similarly, wind turbines, wind plants, and the rest of the energy system infrastructure generate huge amounts of data. Digitalisation can be seen as the process whereby wind lidar data, wind energy system infrastructure data, and other data are used together to enable more reliable and more valuable energy. Together, they will enable the wind energy plant of tomorrow (Figure 1).

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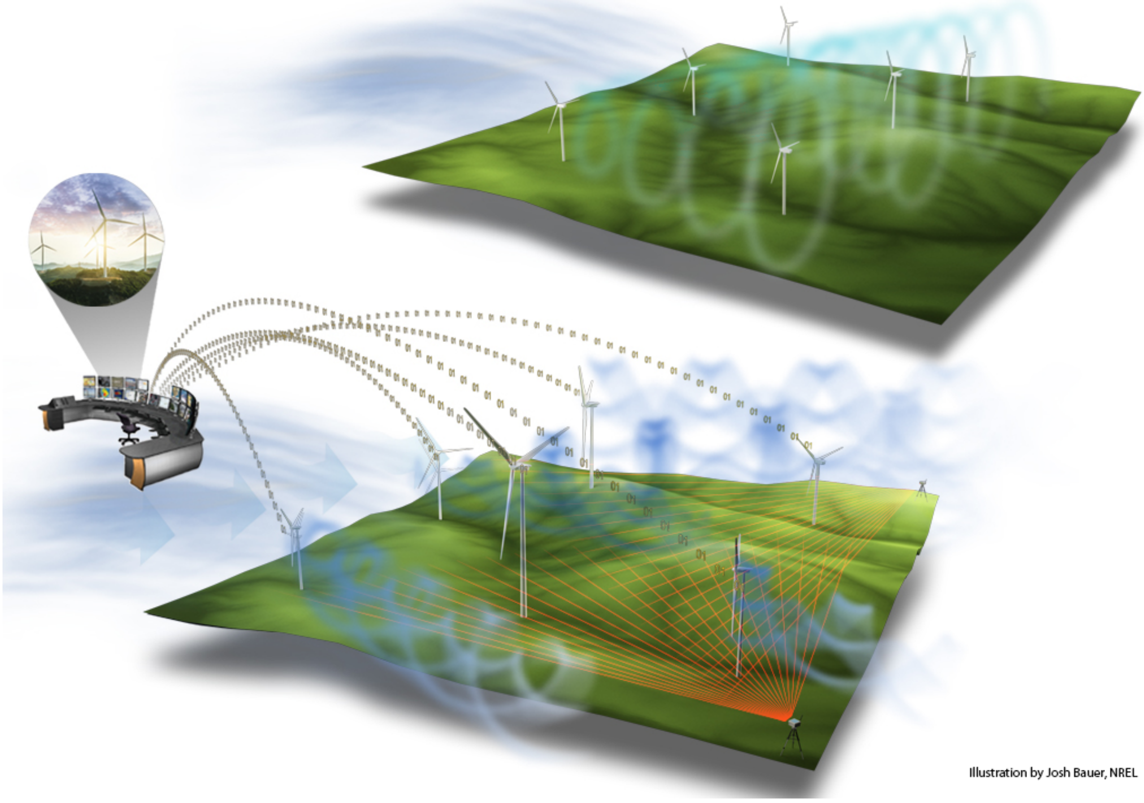

Figure 1: Digitalisation of wind lidar and wind plants will enable the transition from the wind plant of today (top) to the networked wind plant of tomorrow (bottom). Figure courtesy Josh Bauer, NREL

However, it is difficult to know what digitalisation will involve until we have tried it. Therefore, this workshop set out to develop user stories for several different wind lidar usage scenarios. These are discussed in more detail in Section 3.

3 Digitalisation in practice

The workshop started with presentations by three groups that have all been exploring digitalisation of wind lidar.

3.1 How the common lidar data format improved our data processing (Ines Würth, SWE)

In 2018 DTU, Fraunhofer IEE and others published the report from their e-WindLidar project [1] in which they introduced a common format for wind lidars. Up to now, lidars from different manufacturers spit out data in different formats using different variables. In Stuttgart we therefore developed different code for each lidar in order to process the data.

The common format brings only advantages: in Stuttgart we implemented it in our code and now only have one data processing routine for different lidar systems. Collaboration is facilitated because exchange of code and data is very easy. Interfaces where data is exchanged are clearly defined. Therefore we believe that the common data format is the basis for a digitized lidar infrastructure of the future.

The presentation can be found at https://doi.org/10.5281/zenodo.4629675.

3.2 The Smart Lidar Concept - New Opportunities for the Lidar Community (David Schlipf)

We believe that lidar systems will follow the general trend of technology by adapting to their environment and becoming more adjustable. Here, the "smart lidar" concept intends to provide a helpful framework.

The smart lidar consists of a reprogrammable lidar device that can be modified or extended by "apps". A first version of smart lidar was developed as part of the international research and development (R&D) project between Flensburg University of Applied Sciences, MOLS and sowento. A commercial lidar has been modified to process third party algorithms which can be directly integrated in common simulation tools for wind turbines, which significantly simplifies the certification of lidar-assisted control applications. In future we anticipate that these apps can be provided by specialists, allowing lidar users and their customers to take advantage of the wide range of experience in the international wind lidar community.

The presentation shows the main advantages, current advances, and new opportunities for various stakeholders in the lidar community.

Further details can be found at https://doi.org/10.5281/zenodo.4627168.

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3.3 Modular wind lidar (Andy Clifton, Task 32)

Wind lidar are complex devices that are optimised for particular tasks. However, they often contain basically the same modules - power supply, communications, laser source, optics, scanner - that have different properties and capabilities depending on the task. In 2015 a group of Task 32 members came up with the "Open Lidar" concept for modular lidar [Figure 2 and 2], whereby different hardware and software would be combined for different applications. Modular wind lidar have been built in the past but are not commercially available at this time.

The Open Lidar concept has since been applied as a generic, modular architecture for lidar, which is now documented in the Task 32 Wind Lidar Ontology. This generic architecture with clear definitions in turn enables the development of a "digital twin" for wind lidar - software representations of real-world hardware.

The first wind lidar digital twin - *Qlunc*, designed to quantify the uncertainty of a lidar device - has just been released (DOI: 10.5281/zenodo.4600881). Qlunc uses the open lidar architecture and defines uncertainty for the hardware components within each module. The uncertainties can then be combined to estimate the uncertainty of line-of-sight wind speed measurements and the total pointing and range uncertainty. This, in turn, can be used as an input to other tools, such as MOCALUM or YADDUM.

Together these tools offer the chance to effectively simulate wind lidar hardware for many different applications, and optimise them before building or deploying them.

4 User stories for wind lidar digitalisation

The workshop participants next split into small groups to create user stories for four different situations. These situations were proposed by the workshop organiser as representative of common situations:

- Wind resource assessment
- Monitoring offshore wind turbines
- Lidar for wind plant control
- Lidar solution providers

The groups further defined the scenario and the current actors. They identified how these actors interact and what challenges they might face. They then considered how that scenario might change over the next three to five years, and how digitalisation might impact those scenarios. Finally, each group identified any potential "show-stoppers" and the highest priority activities to enable success. The results are summarised in the following subsections and are based on a template provided by the Workshop organiser. The results have not been edited and may include spelling errors or be unclear.

Please report any corrections to the Task 32 Operating Agent.

4.1 Wind resource assessment

This group considered a scenario in which a wind plant developer wants to deploy a wind lidar for a wind resource assessment campaign. The users include the lidar provider and several customers, including a data analyst, a data manager, and a project manager (Table 1).

This group felt that the biggest potential from digitalisation was the ability to feed back experience from measurement campaigns into the next campaign, and thus build up repeatable, high-quality wind resource assessment processes.

The group expected feedback to be enabled in the near future by the availability of more data and better data storage and retrieval. They expected the same actors still to be present in a wind resource assessment campaign, and with similar concerns as to today (Table 2).

The group identified the following things as being important to making this vision a reality:

1. **A data hub**: software and services to receive, manage and process data. This should be based on community standards and should be delivered by the lidar provider(s) and the community. It was noted that this should not be too complex, otherwise it might prevent adoption.
2. **Data standards**: clear standards for data and data products at different stages of the wind resource assessment process are required. They should be compatible with all sections of the wind energy industry. This should be delivered by the wind lidar and wind energy community. These were also seen as a priority.

4.2 Monitoring offshore wind turbines

This group chose to explore the effects of digitalisation on forecasting for energy trading on 5- to 10-minute time scales.

They identified three actors involved in this at present:

- Alice, a wind farm operator. They currently record SCADA data and have no way to use this in their market. They are sometimes required to down-regulate their turbines by the grid operator.
- Bob, a weather forecaster. They obtain satellite and other data to create a weather forecast
- Chris, an energy trader. They trade energy from various sources.

Currently the three actors operate independently (Table 3). The group imagined a future state where the actors are able to interact and share data, enabling energy trading (Figure 4).

The group identified several things that would be needed to make this vision a reality:

1. **Good wind speed measurements from lidar**. The Lidar system with high range resolution would also need to provide a data flow to the forecaster. This should be provided by Lidar OEMs.
2. **Feedback from the market**. This would take the

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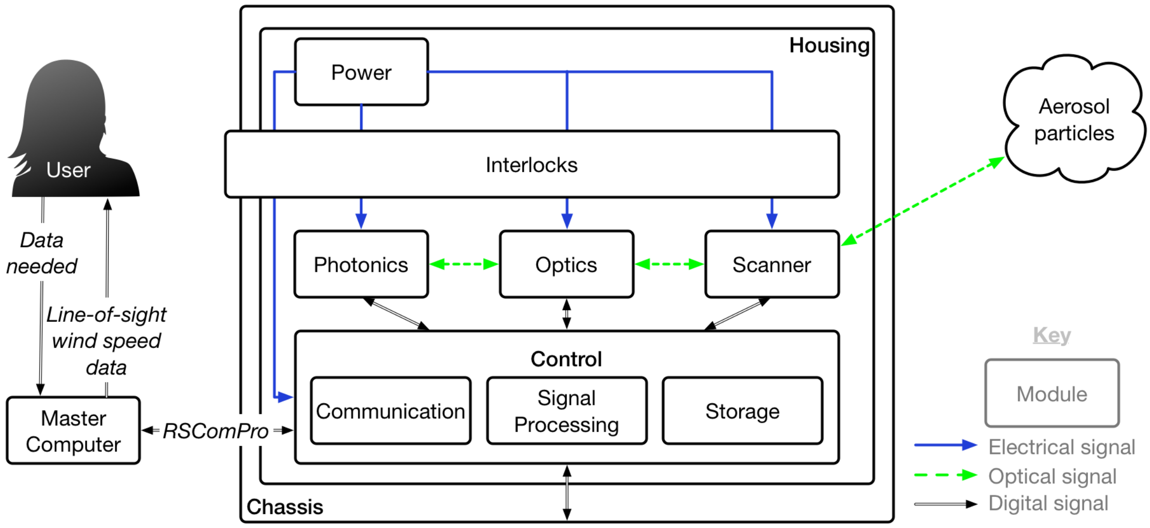

Figure 2: The OpenLidar modular wind lidar architecture [2]

form of e.g., a command for regulation of the turbines. It was thought this would be provided by new companies.
3. **Improved forecasting method using lidar data**. Good forecasts are achieved with lidar data, so the data flow needs to be established between the wind farm operator and forecaster. This needs to be enabled by the forecasting company.
4. **Realtime data for energy trading and market flexibility** to enable real time energy trading. This needs to be done by Bob and the market.
5. **Standardized data formats**. We need standards for all data flows. This should be done by expert groups from IEA and IEC.

The main potential barriers were seen as market regulations and the difficulty of establishing reliable, timely data flows.

4.3 Wind plant control

This group chose to explore the concept of "Smart wind farms: Nacelle-mounted lidar for wind farm optimisation". This is currently an area of active research but very limited commercial adoption (Table 4).

The future user story was split into two phases (Table 5). The first phase takes place during the project execution:

1. Fred invests into a development project
2. Fred and Alice together provide communication network, database, processing power
3. Diane provides consultancy and advanced control algorithms
4. Bob connects lidar to the network and integrates lidar (reacts to commands)

The second phase was after the project was complete:

5. All together publish their success stories
6. This will push others to do the same and can build up on the experience
7. Bob and Alice can improve their lidar / turbine to make them even smarter and can add more features.
8. Diane can develop better algorithms
9. Fred is happy and invests into more smart wind farms!

Several things were identified as being required to make this vision a reality:

1. **Proof of concept**. First successful field testing needed. This could be done through a research project or JIP
2. **A common interface**. This would allow communication between lidars, turbines and the wind farm controller. This could be done by IEA Wind Task 32 + new wind farm flow control task
3. **Understanding of economic benefit**. How much is there to gain? How much are the investment/maintenance costs? This could be done by a research project, JIP, or in collaboration with IEA Wind Task 37.

The main barriers to this happening were:

1. Data privacy / security issues
2. Unwillingness to share intellectual property
3. Lack of budget for development.

The group felt that the priority for 2021 should be an economic model to convince the various players to step in.

4.4 Lidar solutions provider

The last group took the perspective of a lidar solutions provider (Alice), working with a customer (Chris) and a technician (Bob). Today, the lidar solutions provider and customer are not well connected (Table 6).

The group expected moderate changes in the lidar market in the next five years (Table 7). Specifically, they expected a shift to renting modular lidar that might be built with modules from several different hardware and software manufacturers, depending on the customer's needs.

The group identified several enabling steps that would

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be needed to make this vision a reality:

1. **Modularity within lidar manufacturers**. Make lidar modules interchangeables. Software as well, monitoring,... This should be done by the manufacturers
2. **Standardization of lidar interfaces**. Provide standard data processing methods, interfaces. This should be done by IEA Task 32

The major challenge to this was felt to be a lack of competition, i.e., the lack of pressure to change business practices.

The suggested priority for 2021 was the creation and use of a common and modular lidar interface for the input, output, and control of wind lidars.

5 Summary

The following section is a summary of the workshop and was prepared by the Operating Agent after the event.

5.1 Priorities for 2021

The following were seen as priorities to enable the digitalisation of wind lidar:

1. **Data standards** were required to enable wind lidar to be used for wind resource assessment, forecasting, wind plant controls, and to enable flexible, modular lidar.
2. **Data flows** to simplify data transfer from lidar devices to other devices and to users. This would be easier with data standards.
3. **A common and modular lidar interface** to enable data input and output, and control of the wind lidar.
4. **Faster tools** that can be used as part of wind lidar-based processes, e.g., for energy forecasting.
5. **Energy market flexibility** to allow new business models based on faster reaction times or greater flexibility, e.g., 5- to 10-minute-scale energy forecasting.
6. **Economic models** for different applications that demonstrate the economic case for investing in lidar.

Other longer-term needs were identified for each scenario.

5.2 Potential barriers to digitalisation

1. **Complexity**. Digitalisation is not easy and is a change from today's processes.
2. **Standards** that are too specific and incompatible.
3. **Market regulations** and the difficulty of establishing reliable, timely data flows.
4. **Data privacy and security issues**, including unwillingness to share intellectual property.
5. **Lack of budget for development**, limiting the scope for businesses to explore digitalisation.
6. **Lack of competition** to encourage change and new business models.

5.3 What can Task 32 do?

This workshop showed that there are several things that IEA Wind Task 32 can do to support the digitalisation of wind lidar and it's integration into a digitalised wind energy business.

1. **Push data standards.** Some nascent data standards already exist, for example the e-WindLidar data format [1] and the Lidaco data converters. However, these only exist for line-of-sight data and need to be extended to include processed wind lidar data.

   > Task 32 will work with the developers and users of the e-WidLidar data format to extend it.

2. **Provide examples.** It is not always clear how digitalisation might work. Detailed examples for real use cases will help show the technology and processes that are required, and help understand the costs and benefits of digitalisation.

   > Task 32 will set up some examples of modular, multi-party collaborative data processing.

3. **Encourage collaborative and open R&D projects**. Task 32 members are already heavily involved with low-TRL projects that rely heavily on wind lidar data. The results from these projects need to be shared. And, where possible, the foundational tools that are developed should be shared with the rest of the community to help establish the infrastructure and market needed for digitalisation.

   > Task 32 will continue to provide a platform for the international wind lidar R&D community to meet and exchange ideas and experience

4. **Collaborate with other IEA Wind Tasks**. Some Task 32 members are also involved with other relevant initiatives, for example IEA Wind Task 43 on the digitalisation of wind energy.

   > Task 32 will work with other stakeholder groups to explore how digitalised wind lidar would interface with other parts of the wind energy community.

6 Conclusions

The results from this workshop are similar to those seen for studies of digitalisation in other areas of the wind energy industry. They include:

- Digitalisation happens from the bottom up when users try to automate or reuse old processes, or to share them with colleagues. This can lead to competing, incompatible activities. We may be able to avoid this for wind lidar by leveraging common data formats at different parts of the process, for example the e-windLidar formats [1].
- Digitalisation can also be top-down, for example by tasking internal teams or by buying in services. This can lead to an adoption problem, that can be

avoided by working together with users to create the tools they need, and train them to use them.

- However it happens, digitalisation needs to be treated as an important (or even strategic) change that can heavily impact users.
- Like many businesses, the wind lidar business will become modular. Users will increasingly create their own processes based on a mixture of hardware and software tools.
- Service providers - hardware vendors, consultants, researchers - therefore need to work on simplifying the interfaces between their parts of the process.
- Standards will help with many aspects of digitalisation, as would data and app marketplaces.
- None of this will happen without management support and encouragement.
- We need ways to talk about the costs and benefits of digitalisation.

IEA Wind Task 32 will be convening a working group to make progress on some of these issues. Please get in contact if you would like to take part.

References

[1] N. Vasiljevic et al. *e-WindLidar: making wind lidar data FAIR*. Jan. 2018. DOI: 10.5281/zenodo.2478051. URL: https://doi.org/10.5281/zenodo.2478051.
[2] A. Clifton et al. ‘The OpenLidar Initiative for collaboration on wind lidar hardware and software’. Sept. 2019.

This document was self published by IEA Wind Task 32.

The International Energy Agency is an autonomous organisation which works to ensure reliable, affordable and clean energy for its 30 member countries and beyond. The IEA Wind Technology Collaboration Programme supports the work of 38 independent, international groups of experts that enable governments and industries from around the world to lead programmes and projects on a wide range of energy technologies and related issues.

IEA Wind Task 32 exists to identify and mitigate the barriers to the deployment of wind lidar for wind energy applications.

For more information: See the Task 32 website. **Author team:** Andrew Clifton (Task 32 Operating Agent, University of Stuttgart, Germany), Ines Würth (SWE, University of Stuttgart, Germany), David Schlipf (Task 32 operating Agent, Flensburg University of Applied Sciences, Germany). **Images:** Banner, left to right: Alexandre Debiève on Unsplash, SWE U. Stuttgart, Markus Spiske on Unsplash.

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Table 1: Actors in today's lidar-based wind resource assessments

	Alice	Bob	Darla	Cory
They are:	Lidar provider	Data analyst	Data manager	Business / Project Manager
Their biggest problem is:	Selling the lidar. Deploying it on time	Configuring the lidar Uncertainty about metadata	Getting data into the organization and managing it.	Knowing when to invest in using lidar.
Success for them is:	Successful campaign with feedback from other campaigns	Good verification & validation	No issues during LiDAR data measurement	Clearer guideline on when investing in Lidar makes sense; Financing as planned
Problem statement	Need to get a "good enough" measurement for funding (enough data with sufficient uncertainty)			

Table 2: Actors in near-future lidar-based wind resource assessments

	Alice	Bob	Darla	Cory
They are:	Lidar provider	Data analyst	Data manager	Business / Project Manager
Their biggest problem is:	Selling the lidar. Deploying it on time	Configuring the lidar; uncertainty about metadata	Getting data into the organization and managing it.	Knowing when to invest in using lidar
Success for them is:	Successful campaign with feedback from other campaigns	Good verification & validation	No issues during LiDAR data measurement	Financing as planned / Clearer guideline on when investing in Lidar makes sense
Digitalisation helps by:	Providing info	Validation reports visual	Smoother installation & data management	Enabling Live queries of the project data and results
What problems are left?	Maintaining standards	Visual communication / reports	Monitoring the lidar function, data storage, and security	Uncertainty; ROI not clear

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Table 3: Actors in energy forecasting for offshore wind farms today

	Alice	Bob	Chris
They are:	Wind farm operator	Forecaster	Energy trader
Their biggest problem is:	Unknown wind conditions in the future	No data	If they cannot deliver sold energy
Success for them is:	Wants to sell her energy	Having low uncertainty forecast	Highest revenue
Problem statement:	We need the best wind data to produce a low-uncertainty energy yield forecast		

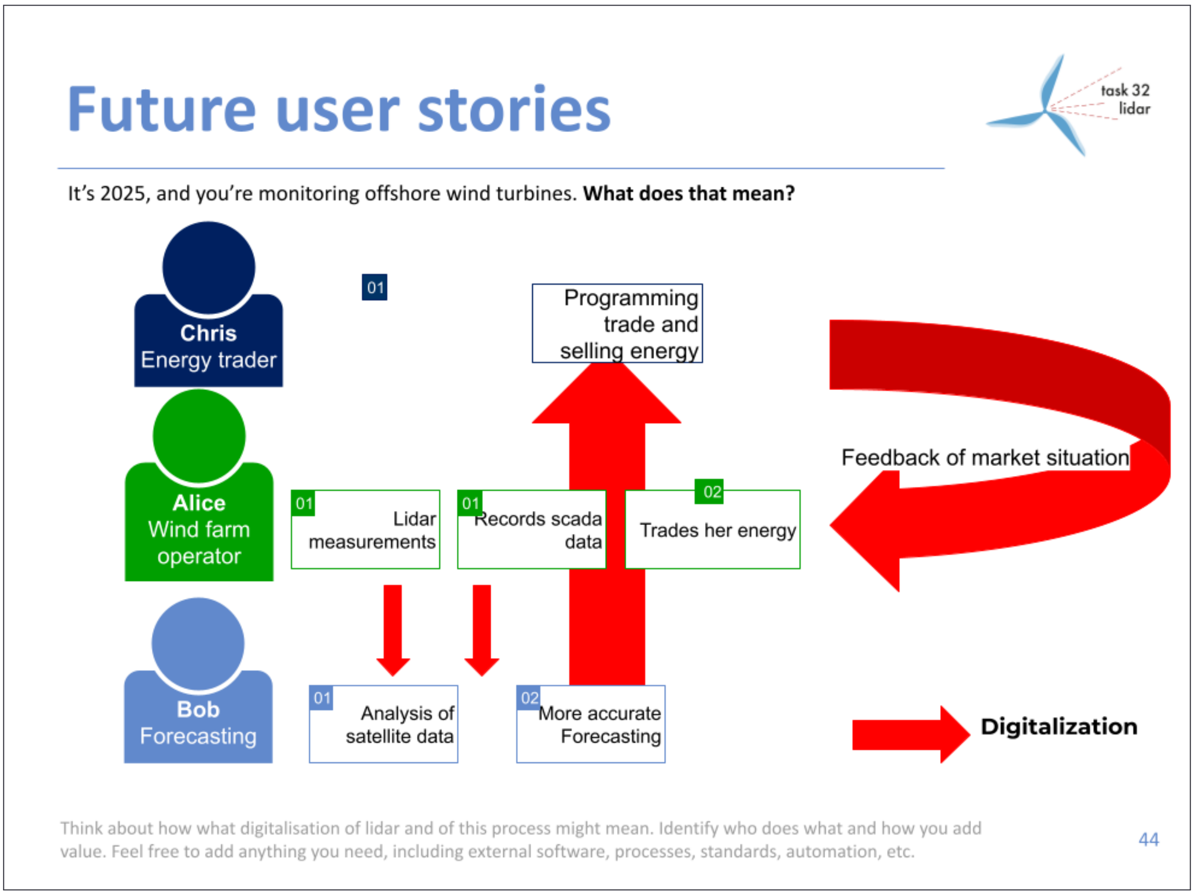

Figure 3: A vision for future energy trading for offshore wind

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Table 4: Actors in today's lidar-enabled wind plant control

	Alice	Bob	Fred	Diane
They are:	Turbine OEM	Lidar OEM	Farm owner / operator	Independent analyst / engineer
Their biggest problem is:	Maintaining customer trust (customer already wants turbine), but OEM has to ensure performance. Ensuring equipment operates in the best way. Need to avoid bad publicity as the turbine OEM is often blamed first.	Ensuring durability of equipment. Clear view of what the data is being used for and how this can benefit.	Access to turbine controller to allow lidar to optimise farm for them. O&M schedule increase turbine downtime (perhaps).	No access to data. Standardised data format could cause problems for them also.
Success for them is:	Better understanding of turbines and performance in non-benign conditions. Better experience for end user. Critical failure avoidance.	Ensuring durability, performance, acceptance and value proposition of systems.	Optimised asset(s) (higher AEP, lifetime extension, lower O&M, reduced LCoE).	Credible service development, success of data science application.
Problem statement:	No real solution for data to be compiled and interpreted in an easy and efficient way to make the most of this solution. No one wants to cover the overall development costs for proof on concept. Data security. Infrastructure for data sharing/communication across parts of the site			

Table 5: Actors in future lidar-enabled wind plant control

	Alice	Bob	Fred	Diane
They are:	Turbine OEM	Lidar OEM	Farm owner / operator	Independent analyst / engineer
Digitalisation helps by:	Certification. More realistic simulations. More awareness of their turbines. Strengthened relation with customer.	Make lidar systems more - helpful - accepted - adjustable - adaptive	Having more control of the farm output. Having more flexibility in the way it which the farm can be operated. AEP/load balancing.	Accessing large quantities of data and develop apps/tools to bundle them and process them into more valuable refined product.
Any problems left?	–	–	–	–

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Table 6: Actors in providing lidars today

	Alice		Chris
They are:	Provider		Customer
Their biggest problem is:	Provide the right device to Lisa		Can't correctly interpret the data or get out needed data
Success for them is:	Provide the right device for the right price		Long term use of the device
Problem statement:	The connection between the provider and customer is missing		

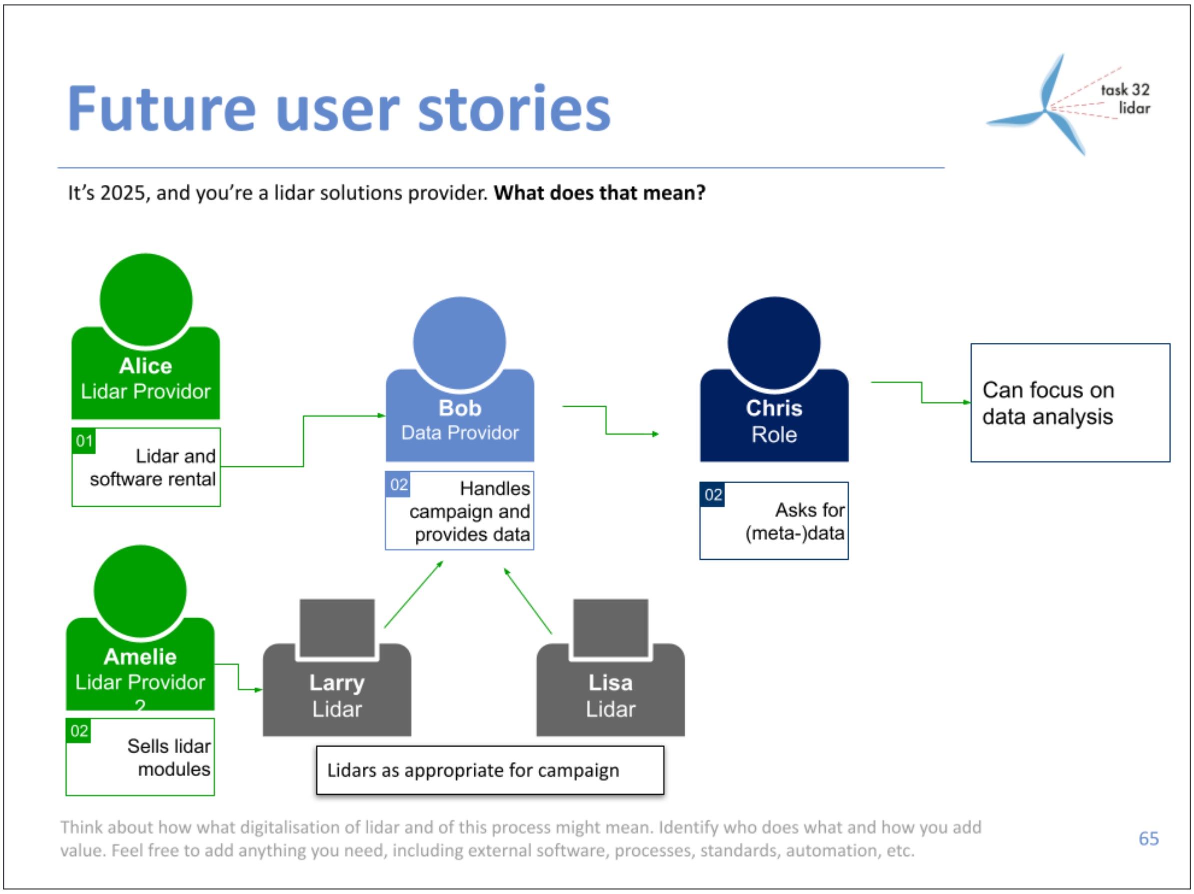

Figure 4: Actors in a future lidar market

Table 7: Actors in providing lidars in the future

	Alice	Bob	Chris
They are...	Lidar Provider	Data Provider	Customer
Their biggest problem is:	Selling less lidars because they will be rented	Handling different lidar data	Need to define clearly what type of data is needed
Success for them is:	Operating a fleet of lidars for customer	Get a common method to analyze data from different lidars	More time for data analysis
Digitalisation helps by:	Managing and monitoring lidars, gaining knowledge	Compare data Finding the most suitable lidar depending on site characteristics/ino want to get out	Providing insights and solutions faster. No need for handling lidar by additional staff.
Any problems left?	Have to stand out among other lidar providers. Modularity of software and hardware	Defining tasks of data provider, common data and interface formats. Managing lots of lidars effectively.	Who owns the data (only licence for usage or ownership)?

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Table 8: Participants

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