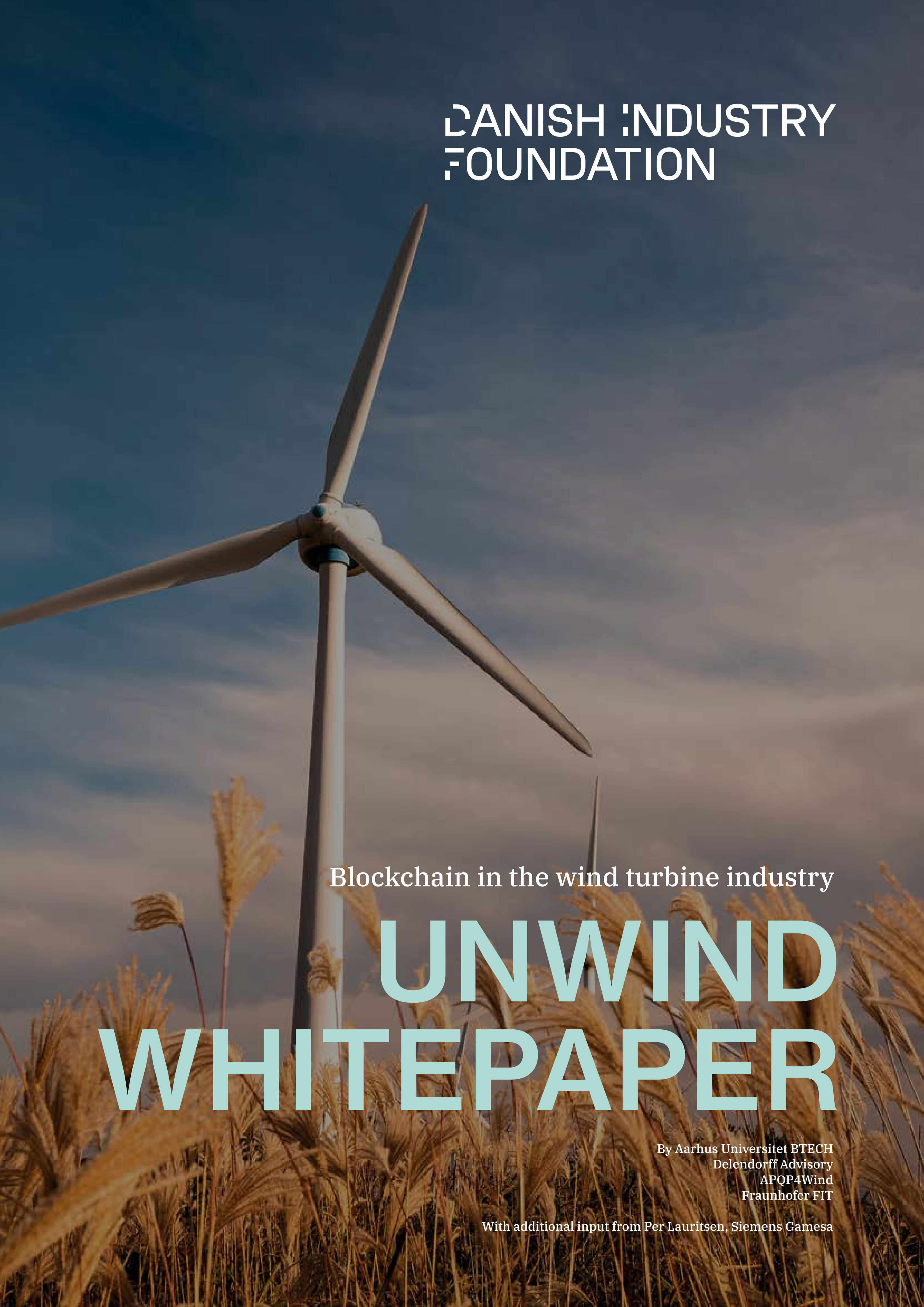

DANISH INDUSTRY FOUNDATION

Blockchain in the wind turbine industry

UNWIND WHITEPAPER

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1. Background

In recent years, the wind turbine industry has experienced rapid growth. This has created a market in fierce competition and a greater distance between wind turbine manufacturers and subcontractors in an attempt to ensure the highest level of competition. The tough competition thus creates a culture where sharing knowledge and finding common solutions are replaced by a focus on optimising the companies' own solutions and own business – a culture that hampers the general innovation in the industry.

UnWind is a research and development project funded by the Danish Industry Foundation, which focuses on strengthening the collaboration between subcontractors in order to increase innovation in the industry. This is done by introducing blockchain technology, which is based on systematic data-driven knowledge sharing. The purpose of the project is thus to create better opportunities for collaboration and knowledge sharing in the construction process by giving suppliers equal access to data as well as insight into and consensus on changes in the documentation.

By developing and testing a blockchain usecase, this project will support quality assurance in a selected part of the value chain from subcontractor to – and including – the wind turbine manufacturer.

Aarhus University (BTECH) is leading the project, which includes the following partners: APQP4Wind, Delendorff Advisory and Fraunhofer Blockchain Lab.

1.1. The focus of this report

A project like UnWind triggers many discussions and reflections on business, technology and the interplay between organisation and strategies. Through ongoing interviews, dialogue and interaction with companies in the wind turbine industry and across the group of partners, we have with our action research approach explored the potentials and challenges for business, technology and organisation in the development and implementation of blockchain technology.

The aim is to achieve maximum value from the usecase by continuously focusing on significant points of attention that can either promote or pose challenges for the future use of blockchains. This is supplemented with a broader perspective from the industry by involving, interviewing and seeking sparring among employees in different positions in the individual organisations and across the value chain and the whole business ecosystem.

Throughout this whitepaper, you will find text boxes with short answers to some of the frequently asked questions encountered during our work with preparing the paper.

1.1.1. Approach

This whitepaper is based on a series of exploratory interviews and conversations with actors in the wind industry. The actors have been selected with the aim to reach representativeness in terms of knowledge and insight within the industry. A total of 32 interviews and conversations were conducted.

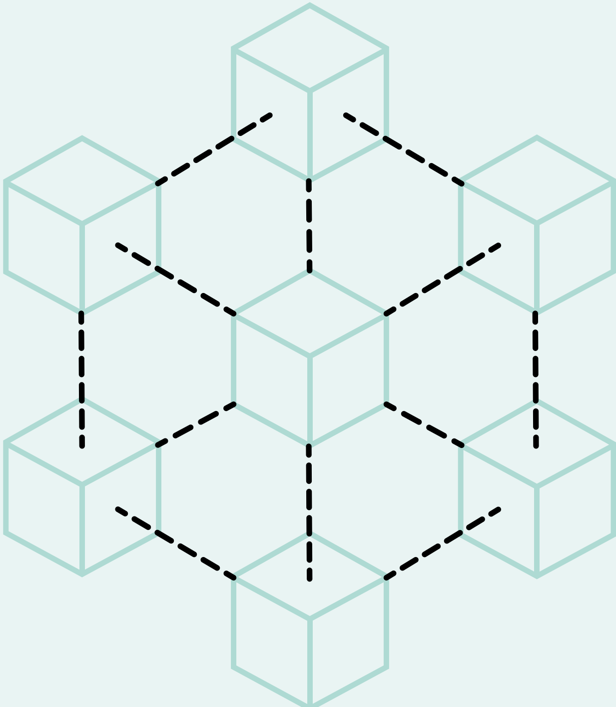
All interviews and conversations have aimed at providing insight into and perspectives on the use of blockchain technology in the wind industry – including opportunities and challenges. In addition, the whitepaper is based on a series of conversations with partners who have been directly involved in the development of the usecase. Their experience with the work within the framework of this project has thus been a significant contribution to gaining a more nuanced understanding of the area and its relevance to the industry. Overall, the data collection and the generous, individual contributions, in terms of people's time and deliberations, have made it possible to define points of attention, drivers and barriers in order to nuance the understanding of the potentials that blockchain technology offers.

All findings and perspectives from interviews have been anonymised and converted into a series of generic elements on which we elaborate in the following.

2. Introduction to blockchain in the wind turbine industry

For many years, the Internet has been, and in part still is, the primary system for sharing information (Internet of Information). Documents can be sent from a sender to a recipient, allowing the recipient to edit a copy of the document. Thus, the copy is worthless in itself, as it can be edited and forwarded. With blockchain technology, it is possible to exchange data that cannot be copied and modified without being traceable. Thus, data can gain new value through blockchain technology, as it makes it possible to prevent copying without this being traceable (Internet of Value).

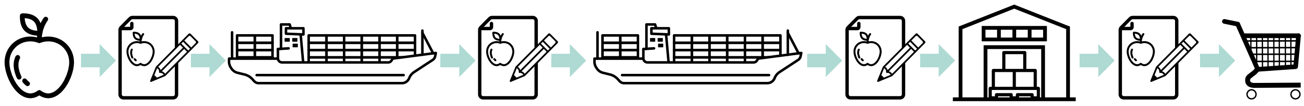
Data is stored by using blockchain technology in so-called blocks of data, which, after editing, are locked with an encrypted key pair and thus are non-editable. Once data is entered into a blockchain, this data is replicated on all devices connected to the blockchain and appears in a transaction log that can be read but not edited. In other words, it is possible to add data, but it is not possible to manipulate data, and, thus, there will be a complete transaction log at all times.



Hence, it is transparent what changes or additions that have been made, when and by whom, and this data is locked, replicated and stored on all computers in the value chain (network). In this way, no single point of failure occurs where we risk losing all our common data simply due to a single failure. This also means that if one blockchain-connected partner withdraws from the partnership, the data in the blockchain of the other partners remain unchanged. It is also possible to invite new partners as long as the partners agree on that and on the rules for doing so. All parties involved thus own the data, which is accessible via the blockchain.

For example, if an apple is to be transported from A to B, as illustrated in the figure on the next page, there are often many touchpoints where the apple must be transferred from one actor to another. Traditionally, the handover of the apple from one actor to the other is registered manually on paper, which increases the risk of errors, delayed or incomplete information. In other words, the paper is our transaction log, but we cannot be sure that it says the same thing on all our documents, and typically, only part of the information will follow the apple all the way to the end customer.

With blockchain, data is made transparent so that data is accessible and unmanipulated to the extent on which we have agreed that everyone should have access.



In other words, blockchains are chains of data that can help create security in insecure situations where values and rights are transferred – such as tokens, houses, cars, money and data – and not least items and sub-components for the construction of a finished and well-functioning wind turbine.

In the example with the apple, we could agree that when we receive the apple, we check if it has the desired quality, and sign if that is the case. Then we call the next link in the chain and tell them that we have checked the apple and that the apple is now on its way to them. In a blockchain, such processes can be automated, and we can ensure that it is precisely the quality-checked apples that are forwarded. This is done by using smart contracts, as described below.

2.1. Smart contracts – the common rules for the blockchain

The partners in a blockchain can enter into the collaboration based on a number of automated rules. These rules are called smart contracts, and smart contracts then define the rules for our collaboration.

An example:
Melanie buys a car from Peter on hire purchase and pays the car by monthly instalments. Last month, Melanie forgot to pay, and when she tried to unlock the car, the car remained locked. Melanie's access to the car is, hence, conditional on the monthly instalments being paid.

The reason why Melanie could not go for a drive, which she was used to doing, was not that Peter had checked his bank account and found the non-payment, and then had agreed with a locksmith to replace the lock. The real reason was that, before the conclusion of the agreement, a common rule had been made for the collaboration – a smart contract stipulating that in the event of non-payment on a given date, the key's ability to operate the locking system would lapse.

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How does data get into the blockchain?

This can happen, for example, the moment a unique identification is applied to the product. Using a smartphone, tablet or other device, the item is scanned and written directly into the blockchain with associated data on, for example, materials, dimensions, production time, batch etc. From this point in time, any activity that affects the item can be linked to the DID (Decentralized Identifier, please see below) and can be documented at any time, just as specific incidents can be.

Can a blockchain run across OEMs (Original Equipment Manufacturer)?

The core of blockchains is that they run in the same way for all partners. Next, there is a local integration to the partners' own system and data warehouses.

On an offshore turbine, one could imagine the following

Example:
John must retighten a bolt in a wind turbine. When the bolt is retightened with the correct torque, and this is registered in the blockchain with, for example, a digital torque wrench, an agreed fee is automatically paid. The payment of the fee is conditional on the bolt being tightened with the correct torque. This is checked automatically via the smart contract, and, if so, the transaction is completed.

This is a fast and efficient way to handle transactions and can mitigate delays in value chains and errors in manual processes.

Using blockchain technology, all data associated with the above example is recorded in the block – the car trade, the monthly instalments, the automated rule as a condition of the cooperation etc. Thus, there are no uncertainties about the history and whether the payment has gone through or not – all data is collected in a blockchain that cannot be edited.

2.2. Governance

Although all data is gathered in one blockchain, all parties do not necessarily need all that data to solve a specific task. Thus, consensus among all parties is needed on what data should be entered into a blockchain, and what data should be available to whom.

In the following, a number of key concepts and characteristics of blockchain are unfolded, which are crucial for the understanding of the technology and its application possibilities.

Is it secure – and what about access control and encryption?

Yes. All data is encrypted in a private blockchain-network. The same is true of access to data. In the blockchain, there are some defined roles that provide access to certain data. Access to data is only given on the basis of the right key.

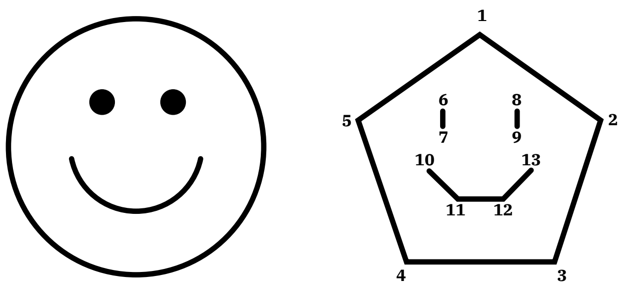
2.3. Digital twin

A digital twin can be described as a collection of data and processes in a virtual representation of physical reality.

It is a prerequisite for the use of blockchain that what you want to follow has a digital existence, and since these are largely physical objects (whether they are bolts, apples or something completely different), then the presence of a digital twin is often needed for blockchain to be applied.

In the real world, large amounts of analogue data are available. Therefore, we can theoretically get all the data we need, and we can, for example, carefully decode a shape or a figure just by looking at it. In the digital twin, the significance and importance of data is determined depending on how many data points and thus nuances are needed. The number of points in the digital twin thus depends on the specific need for nuanced knowledge.

If it is crucial to know the exact shape of a figure, it is necessary to have a digital twin consisting of several data points; in other situations, we can settle for an approximate shape as in the figure below. The more data points we have to describe the shape, the closer we get to the real, analogue world. If, on the other hand, it is sufficient to have just an outline of the form, but nuanced knowledge of the mood, only a few data points about form are necessary, but many data points are needed about elements that tell us something about the mood, such as mouth and eyes.



Reality Digital twin

The digital twin is thus a virtual representation of the physical reality based on selected and significant data from the physical reality. We can therefore ask ourselves what is central to know and to log when it comes to, for example:

- Materials
- Producer
- Production process
- Delivery time
- Test
- Maintenance
- Recycling
- Etc.

In the digital twin, simulations and processes can be run in the examples with Melanie and Peter, the car purchase or John retightening a bolt. The need for simulations and processes in the digital twin determines how fine-meshed the data network should be – how many data points are needed, and how much or how little manual registration we need to make. The complexity of creating a digital twin thus depends on the amount of data as well as the technological readiness of the value chain in relation to data collection and data management. In order for us to enter data into the digital twin, we need to know what the individual actors and items are called: the bolt, the technician, the tool and the car, the key, the account etc. For this purpose, a DID is used, to which the next section introduces you.

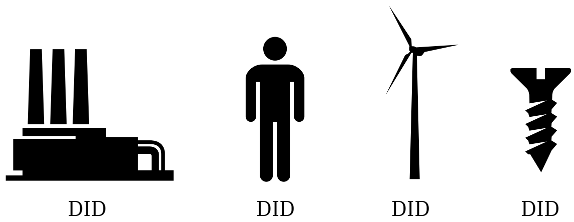
How expensive is it to make a unique identification (DID) of an object per unit?

It depends on the degree of complexity, and the prices therefore vary a lot. Laser engraving in metal would typically cost approximately 0.5-2.00 euros per unit. An RFID tag is available for approximately 6 cents. You can also use, for example, a QR code on a sticker that costs around 10 cents per unit. A traditional serial number can also work if it is unique. Typically, you assign a DID to a bolt like this: TYPE (bolt) / COMPANY (Bill's Smithy) / NUMERIC SEQUENCE (abcdefg123456789)

2.4. Decentralised Identifiers (DIDs)

The blockchain enables decentralized identification of entities, such as organisations, individuals, objects etc. As opposed to traditional identifiers, which are controlled by central authorities and are assigned and removed at their whim, decentralized identifiers (DIDs) are created by and for the entities that they are assigned to, are persistent and resolvable. A DID makes it possible to identify all devices and objects – just as a URL makes it possible to identify a website

What is a DID – Decentralized Identifier



Each DID can be linked to a series of data stored in the blockchain, and this data can be accessed via the DID. On a screw, it can be data about production, mounting, materials etc. With a DID, a physical object is recreated as a digital twin that can be attached to a blockchain.

The significance of DID's can be illustrated using the example of John having to retighten a bolt on the wind turbine.

An example:
John has been given the task of retightening a bolt in a wind turbine. During the retightening, John discovers a defective bolt, which means that it cannot be retightened sufficiently due to a defect in the thread. The bolt needs to be replaced to prevent failures, and John estimates that it could look like a general production defect. Using a DID on the bolt, which is registered in a blockchain, access is given to pieces of data about the bolt for which the DID is assigned – for example manufacturer, production time, batch, raw materials, assembly time, technician, position etc. As all bolts are marked with a unique DID with associated mounting location, it is possible to identify other bolts with the similar properties attached and thus track the bolts in order to replace them so that failures can be avoided.

For a DID to work, it must be put on an object – for example in the form of a QR code, an RFID tag or just a simple, unique serial number, which can be read and gives additional information about the location of the associated data in the blockchain.

How much does the blockchain solution pollute?

Cryptocurrencies, like bitcoin and other public, permission-less blockchain solutions, use a lot of computing power during transaction verification, whereas private, permissioned blockchains, like the ones described in this whitepaper, have a much less intensive verification process of transactions since only trusted partners are allowed into the blockchain. Thus, the closed blockchains require the same amount of energy as it usually requires operating a network for the exchange of encrypted data between companies.

It is thus crucial that all the items you want to track are marked with a DID. At the same time, you must be aware of where on the item you place your DIDs and in what form. In the case of wear parts, the DID should be placed so that it is not worn and damaged. Special temperature conditions, including weather and wind conditions, may also be necessary to take into account. Finally, it is essential that the DID can be read and resolved without causing unnecessary downtime. In sum, there is a lot to consider in relation to DIDs, and overall, one should consider durability, costs and that the solution is easy to use.

An example:
In the usecase, the bolts have an estimated service life of 25-30 years. These bolts will be exposed to significant amounts of salt due to their position, and hence corrosion will occur.

A QR code on the items was laser engraved in different depths, and techniques and bolts were tested in a laboratory for three weeks. It turned out that the QR code would be unreadable in just 10-15 years. Therefore, another solution was found. You can read more about this in section 3, A bolt's journey in the value chain – a usecase in the unwind project, which describes the usecase.

Thus, it is necessary to test your carrier of the DID if longevity is essential for value creation.

2.5. Verification of digital certificates

A fundamental feature of blockchain technology is, as previously mentioned, that data cannot be manipulated and altered, creating security in transactions. Each time data is registered in a blockchain, data is verified with the other partners in the network. In case of a private blockchain-network, data is thus subsequently locked with an encrypted key. The possibility to verify the authenticity of a transaction is thus a key element of blockchain technology in several aspects.

Some of the objects that can be verified in a blockchain are certificates. When, for example, machines or parts of a machine are to be serviced, there is a need for a certified service technician who can document the right competencies and qualifications to service the machine in question. It is important that the technician has the right competencies as the process of servicing a machine is complex and mistakes might cause technician injuries or damages equipment leading to down time. The right technician competences could be documented via a digital certificate. Certificates may be revoked, if needed, for example, when the acquired competencies are deemed to be refreshed or updated.

In the context of a blockchain, digital certificates can be issued by a trusted authority, for example, a course or education provider. Since the certificate is signed with the private key of the issuer, its contents cannot be changed or manipulated. However, it can be cancelled if a certificate is no longer valid. The certificates may be verified for their validity by any external instance, by accessing a webservice of any node in the network that makes sure the signature matches the public key of the certificate issuer. This makes the blockchain an effective technology for issuing and verifying digital certificates and thus avoiding cheating, potential accidents and defective machines.

Let us return to the example of John having to retighten a bolt in a wind turbine.

Who owns data in a consortium blockchain?

The short answer is that no one does and everyone does – simultaneously. Thus, no single central server is hosting the data. Data is located on all devices at all times. This has the advantage that there is no single point of failure. In other words, collaboration in the blockchain can continue with intact data if a partner drops out.

An example:
John has been given the task of retightening a bolt in a wind turbine. Three years earlier, John took a course that gives him the skills to retighten bolts on wind turbines. He has received a certificate, which has been issued by the course provider, who is identified by its DID. Via the blockchain, John is assigned the task, and his certificate is automatically verified through a smart contract that checks that he has a valid certificate. Once the certificate is verified, John can receive more information about the task. John can thus only solve the specific task if his certificate is verified. During the task solution, John checks in a number of data in relation to his work and his actions. For example, which tool has been used, position of the bolt, torque when tightening, time etc. The check in of data can be done manually, via scanning of DID-marked tools or perhaps using an IoT (Internet of Things) tool as a digital torque wrench. After completing the task, John answers some questions about the task, which are also registered in the blockchain. After this data entry, the work is registered as completed, and payment of a fee can take place.

Rather than spending work hours checking the authenticity of certificates, this can be turned into an automated process in the blockchain and as an integral part of the task solution. This reduces the risk of human errors and failure to verify certificates in time-constrained situations.

The following illustrates how a blockchain solution can also help reduce potential tampering with acquired competencies.

An example:
Mike dreams of writing a PhD at the University of Hamburg. Mike studied for a master's degree at the University of Falioré in Italy but did not pass the final exam. However, Mike is cunning – he has tampered with a fellow student's diploma so that it looks as if Mike has been awarded a master's degree. In a blockchain-based application process, Mike is applying for a PhD position at the University of Hamburg, but the University of Falioré is also part of that blockchain and cannot validate Mike's diploma. Mike will therefore not be awarded a PhD position.

The example illustrates how blockchain technology makes it possible to continuously verify information, competencies and actions and thus create security and transparency. This significantly reduces the cost of checking facts and data, and it can increase security during wind turbine installation and for the employees.

2.6. Blockchain network – public, private or consortium

When a blockchain is created, a series of parties that participate in the network have the right to write in the blockchain and decide whether further parties may join the blockchain network. Three types of blockchain networks generally exist.

2.6.1. Public blockchain network – permission-less

In a public blockchain, everyone may be part of the network and thus have access to data and the right to add data to the blockchain. Typically, public blockchains introduce a cryptocurrency and use time- and energy-consuming consensus protocols to keep the network secure.

2.6.2. Public blockchain network – permissioned

In a public permission-based blockchain, everybody can read from the ledger (the series of blocks, on which transaction details are recorded), but only certain partners are allowed to write data in the ledger. Furthermore, this type of network is managed similarly to a private-permissioned network.

2.6.3. Private blockchain network – permissioned

In a private blockchain network, only a closed group of parties have access to data and the right to enter data into the blockchain. Additional partners may participate by means of invitation and are then included in the network typically by vote from the current members.

A private blockchain network is useful in business contexts where a consortium of actors collaborates on a project. Data is thus shared only with the actors that are relevant in solving particular tasks.

3. A bolt's journey in the value chain – a usecase in the UnWind project

The wind turbine industry is an industry, which is dependent on many subcontractors and safety procedures in the production, transport and installation of wind turbines. Thus, there is a lot of information, which is essential to share and pass on throughout the process to ensure the most efficient and secure processes.

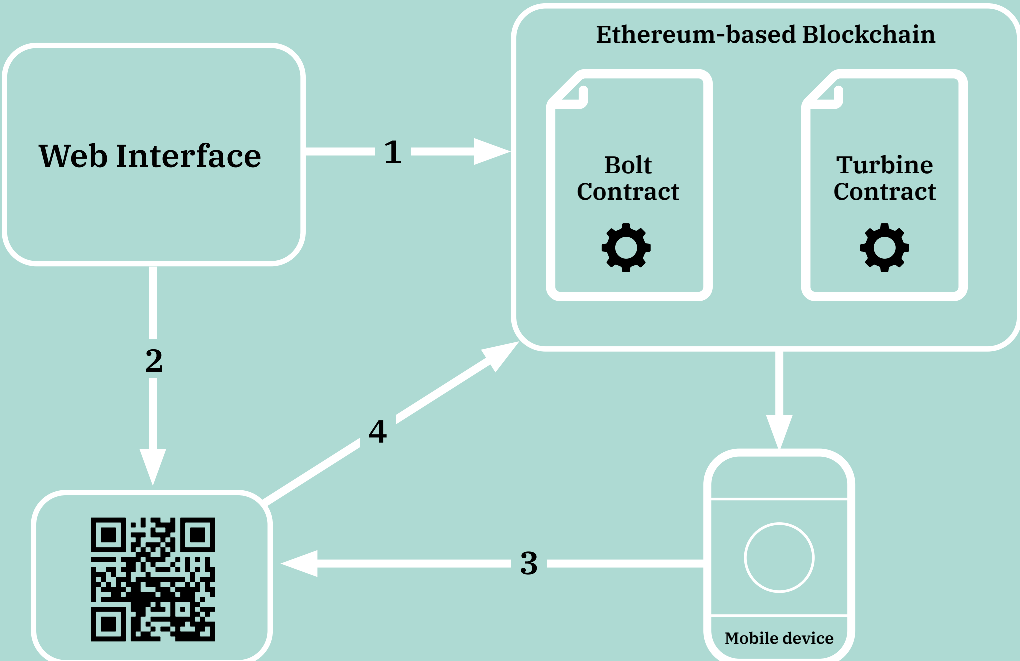
For example, in all wind turbines, thousands of bolts connect the parts of the wind turbine. These bolts are crucial to the performance of the wind turbine, and a defective bolt or its mounting can result in faults or failures in the wind turbine.

Today, the majority of all data and information about the wind turbine components is stored in digital documents. The remaining part is stored in paper form. Thus, the availability of the information may be limited, and the information is rarely updated in real time, implying that changes are not necessarily registered. This makes it difficult to handle unforeseen events in the value chain and can make it difficult to predict faults and failures and subsequently check the respective liability. Both unforeseen events and failures have major safety and financial consequences for wind turbine manufacturers.

The UnWind project demonstrates the application possibilities of blockchain technology based on the bolts that connect components in a wind turbine. More specifically, the purpose is to establish a usecase based on the following four phases.

3.1. Phase 1 – registration

In phase 1, a blockchain network is created with the corresponding parties (bolt and turbine suppliers, service maintenance and recycling parties) and the first data records are registered on the ledger consisting of the initial supply of DID-marked bolts and available turbines.



The registration phase consists of the following actions: 1. Supplier fills in bolt / turbine properties and adds the record into the smart contracts in the blockchain 2. QR Code to blockchain interface gets generated 3. Mobile device scans QR Code and follows the link 4. A call to the Smart Contract gets issued 5. Smart Contracts return the requested bolt / turbine record.

3.2. Phase 2 – service

The bolts are initially mounted in turbines at specific positions by the service technicians. The technicians also verify the bolts tensions periodically to check whether the bolts are in good condition. The service technicians register their certificates in the blockchain ledger. Once the certificate is verified, a bolt-mounting or verification task is assigned to the service technician. The date/time of action, the tools used, and further collected data etc. are registered in the ledger.

3.3. Phase 3 – completing a task

After servicing the bolts, the result is registered in the blockchain ledger: Was the servicing successful, or did points of attention or faults emerge? Once the result has been verified by the person requesting the task, the task is completed and payment for the service takes place through the blockchain.

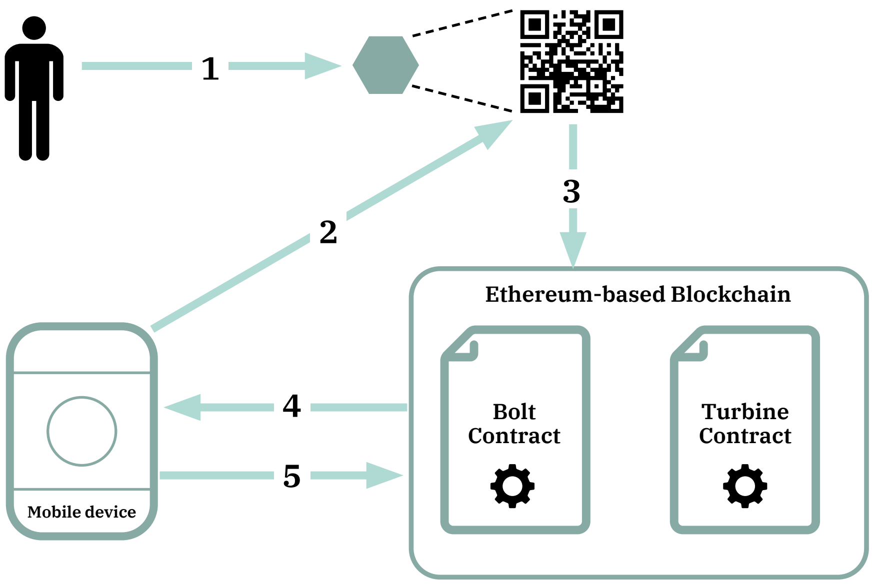
The model below illustrates the use of blockchain in the wind turbine industry – including the data available in the blockchain and the order in which data is entered into the blockchain.

The maintenance phase takes place in several steps: 1. Service Staff verifies tension of mounted bolt. QR Code on bolt is being scanned with mobile device and follows the link 2. A call to the bolt / turbine Smart Contracts is issued 3. The identified bolt and turbine are retrieved and shown on mobile device 4. Outcome of maintenance is added to the blockchain

3.4. Phase 4 – circular "decommissioning"

When a bolt is removed, it is marked as "not in use" in the blockchain ledger. For example, if an entire turbine is taken out of operation or if an individual bolt is replaced. The bolt can then be reused or the metal from the bolt can be included in the creation of new components with full traceability and documentation of the bolt's journey from cradle to cradle.

By using blocks of data, all of which are accessible in the same system, the intention is thus to demonstrate the possibilities of sharing knowledge and conducting intelligent data analyses that may, for example, be useful when backtracking and forecasting in relation to wind turbine failures.



4. Drivers and barriers for blockchain in the wind industry

Through conversations with wind turbine manufacturers and subcontractors, a number of drivers and barriers for the development and implementation of blockchain technology in the wind industry can be identified. The conversations are about the business opportunities they see in the technology and considerations about the barriers that will potentially be encountered during implementation. Depending on the interviewees' knowledge of blockchain, the conversation has either been based on 1) the blockchain technology where conversations addressed potential business opportunities, or 2) the existing business and its challenges where the blockchain's properties are presented and discussed as a potential solution or improvement.

4.1. Drivers for blockchain in the wind industry

The following describes the drivers that are crucial for wind turbine manufacturers and subcontractors in relation to taking the first steps towards blockchain technology implementation.

4.1.1. Competitive cooperation

A recurring theme in the conversations with contractors and turbine manufacturers is that a blockchain solution and the prior work on standardisation of business processes not only benefit from, but almost depend on, a collaboration among companies that normally compete. In other words, if the turbine manufacturers cannot agree that certain business areas should be collaborative rather than competitive, then the blockchain solution will not create value (or at least not as much value as it potentially could), since the technology is indeed meant to improve the business ecosystem (i.e. the industry as a whole) rather than just benefitting a single or a few companies. Exactly this willingness to cooperate with competitors, in order to achieve common value, is one of the characteristics of the industry and this usecase. During several independent interviews, industry representatives made it clear that they see advantages in cooperating with their competitors. In addition, what may seem surprising at first is that it is the closest competitors in which you see the greatest cooperation potential, as you know that these companies deliver reliable products on a par with those produced internally in your own company. The repeated examples of willingness to cooperate are about making the cake (i.e. the market) bigger, rather than taking a bigger slice (i.e. market share) of the cake. This can be done by lowering costs in the value chain through standardisation and having the common view that the real competitors are, firstly, producers of solar energy and other renewable energy sources and, secondly, fossil fuels.

4.1.2. New business opportunities – joint innovation and digitisation of service sales

The prior work on standardising business processes and the willingness to collaborate in the industry do not only pave the way for the blockchain usecase, but also for other kinds of collaboration within innovation processes. By creating common conditions for business processes and by having a common platform for data storage and sharing, an opportunity is also created for further innovation across company barriers. The digitisation and standardisation of transactional business processes on a common platform, such as blockchain, creates a larger availability of data that forms the basis for optimising various processes in the industry. Due to the cryptographic anonymization of data, which blockchain uses, big data analyses of the available data in the blockchain could potentially lead to new experience and opportunities based on this larger availability of data than what the individual companies have access to. A further advantage of compiling and digitising the transaction history is that the sale of the service information is made possible allowing the companies involved to resell additional data to their customers. Especially in a service context, companies can benefit from being able to access additional information from suppliers more quickly, which is made possible by the smart contracts in the blockchain.

4.1.3. Reduce costs

Of course, wind turbine manufacturers make a living from producing energy based on wind power. Thus, if a wind turbine does not produce energy, it has large economic costs. Bolts are among the many key components ensuring a turbine's efficient production, and they are vital for the wind turbine's operation and thus profitability. For the same reasons, one of the biggest drivers for implementing blockchain technology is the opportunity to reduce wind turbine failures, but also to be able to quickly determine who is responsible for failures and to gather learning from the failures that might occur. The following presents two perspectives on reducing costs associated with failures.

Backtracking – quick troubleshooting and clarification of legal liability

When a defective bolt is identified, it is crucial that a backtracking process is initiated: What type of bolt is it? Where is the bolt produced? For how long has it been in the wind turbine? When was it last checked? The purpose of backtracking is to obtain clarity on the factors that have caused the malfunction, which again resulted in a failure. This is to prevent similar failures.

Today, it is possible to identify a bolt at the batch level through written documentation from subcontractors – typically stored in office binders or simple Excel sheets. This implies that identifying a specific bolt is impossible and that it is a time-consuming process to identify a bolt at batch level. Consequently, the backtracking process becomes blurred, and hence, it is impossible to isolate all the relevant factors causing the failure.

Another aspect of extracting data from a blockchain and performing intelligent analysis is the opportunity to reduce costs associated with legal disputes. By extracting verified data from the blockchain, any dispute, including its associated data, can be submitted to a judge who can then settle it. Thus, the internal use of resources can be reduced in the respective organisations.

Forecasting – predictive maintenance on shared data pool

When a defective bolt causes a wind turbine failure, the backtracking process, as described earlier, begins. In addition to being able to identify the failure, the backtracking process contributes to forecasting future failures. The more data a wind turbine manufacturer has about a specific bolt, the easier it becomes to identify other bolts that might also fail. Today, it is often the case that only very general data on the bolts is available, which may lead to intact bolts being checked for no reason or even replaced which is a costly procedure.

Blockchain thus enables a more proactive (rather than the current reactive) approach to the replacement of components, so that the quality assurance of the turbines' uptime is generally enhanced and it is not merely a question of performing quality control of the individual turbines.

The possibility of being able to collect and store larger amounts of data in a blockchain and thereby make intelligent analyses of data in connection with backtracking and forecasting is thus considered a significant element of blockchain that can reduce costs associated with failures considerably.

4.1.4. Updated and shared data

From the time a bolt is produced until it is mounted and subsequently checked, it has undergone several processes and may have become part of a large collection of components. As in the example of the apple changing hands many times along the way before ending up in the consumer's shopping cart, the transfer of bolts often takes place on paper or in simple digital documents, which are sent from one company to the other. The risk of errors and delayed information is therefore increased. This is a challenge in an industry where fast action is often needed and where safety is a crucial factor.

In a blockchain, all actors connected on the blockchain have live access to the necessary and correct data to which they are assigned access. For example, a subcontractor who produces a component for a wind turbine thus has the option of extracting the exact data about the wind turbine from the blockchain before production starts and is thus not dependent on the wind turbine manufacturer submitting the necessary and updated data in time.

The possibility for all actors involved to exchange data immediately is thus considered a significant driver in terms of streamlining and reducing errors.

4.1.5. Verification of tests – greater confidence in test processes increases quality and reduces costs

In cases where documentation processes are manual, testing of components and competent servicing of parts on the wind turbines depend on the trust in the individual test employee or service technician: Confidence in the fact that what is documented is an expression of reality. In global value chains where one supplier can easily be exchanged by another, a risk may be that the documentation material is incomplete. For example, components may have undergone multiple tests before passing but this fact is not mentioned in the documentation material.

In a blockchain, all data about testing, certification, etc. is collected and made available to the company, which is why all knowledge about production, testing and certification is transparent.

The fact that the possibility of cheating is removed is thus of crucial importance for the company, especially in relation to ensuring quality and reducing failures.

4.1.6. Common standards for Decentralised Identifiers (DID) will lift the industry

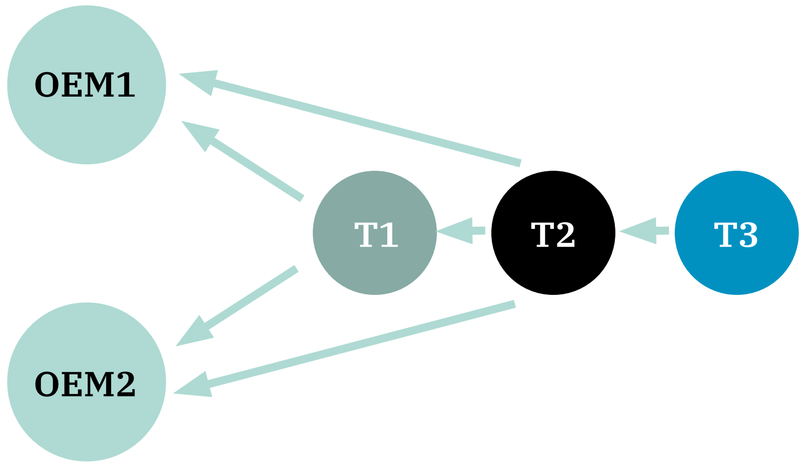
A wind turbine manufacturer's value chain consists of a large number of suppliers and subcontractors. In many cases, these suppliers and subcontractors supply components to more than one wind turbine manufacturer, as illustrated on the next page.

Each OEM (Original Equipment Manufacturer) works according to a number of standards for the components used in the construction of a wind turbine. Due to different standards at the OEMs, there are also different requirements for suppliers and subcontractors regarding standards and data transparency. Due to all these different standards and requirements, it will be difficult for suppliers and subcontractors to label their components with a DID, as these will differ among OEMs.

A higher degree of transparency in the value chain enables standardising components and developing a common DID that makes it possible to establish a blockchain where all actors in the value chain can be included. In addition, standardisation is considered an enabler for raising the quality of the developed components.

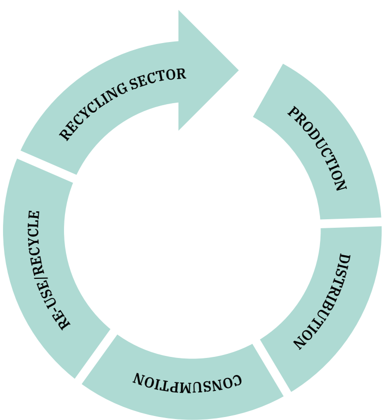
4.1.7. Sustainability – where do the turbines end up when not in use? Documented reuse, recycling and sustainable disposal

For many companies, sustainability is gaining increased focus and over time, it is incorporated into the company's business model. This also applies to companies in the wind industry where the ambitions and requirements for documented sustainable behaviour are high. In the wind turbine industry, sustainability is a basic condition, as wind energy in itself speaks into the sustainable agenda. The industry is experiencing, however, that ever greater demands are being made on the company's activities, which go beyond the actual production of energy. These demands include purchasing, the company's own energy consumption, transport and not least recycling of end-of-life turbines. There is a requirement for documentation of how the



OEM; Original Equipment Manufacturer: Company supplying finished products for wind farms such as wind turbines (tower, nacelle, blades), foundations, substations, cables etc.
Tier1 supplier: Companies that are direct suppliers to OEMs by supplying modules, assembled systems etc. and handle smaller suppliers towards OEMs.
Tier2 supplier: Companies that are suppliers to Tier1 companies by supplying sub-components e.g. parts for gearboxes.
Source: https://studypedia.au.dk/fileadmin/user_upload/Vejledning_Professionshoejskolen_metropol.pdf

turbine components can be recycled which is not possible to a sufficient degree today.
Empirically, sustainability and being able to document sustainability are described as crucial for the choices the company makes. The transparency that blockchain creates in relation to materials and their use thus enables the correct disposal of bolts and other materials, which through the blockchain can be documented and used in the company's sustainability accounting.



Thus, the individual sub-components can be traced via their DID from cradle to grave and to cradle again. This is seen as a significant driver for the implementation of blockchain technology. Especially because Wind Power Customers (WPC´er) such as Ørsted, Vattenfall, BP, Shell etc., increasingly becomes a more active part of the value chain. Both in terms of construction, service, maintenance and decommissioning.

4.1.8. Energy consumption and Levelized Cost of Energy (LCOE)

In the energy sector, one of the most important economic perspectives within production technologies is the Levelized Cost of Energy/Electricity (LCOE), which is a measure of the average net present cost of electricity generation for a generating plant over its lifetime. An example of a unit of measurement is EUR/kWh.
This perspective is worth noting for this usecase, as it is ultimately the overall goal of the wind industry to reduce the LCOE as much as possible since this implies that wind energy becomes more competitive with other energy sources such as fossil fuels.

The reason why this usecase will help reduce the LCOE for wind energy is the fact that the service of wind turbines will be significantly streamlined through the common database that blockchain offers. By making the service processes more efficient, the downtime for the wind turbines will thus be reduced, and the operational time during which energy can be produced will increase, which means that the turbine produces more power during its lifetime and reduces the LCOE.

4.2. Barriers for blockchain in the wind industry

Just as the industry has clear drivers to move in the direction of blockchain becoming a technology for more competitive individual organisations, value chains and business ecosystems, there are also obvious and fundamental barriers that should be addressed.

4.2.1. Uncertainty about the possibilities of blockchain – show us that it works and make a business case

One of the biggest barriers to the interests of wind turbine manufacturers and suppliers in the development and implementation of blockchain technology is the lack of knowledge about how the technology works, its applicability and the company requirements in relation to being able to implement the technology. The uncertainty thus ranges from general questions about application possibilities and potentials to specific questions about how, for example, a bolt is marked with a unique DID and what equipment it requires to use the technology.

A consequence of the lacking knowledge about the technology is thus that the view on the technology's application possibilities is limited to what the individual person knows. Therefore, there is a need for a demonstration of blockchain technology: how does it work, what are the possibilities, and what does its application require of the company? In other words, there is a need for both usecases and business cases.

4.2.2. Is transparency always full? – Necessary and secure control of access to data

The question about data transparency has been asked in many contexts and is often seen as a prerequisite for using blockchain technology but this view is wrong. From the individual company's perspective, full data transparency is thus seen as an advantage when it comes to the company gaining access to subcontractors or competitors' data on materials, production, tests etc. Being able to analyse on a large data set is considered value creating and crucial in the attempt to minimise the risk of failures. From the companies' point of view, the challenge with transparency is that data from the company also becomes visible to the subcontractors and other business partners. This raises the concern that full data transparency gives business partners a competitive advantage exemplified by the following statement.

"If we store [information] in a common blockchain, we are not interested in our customers being able to see everything we upload – nor in the fact that our suppliers will be able to see everything as well. We do not want full transparency so the question is whether blockchains can be used in our company at all."

Here, it is important to note that the individual person's access to data is regulated by predefined roles and what kind of access to data that role gives. Although data is shared in a common structure, the data is encrypted. Thus, only actors with specific access rights can look at the data matching these rights. Transparency in data is, therefore, more like a perceived barrier that often exists before a company starts using blockchain technology, rather than a real technological barrier since the control of data and access to data is an implicit functionality.

4.2.3. Implementation of blockchain technology – finance/investment

Implementing a blockchain in the form of developing or purchasing technology requires a financial investment. The size of the investment depends on the level of digitalisation in the organisation. Companies often see it as a challenge to commit themselves to this investment, as long as the technology is not a direct request or the value creation is not clear.

4.2.4. Data hosting and maintenance – do we have the skills and do we want to spend the time?

The amount of data embedded in a blockchain requires hosting with the individual partners. At the same time, the blockchain's smart contracts and data structure must be maintained. This requires time that an actor must be willing to spend. When it is not clear who this actor is or how long it will take, it becomes a barrier to the organisations' interest in implementing blockchain technology.

4.2.5. Local is not enough – it must work in a global network

OEMs operate both nationally and globally. Components and materials are also supplied from all over the world. In order for the technology to create the desired data transparency, there is thus a need for a global network of actors who use the technology.

4.2.6. Trust in suppliers: technology-based trust or control?

Contracts form the legal and formal "glue" that binds value chains together and that handles disputes and placement of liability. However, not everything is described, nor is it practically possible to describe all possible scenarios and their consequences. Suppliers, partners and customers' repeated interaction builds levels of trust over time. Supported by dyads of relationships, and accumulated, the individual levels of trust are linked to entire organisations in the form of an overall external perception of, for example, a company's reputation.

Therefore, trust can at times become the lubricant that reduces the transaction costs of critical events and of the conclusion of agreements. It is a means of increasing the speed with which agreements are concluded and of reducing certain parts of the associated administrative burden. Conversely, value chains also risk becoming more rigid regarding the possibility of replacing partners in situations where the cooperation is largely based on trusting relationships than on explicit contractual relationships and transparency. In other words, trust takes a long time to build and a short time to break down, and trust presupposes a history of exchange of services.

It is therefore costly to replace a supplier, to which you have close trust ties, with a new supplier without these ties, and it is difficult for external parties, such as investors, to qualify trust. In other words, it can be difficult to obtain an additional price based on long-term investment in building trust and close cooperative relationships. Instead, companies have to capitalise on the investment through repeated successful deliveries and reduced transaction costs between the actors.

To a certain extent, blockchain offers a technological opportunity to substitute relationship-based trust with technology-based trust. The closeness with which a common blockchain is integrated into the partners' ERP systems, and the depth with which it is anchored (as-built, smart contracts, mounting, documentation, test data etc.), determines the level of trust.

"After all, introducing blockchain technology would be a breach of trust. This is like telling my suppliers that I do not trust them - that they have no control over their production, or that they are trying to cheat."

Or put another way, the argument for not complementing the relationship-based trust is that "if you try to control trust with technology and quantify it, it disappears while you are trying to find the measuring tape". Here, the opposite argument would be worth considering, i.e., to which extent our established trust between business partners also has an impact on potential investors.

5. Blockchain in the wind industry – are we ready?

The work during the UnWind project has resulted in the above drivers and barriers and how they affect a company's readiness regarding the implementation of blockchain technology. These drivers and barriers can be further categorised into a range of themes describing their nature. In relation to a company's readiness, the following themes have emerged:

- Technological readiness
- Organisational readiness
- The readiness of the value chain
- The readiness of the business ecosystem

In the following, the above is explained further in order to clarify the elements that affect whether a company is ready to implement blockchain technology. In addition, some reflection questions are presented, which aim to strengthen companies' awareness of their own organisation and clarify challenges and potentials regarding the implementation of blockchain technology.

The aim is thus to ask you a few, relevant questions, which originates from our research within the industry, and which can help to clarify whether blockchains are something that you as a company, as (part of a) value chain and business ecosystem should give greater focus, or whether it is not the right time yet. The final decision is necessarily more complex, but the questions below have proven to be some of the key elements that should be addressed first and discussed.

5.1. Technological readiness

To a large extent, a company's overall readiness in relation to blockchain implementation depends on the company's technological readiness. In recent years, many companies have focused on digitising processes and procedures in order to streamline them. Companies that mainly work analogously need to make greater investments, also in terms of time, to digitise processes and procedures in order to be able to implement blockchain technology as opposed to companies where processes and procedures are already digitised and automated. Furthermore, technological readiness

is influenced by the company's digital infrastructure. For example, do all relevant devices have an internet connection that can be used in order to access the blockchain?

Thus, companies that store data in office binders; companies that collect data in Excel sheets and share them via email; and companies that collect data in an internal database to which all employees have access have different technological starting points for implementing blockchain technology.

Although a company has a high degree of digitisation, its technological readiness may be lower than expected: In addition to the degree of digitisation, a company's technological readiness is influenced by whether its digital solutions can be integrated with the blockchain technology.

In other words, technological readiness is influenced by a company's degree of digitisation, digital infrastructure and the ability to integrate blockchain technology into the company's existing systems.

5.1.1. Reflection questions

- How digital are we in our work processes, and how capable are we at documenting and managing data in a disciplined and structured way?
- Do we have the necessary infrastructure? And do we know what it takes to scale globally?
- Can our existing systems integrate with blockchain technology?
- Did we undertake technological efforts with which we did not succeed due to lack of support and commitment from suppliers?
- Do our current systems limit us in achieving our visions for how technology should support business and the integration of the value chain? And can blockchain be a possible alternative in this context?

5.2. Organisational readiness

Whether a company is ready to implement blockchain technology is greatly influenced by the company's organisational readiness. Organisational readiness relates to the resources, competencies and qualifications that should initiate and enable the implementation of blockchain technology, as well as the frameworks and structures that influence the company's processes and procedures.

What is crucial is that blockchain implementation is a strategic focus, not only on the technological part but also on the entire business model of the company. Blockchain technology will trigger several changes in the company if its full potential is to be achieved – both concerning workflows and processes but also concerning the company's value propositions. Without a strategic focus, the risk increases that the technology becomes a decoupled system demanding many resources without creating real value.

To ensure a strategic focus, the management must be able to see the possibilities of the technology. The organisational readiness is therefore dependent on the management's ability to see the possibilities of the technology in relation to its business model – even though it is a technology and a number of application possibilities that are still under development.

The implementation of new technology like blockchain requires many different digital competencies. These competencies are needed to implement the technology and to operate and maintain it after implementation. Thus, it is not enough for a company to buy external help in the implementation phase – there is also a need for employees with special competencies when the technology is to be used.

Many companies have gone through endless change processes, including digitisation processes. This demands that employees are ready for change, that new competencies are acquired and that workflows are reorganised. Technological change cannot be implemented successfully without the employees, and therefore, the organisational readiness is greatly influenced by the management's and the employees' belief that digitisation creates value and makes sense for the company, the employees and the customers.

5.2.1. Reflection questions

- Are we prepared for the fact that blockchain technology cannot be implemented with a technological focus only, but that it also requires a strategic decision at management level to ensure sufficient implementation power and coherence with our strategic business model?
- Can our management see the perspectives in blockchain technology, and is it willing to prioritise resources to gain experience with this technology?
- Do we have the competencies to operate our part of a blockchain server and the associated tasks in relation to retrieving data from DID's, or can we acquire these compentencies?
- Do we have positive experience from the past with the implementation of new technology paradigms that have required rethinking of work processes?
- Do we believe in digitisation version 3.0 with increased transparency and sharing of certain data types?

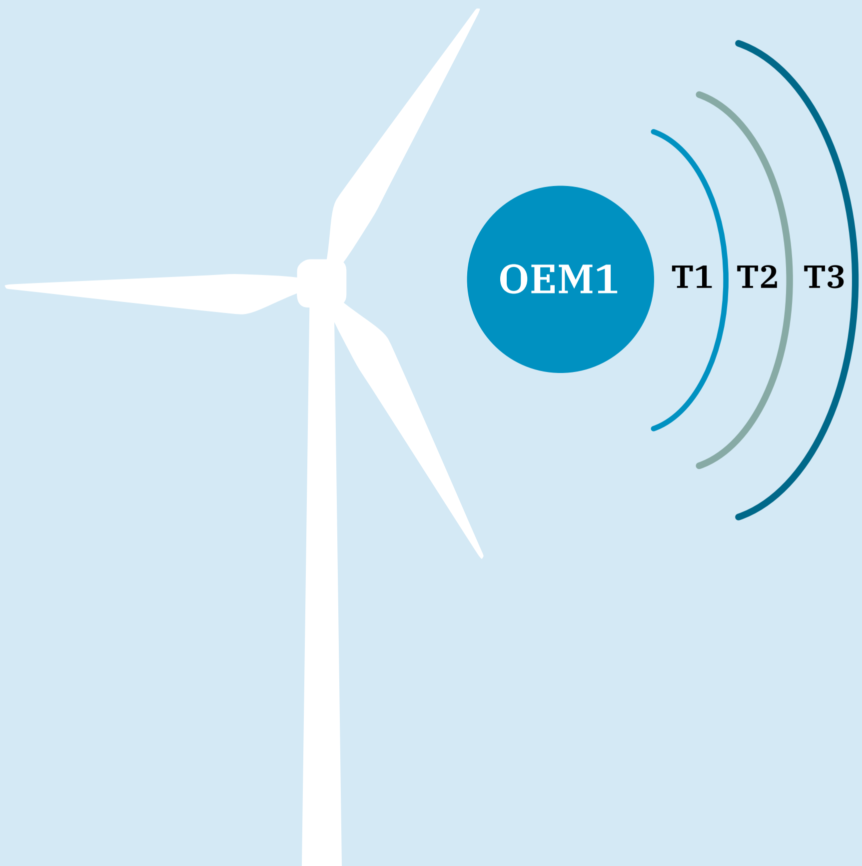
5.3. The readiness of the value chain

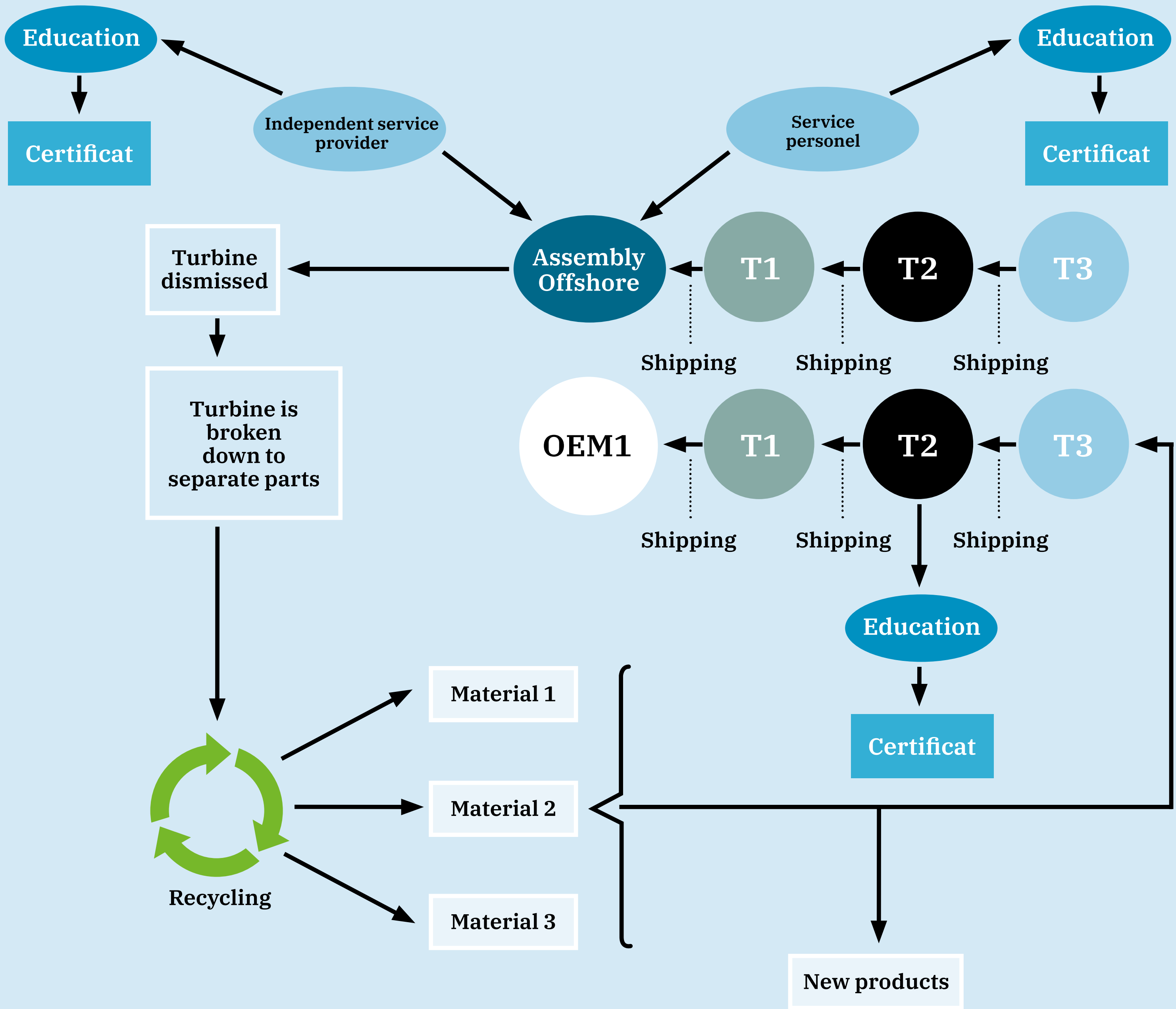
Once we have addressed the company's technological and organisational readiness, it is equally important to address the overall organisational and technological readiness of the value chain, which is the result of the sum of all actors' readiness. The use of blockchain technology in the wind turbine industry requires that all parties involved use the technology, including the bolt manufacturer, the logistics companies, the wind turbine manufacturers etc. so that all relevant data can be registered.

Most value chains have good data on which their transactions can be based. This data can move between customers and suppliers. The speed at which this data can move often depends on how manual or automated the data generation and the data flow are. When assessing the readiness of the value chain, it therefore makes good sense to consider whether actors in the periphery of the value chain have processes that are slower and more manual than we want and aim for.

5.3.1. Reflection questions

- Do we collect digital data?
- Do we store digital data?
- Do we process data in a structured, uniform way across the value chain?
- Do the blockchain capabilities contain potential value-creating elements that go beyond what we can expect to achieve with our established systems that support the value chain's collaboration?

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Shipping
Education
Certificat
Material 1
Material 2
Material 3
Recycling
New products

The last question is particularly important because the use of blockchains requires that we are operationally mature throughout the value chain. Do we process data in a structured way – without any deviations? Do we balance the deviations with each other? If not, we risk building on a false foundation. Here, it is worth considering how the introduction of blockchain can contribute to moving towards more uniform data management and use of data.

Once the questions above have been answered for the whole value chain, the next step is to answer the questions about organisational and technological readiness for each partner in the potential collaboration.

5.4. The readiness of the ecosystem

In a value chain and its periphery, the degree of dependency may vary across actors. However, even more peripheral actors are part of the focal companies ecosystem and may remain decisive for whether an organisation, a value chain or a single supplier succeeds.

The figure above is an example of an ecosystem in and around a value chain in the wind turbine industry.

Based on the model, you can try to answer the questions below from your perspective on your organisation and your surrounding ecosystem. The model thus aims to contribute to new perspectives on your value chain and ecosystem.

5.4.1. Refleksionsspørgsmål

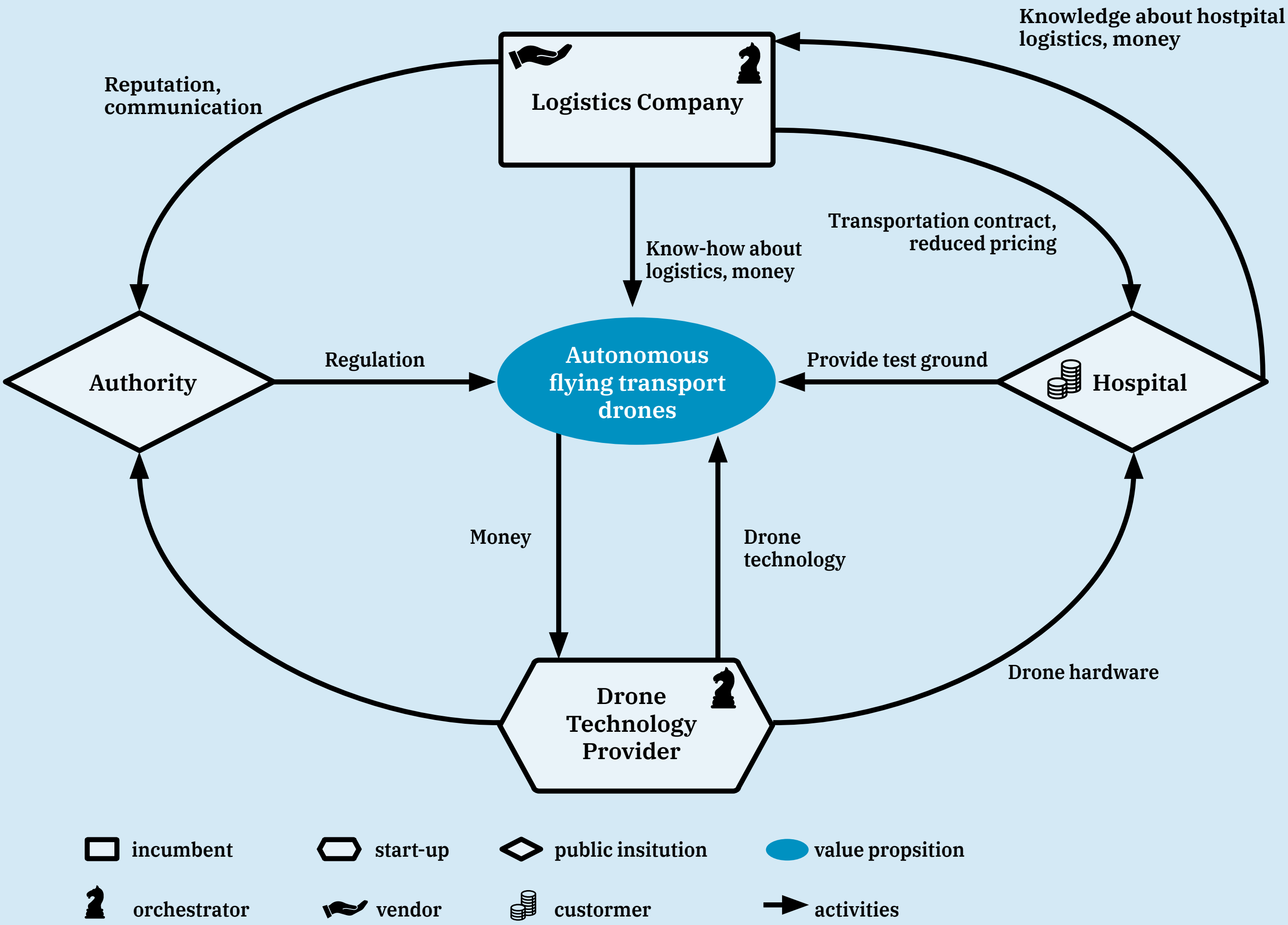
- Does our ecosystem contain areas on which it would be beneficial to achieve greater transparency? For example:
  - Training of subcontractors' employees
  - Test systems, their use and maintenance
  - Service technicians and installers and their certifications
  - Documentation of materials and recycling in connection with dismantling of end-of-life turbines
- Is it possible to enter into an open and developing dialogue with key representatives from the individual actors in the ecosystem about the possibilities of blockchain?
- Is there an advantageous business model for all actors in introducing blockchain in the ecosystem?

In continuation of the above considerations about deciding to initiate a blockchain initiative, it should be considered whether it is sufficient to assess this based on expected profitability in your company's business model. The traditional focus is here whether the potential value creation internally in one's own organisation is commensurate with the expected use of resources required to realise the potential of a certain blockchain effort. The approach is intuitively the right one regarding the internally established decision-making and evaluation structures in the established industry structures. Conversely, and due to their position and bargaining power, major players risk initiating blockchain (or other) initiatives that, in the long run, are not based on a sustainable business model for the overall ecosystem. It will often be possible to engage external partners in the early phases, but without an explicit assessment of the individual actor's business model, the risk also increases that projects do not succeed and, hence, they do not become implemented and value-creating solutions for everyone in the ecosystem.

Thus, this is not a question of your standard or mine, but a question of choosing a technology together that can handle diversity and contribute to movement from one company to another company; from the current value chain to another value chain and to future competition between one ecosystem and another ecosystem.

From a structural perspective on ecosystems, the focal organisation decides to initiate a development project based on the profitability of the organisation's business model, while weighting profitable partner business models with the same weight. This ensures a long-term commitment and a clearer understanding of the partners' changing roles during the project's development period.

"If we are to do this [use blockchain technology], we are going to do it together and talk openly about what we can each contribute and get out of it."



(Lingens, Miehé & Gassmann, 2021)
The ecosystem blueprint: how firms shape the design of an ecosystem according to the surrounding conditions: Bernhard Lingens, Lucas Miehé, Oliver Gassmann; Long range planning: LRP; international journal of strategic management. - Oxford: Elsevier, ISSN 0024-6301, ZDB-ID 160984-1. - Vol. 54.2021, 2, p. 1-53

In order to understand the partners' business models in more detail and to assess their contexts and, hence, clarify the different roles and how they develop, you can, for example, use business model blueprints as a tool and method.

6. Conclusion – potentials are significant

Based on the actual application of the technology in the usecase, the hands-on work with blockchain technology in the wind industry has documented significant potential for using the technology in the industry but also a number of challenges for realising these potentials.

- Greener industry
- More agile value chains
- Increased uptime
- More efficient service planning
- Decreasing Levelized Cost of Energy

Blockchain technology is, thus, a possible technology for realising the above potential. Some of the challenges for realising this potential are:

- Value chain readiness – are all actors in the value chain ready to use the technology?
- Technological readiness?
- Organisational readiness?

Next step

There are still many questions to answer prior to the commercial use of blockchain technology in the wind industry. The next step in the process is very much about cooperating and letting the sustainable agenda become the guiding star. In the industry today, there is generally a sharp focus on increasing the transparency of components and turbines' total CO2 footprint during their entire service life. Already today, parts of, for example, end-of-life turbines are recycled. But which ones are recycled? In what context? And with what kind of documentation and security? Similar questions can be asked for towers, wings etc., and it is expected that these and similar questions will become more frequent and more insistent in the future, regardless of whether they come from industrial customers, external investors or private end-users.

Creating the basis for this transparency is, of course, not a task that can be solved with one subcontractor's or OEM's effort, but it is something that the industry must decide to prioritise and cooperate on. Often, companies in the industry develop in individual ways, whereas the next step towards using blockchain technology requires that the industry as a whole develops in the same direction. The future competition is not about company against company, but rather about industry against industry, and here, there are signs that blockchain technology can contribute as being an important tool in order to meet the future needs in the market.

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