Technology

Blockchain in the Energy Sector

The Potential for Energy Providers

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The translation is from the German language edition, with the exception of the last chapter of the study, "Blockchain in der Energiewirtschaft – Potenziale für Energieversorger." The study was issued and published by the BDEW and done under the technical expertise of the Institute of the Energy Economics (INEWI) at Fresenius University.

Editorial

Blockchain offers the energy sector a new and extremely interesting technology that everyone is currently talking about. Experts assume its potential for driving innovation and change to be comparable to that of the Internet. The development of growing numbers of applications based on blockchain technology and the many projects initiated by energy providers underscore the scale of activities in this area and the high expectations associated with them. Utilities that become actively involved in development at this early stage will be able to secure new roles and segments for themselves.

The characteristics of blockchains promise solutions for the needs of today's energy sector and its customers. In a decentralized energy world, smooth, trouble-free information transfer between generation plants, grids, and storage facilities is essential if the energy management system as a whole is to function properly. Blockchain technology has the potential to drive the transformation to a digitally networked ecosystem comprising millions of devices. It enables secure, decentralized, and flexible information exchange. This foundation is key to enabling an ever-greater degree of networking, automation, control capability, and resilience in the future.

Alongside these opportunities, it is equally vital to analyze the areas where the technology still has technical limitations and to determine whether existing IT solutions offer similar advantages. Legal issues relating to blockchain technology also have to be considered.

Under the leadership of Prof. Dr. Jens Strüker, the BDEW German Association of Energy and Water Industries, (Bundesverband der Energie- und Wasserwirtschaft), has developed an easy-to-understand introduction, including current case studies from the energy sector, as well as future potential and an assessment of the legal situation regarding blockchain technology. This is intended to provide guidance for companies in the energy sector and to encourage the industry to adopt a proactive approach to this revolutionary development.

Sincerely,

Stefan Kapferer
Chief Executive Officer
BDEW German Association of Energy and Water Industries

Executive Summary

Digitalization of the energy sector continues to gather pace. Blockchain technology is emerging as a new driver of this rapid development, which many experts believe can bring about radical changes in the energy sector. Blockchains have the potential to optimize energy processes at almost all stages in the value chain while mastering the growing complexity of an increasingly decentralized energy system.

ADVANTAGES OF BLOCKCHAIN TECHNOLOGY

A blockchain is a constantly growing file containing all the transactions of all stakeholders. This file is stored not on a central server but on all stakeholders' computers. New transactions are added by consensus in an automated reconciliation process. This functionality is the basis for the core promises of blockchain technology: data sovereignty (usage control) and direct interaction between stakeholders (who do not know each other), with no need for intermediation by central authorities. Interaction is not confined to transactions. It also includes applications and processes, which are tamperproof, traceable, and can be executed efficiently thanks to the architecture of the blockchain technology.

RECENT DEVELOPMENTS

However, while the expectations of blockchain technology are high and the number of pilot projects currently under way is correspondingly large, there are still few market-ready applications with reliable findings. There are also very different types of blockchains, both in terms technology and functionality, all of which are developing rapidly. The market for blockchain solutions is, therefore, now diverse. For each potential application, there is the "right" blockchain. In this unclear situation, the study "Blockchain in the Energy Sector" aims to provide guidance on blockchain's potential and to enable readers to gauge the level of technological and economic maturity of the technology. This study is based on in-depth interviews, especially with providers and users of blockchain applications, as well as with IT and legal experts.

POTENTIAL FOR THE ENERGY SECTOR

Digitalization and decentralization are fueling the breaking down of the once-solid boundaries between systems and processes in the different stages of the value chain and driving the development of dynamic value creation networks. The focus of the energy system is shifting to domestic households and businesses, because they are increasingly playing an active role in the market through small-scale interactions. But it is not only users and consumers who will benefit from blockchain technology.

From an economic perspective, the opportunity to increase network utilization and efficiently organize allocation of flexibilities of any scale appears particularly appealing. Blockchain's ability to make even the smallest transactions economically viable ultimately entails new degrees of freedom; for example, for the provision of control energy, for direct electricity trading between market players, or even for shared investments. In conjunction with the digitalization of metering, blockchain technology supports new forms of product differentiation, including by generation type, location, and time. Accordingly, pilot projects are currently to be found at all stages of the energy sector value chain. Examples include the charging infrastructure for e-mobility, certification of green and regional power, neighborhood and landlord-to-tenant electricity concepts, the provision of balancing power, and electricity wholesaling. These are analyzed as examples in this study.

BLOCKCHAIN AND THE INTERNET OF THINGS

In the future, blockchain technology will create potential in one significant area. The increasing networking of millions of intelligent, autonomous devices promises to bring new levels of quality in intelligent load control. Blockchain could be the technology that ensures networking of this kind. The link between blockchain and the Internet of Things (IoT) can make a vital contribution to accelerating the speed and scale of developments in this area. Blockchains enable new answers to be found to as yet unanswered questions concerning flexible and secure rights management and reliable authentication of devices.

LIMITATIONS

It has become evident that the realizable benefit of blockchain technology for processes, applications, and services in the energy sector essentially depends on the technical criteria of speed, energy consumption, interoperability between different types of blockchains, and IT security and reliability. Furthermore, economic viability, the legal framework, and, ultimately, acceptance by stakeholders will be crucial for successful implementation of the technology. Companies, users, and IT infrastructures are not the only ones facing challenges from blockchain technology; the legal framework also has to take the associated technological innovations into account. For example, new questions arising from general contract law, energy law, and data protection law must be answered. It is foreseeable that the current regulatory framework will not be able to cover all aspects of certain blockchain applications.

ACTIONS THAT UTILITIES CAN TAKE

Blockchain technology offers energy providers many opportunities. Companies in the sector can play an active part in shaping development in this area, thereby securing new roles for themselves. Because the technology is developing extremely rapidly, they should monitor advances as well as potential changes to regulations constantly and carefully.

To leverage available potential, it is advisable for companies to gain initial experience with blockchain applications in their own organization. For this purpose, it may be sufficient to test applications that are relatively simple and easy to understand. This enables companies and their employees to acquire experience in the practical use of this new technology. It is becoming increasingly crucial to establish and continuously develop in-house knowledge of blockchain. This enables companies to leverage blockchain potential quickly and flexibly and evolve it successfully. The fact that Berlin is currently the global center of blockchain developments for the energy sector gives German energy supply utilities an advantage.

Objective

Digital transformation is now a central challenge for companies in the energy sector.[1] Blockchain technology promises to shape this development in the coming years, because it will potentially contribute significantly to the next evolutionary stage of the Internet and to the trend toward a real-time energy sector with billions of networked devices.[2]

However, there is currently a considerable gap between these high expectations and the low number of market-ready applications and small amount of real-world experience regarding technical feasibility and economic added value. At the same time, blockchain technology continues to develop at a rapid pace.

The market capitalization of the ↑ public blockchains[3] Bitcoin and Ethereum has continued to rise as a result. Figure 1 shows that the rapidly increasing financial value of Ethereum is accompanied by similarly rapid growth in the number of transactions. The resulting overall picture is ambivalent, with very high market expectations of the technology and steady growth in the use of the technology (transactions) on the one hand and an as-yet small number of market-ready and scalable solutions on the other.

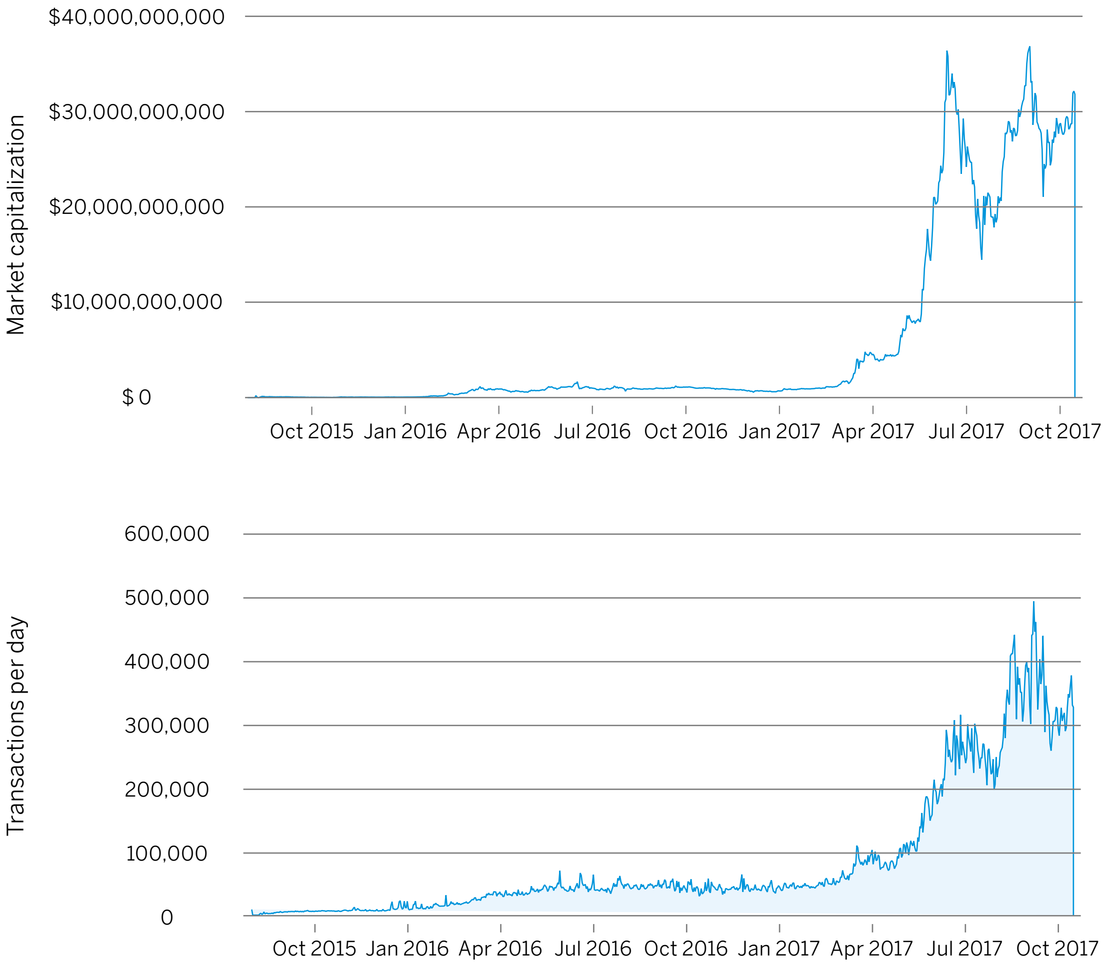
Against this background, this study aims to provide an estimate of the technological maturity and economic potential of blockchain technology for the energy sector. It is based on interviews with experts (providers and users of specific blockchain applications for the energy sector). Conducting semistructed interviews with room for discussions ensured not only that existing expectations and assumptions were examined, but also that there was scope for differentiated considerations and explanations. The content of the explorative interviews was analyzed and summarized and helps separate the hype surrounding blockchain technology from its realistic potential, thus providing guidance for the sector.

"We are undergoing a deep energy transition. Digitalization is the door to new energy realities. Blockchains may well be the key to unlock that door."[4]

Christoph Frei, World Energy Council, Energy Web Foundation

1. In 2016, the BDEW, together with its member companies, prepared a comprehensive analysis of digitalization in the energy sector in the following publication: "Die digitale Energiewirtschaft – Agenda für Unternehmen und Politik" [The Digital Energy Sector – Agenda for Businesses and Politics (German only)], BDEW, 2016.
2. Strüker (2017) and Albrecht et al. (2018).
3. Key terms are explained in greater detail in the glossary. The body text uses ↑ to refer to glossary terms.
4. BDEW (2018).

Figure 1: Ether Historic Market Capitalization (in US$) and Ethereum Transactions[5]



> "10% of global GDP[6] will be stored in blockchain by 2027."[7]

5. etherscan.io
6. GDP = gross domestic product.
7. World Economic Forum (2015).

The Blockchain Promise

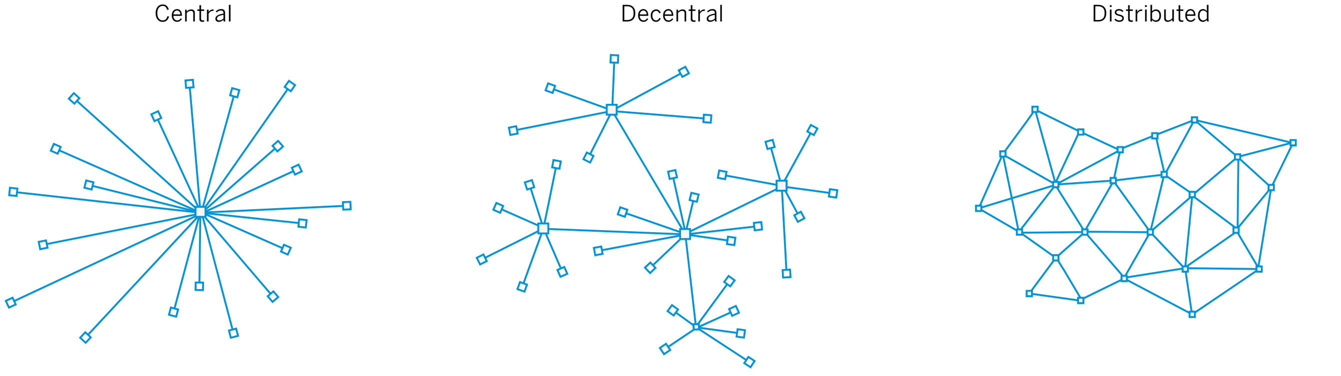
WHAT IS BEHIND THE DEVELOPMENT OF BLOCKCHAIN TECHNOLOGY?
The idea for blockchain originated in the field of cryptocurrencies. In 2008, a developer[8] with the pseudonym "Satoshi Nakamoto" drew up a concept for a distributed, autonomous neutral, and totally digital payment system that allows individuals to make transactions without intermediaries. Blockchain is the theoretical and technological foundation that combines existing peer-to-peer (P2P) databases, encryption technology, and an incentive system for activating network effects. The digital currency Bitcoin was implemented on this basis in 2009. It uses a distributed computer network (Figure 2) to process and store transactions.[9]

To generate trust without a central authority within the network, all transactions in the Bitcoin network are stored transparently, chronologically, and immutably on numerous devices. The transactions are checked and recorded by the distributed computer network. Blockchain acts as a kind of public, distributed ledger that provides all participants with a visible transaction history. However, new transactions are not all entered individually. Instead, they are collected and then combined in blocks. This results in a **constantly growing chain of data blocks.**

WHAT EXACTLY DOES A BLOCKCHAIN DO?
The computers networked in the blockchain first collect the transactions that are to be confirmed through the blockchain system. These transactions are combined in blocks, which are then attached to the previous blocks of transactions. This may sound simple, but it is actually a highly complex cryptographic calculation process designed to ensure the security, immutability, and transparency of the blockchain.

The example shown here illustrates the process for a transaction in a blockchain. The functionality in the example refers to the best-known blockchain on which the cryptocurrency Bitcoin is based. Currently, more than 520,000 blocks are concatenated in the Bitcoin blockchain (as of May 5, 2018). On average, there are around 1,500 individual transactions in a block.[10]

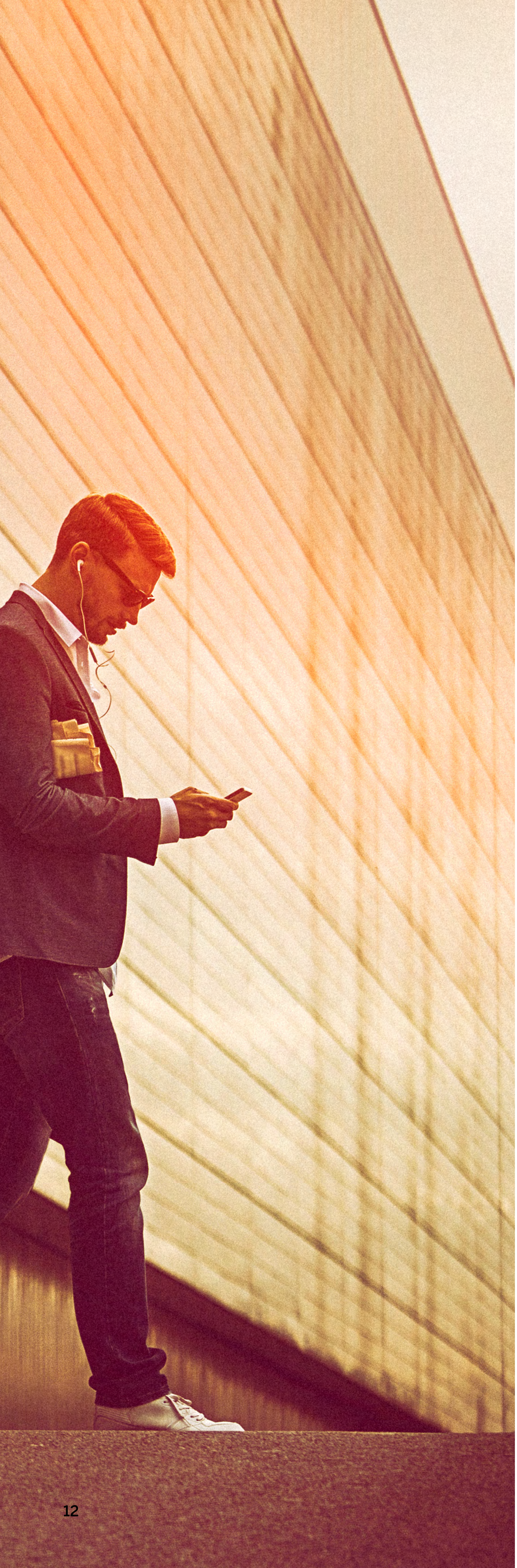
Figure 2: Distributed Network As the Basis for Blockchain



8. Nakamoto (2008).
9. Distributed databases, such as blockchain, store the entire data record at each node, while decentralized databases back up different parts of the data at individual nodes.
10. O A (2017).

Example of Process with Blockchain Technologies

	Transaction in Blockchain	Example
1	Trading partners agree on a transaction (for example, using an online platform).	Thomas and Andrew agree on a transaction. Thomas wants to pay Andrew €50 for a TV he bought from him on eBay. Each has a wallet (in other words, a digital account) on the same blockchain. Accounts on a blockchain have a public address in the network, similar to an IBAN number for bank accounts. However, only the account holder is authorized to transfer money.
2	The transaction is transferred to the blockchain network, also known as the mempool, where there are other as-yet unconfirmed transactions. Miners can now combine any number of transactions in a block.	• Transaction A: Thomas pays Andrew €50. • Transaction B: Betty pays Anthony €10. • Transaction C: Harry pays Alexander €17.20. • Transaction D: Paul pays Fiona €85.30.
3	Transactions are recorded in a block and then sent to the network for checking. Stakeholders who create blocks have no incentive to include invalid transactions in a block, since this results in invalid blocks that are not accepted by the network. Because all transactions ever made are stored, the participants in the blockchain can, for example, determine the "account balance" of a stakeholder or view past transactions and thus validate their correctness.	The system checks whether the information in the transactions in the new block is correct: "Does Thomas actually have €50 in his account to give to Andrew?" The account balances are then updated.
4	The block is assigned a unique name (↑ hash). This designation – a mixture of numbers and letters – effectively acts as a checksum. It includes data from previous blocks, a time stamp, and a kind of checksum of all transactions contained in the block. The name is determined by the algorithm on which the blockchain is based. However, the stakeholders can guess it only by repeatedly trying out random variables. The first stakeholder to guess it receives a cash bonus (after the block has finally been attached to the chain).	The transaction from Thomas to Andrew is then prepared to be attached to existing blocks. For this purpose, the block containing transaction A is given a unique name (#transaction-block100). This name is based on the contents of this block and the contents of all previous blocks. This ensures that no individual block can be subsequently changed.
5	The new valid block is attached to the previous blocks. Only valid blocks are accepted. The connected computers, known as ↑ nodes, check whether the unique name (hash) is free of conflicts with the previous blocks and, if it is, accepts it. The block is now part of the chain.	The transaction from Thomas to Andrew is now officially confirmed and stored immutably on the blockchain.
6	Both parties can see that their transaction is confirmed in the blockchain. It is no longer possible to change the entries.	Andrew can clearly see that the transaction is confirmed in the blockchain and also in his wallet. He then sends the TV to Thomas.



It is important to understand that in this example, Thomas and Andrew do not have to do much to complete their transaction successfully. The process is fully automatic and decentralized, running on the computers (nodes) connected through the blockchain in the Internet, and it takes just a few minutes. No trusted intermediary such as PayPal, Visa, or a bank is required to secure the transaction, because this function is performed by the participants in the blockchain network. The blockchain knows what the transaction partners possess and can execute only transactions that correspond to the data reality ("sufficient coverage"). Furthermore, the two trading partners maintain a high degree of anonymity, because although the transaction history shows what the subject of the transaction was (for example, money transfer), it does not name the persons involved: The (digital) wallets of the two parties do not have identifiable names, but only a number or a pseudonym.

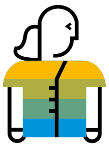
However, the transactions in a blockchain are by no means confined to the monetary exchange shown in the example. A blockchain allows all kinds of data to be controlled (photos, music, documents, meter readings, loading states, and so on). Everything that can be represented digitally can be modeled in a blockchain. In particular, modern versions, sometimes referred to as blockchain 2.0, try to enhance the basic principle of the blockchain with their solutions, thus making it "smart." One of the most important blockchains in this area, Ethereum, enables automated execution of if-then relationships, also known as ↑ smart contracts.

Put simply, these are interrelationships or logic that have been programmed with binding effect in code. To use the example above, this could be as follows: "If it is September 29, 2018, then Thomas will pay Andrew €50." An important role is played here by the ↑ oracles. These come into play whenever the triggering of a transaction stored in a smart contract depends on the occurrence of an (external) event. If real-world information is required for a transaction, smart contracts can be used to store the source used as the oracle. For example, the German weather service can be accessed as an oracle for temperature data if the contracting parties consider this to be a reliable service for this information. Example: "If the temperature in Hamburg rises above 25 degrees Celsius on September 29, then the air conditioning will be switched on in room XY."

Wasn't That a Little Too Easy? Isn't Blockchain Technology Really Complicated?
The blockchain itself or the underlying technology and its algorithms and calculation processes are complex. But it is not always necessary to know every last detail of a technology to understand and use its advantages. If it were, very few people would be able drive to work or use a smartphone. Understanding the benefits of a car or a smartphone does not necessarily require detailed knowledge of the structure of transmissions for vehicles or Internet protocols for smartphones. In the case of the car, the advantages are soon evident: mobility, individuality, and flexibility. In the case of blockchain, the advantages include transparency, cost reductions, security, immutability, and pseudonymity.

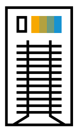
This section deals with the technological component of blockchain in an understandable manner so as to provide a complete picture. The explanations are based on the Bitcoin blockchain and its underlying consensus mechanism ↑ proof of work.

STAKEHOLDERS
First, it is important to understand who "works" in the Bitcoin blockchain. Three groups of players can be distinguished here: participants, nodes, and ↑ miners.



All the **individuals** authorized to make transactions are participants. In addition to a credit balance, all that is needed to carry out a transaction is a digital wallet. Participants do not require a complete transaction history and do not have to confirm transactions or calculate anything.

Nodes are computers in the Bitcoin network that have stored the complete transaction history (currently just under 185 gigabytes).[11] These nodes act as "guards" in the network. For transactions, for example, they check whether the parties involved have sufficient coverage and whether the respective signatures are valid. The big difference between nodes and miners is that nodes do not calculate anything; they only check whether the miners' calculations are correct. They then share the result of this calculation (hash value) in the network. Participating as a node is not calculation intensive and is possible alongside normal operation on a standard computer.

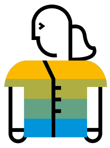
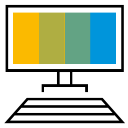
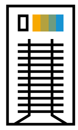


Today, **miners** in the Bitcoin blockchain are specialized computers with very powerful hardware. They act as "workers" in the blockchain. In other words, they are responsible for creating blocks. To do this, they have to solve a complex task and are remunerated if they succeed (currently 12.5 bitcoins for successful calculation of a new block). In principle, miners also need to have the complete transaction history and would thus be "working" nodes. However, today's miners are organized mainly in mining pools (combinations of large numbers of computers). Theoretically, only one computer in the pool needs to have a complete transaction history.

11. Blockchain.info (2018).

The Three Groups of Stakeholders with Their Respective Roles

Roles in the Bitcoin blockchain[12]

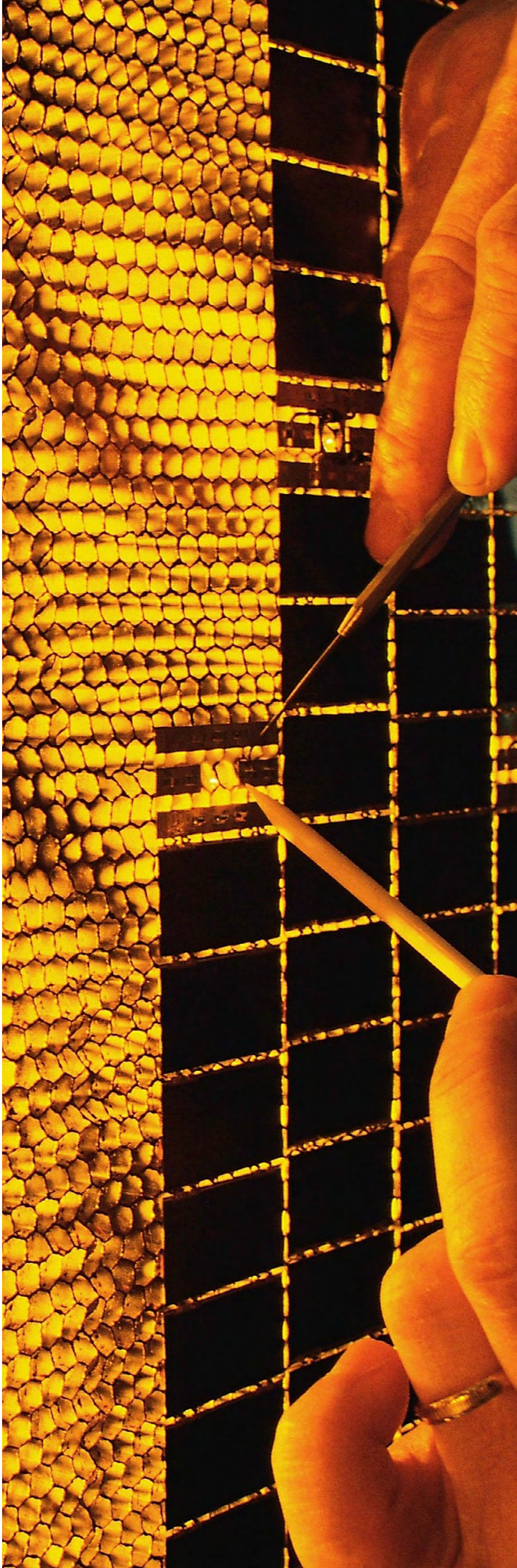
	 **Participant**	 **Node**	 **Miner**
Performed by	**Anyone** who creates a digital wallet	Computer in the blockchain network that have a complete **copy of all transaction data**	Computer with special powerful hardware for **cryptographic calculations**
Number	Approximately 25 million (number of wallets)	Approximately 10,000	Approximately 3 million[13]
Motivation to participate	Performance of transactions	Voting in development, data collection	Monetary remuneration (↑ tokens)
Performance of transactions	✔ (Indirectly through nodes)	✔ (Directly)	✔ (Possible, in principle)
Must possess the complete transaction history	✘	✔	✔ (Possible, in principle)
Verify transactions (coverage, signatures, and so on)	✘	✔	✔
Combine transactions in blocks, create checksums (hash values) of the blocks, generate blocks	✘	✘	✔

12. Blockchain.info (2018).
13. The current network hash rate is approximately 30,000,000 TH/s. It is assumed that approximately 80 % of the mining equipment consists of the latest generation with 14 TH/s. It should also be noted that the number of devices is not equal to the number of stakeholders, since individual companies often operate server farms with tens of thousands of devices. There has been a major process of consolidation among mining players in recent years, but the number of such players cannot be reliably estimated.

TECHNICAL FUNCTIONALITY IN BLOCKCHAINS

Each new block in a blockchain contains the checksum of all previous blocks calculated by an algorithm in the form of a hash value. This ensures that previous blocks cannot be changed at a later date, because then the associated hash value would be invalid. Determining the right hash value in the Bitcoin blockchain is now so complex that a single computer needs several years to deliver the solution. However, since many very powerful computers (or combinations of computers, known as mining pools) are involved in the blockchain network, this can be done in a few minutes.

Each node involved has a complete transaction history of the blockchain in its memory and checks (but does not calculate) this history for compatibility with the new block's hash value with all previous blocks. This mechanism makes the data unalterable, because it is the result of the consensus of all the participating nodes. Unintentional copying and distribution of monetary values – or even of a piece of music or a contract – is prevented or can be exposed at any time. This sophisticated consensus mechanism means that trust between individual market participants in a transaction is no longer required, because the majority of all participants monitor the integrity of the blockchain.



HOW DO BLOCKCHAINS DIFFER FROM EACH OTHER?

As already mentioned, there is no "one blockchain." Many types of blockchain coexist, all with their specific characteristics. Each type of blockchain has particular advantages and disadvantages and is therefore attractive for different applications.

The example of the Bitcoin blockchain presented earlier can be used to show the central elements shared by all blockchain variants: a distributed system that provides a tamperproof log that records all changes.

One crucial aspect in categorizing blockchains is how access to them is designed. A distinction is generally drawn between ↑ public (permissionless) and ↑ private (permissioned) blockchains. Hybrid solutions also include ↑ consortium (shared permissioned) blockchains.

The table provides an initial comparison of the blockchain variants and their characteristics. The three variants with their respective characteristics are then examined in greater detail and explained in the following sections.

	Public	Private	Consortium
Access	Accessible openly (permissionless)	Authorized participants only (permissioned)	Authorized participants only (shared permissioned)
Reference to persons	Identities protected by pseudonym	Reference can be established	Reference can be established
Device authentication	Not required	Required	Conditional
Generation of data blocks	Decentralized through use of resources	Possible centrally by individual computer(s) or server(s)	Depending on design: centralized or decentralized
Consensus mechanism[14]	↑ Proof of work ↑ Proof of stake	Proof of stake ↑ Proof of authority	Proof of work Proof of stake Proof of authority
Manipulability or IT security	Intervention very difficult, decentralized control	Intervention by central provider possible	Depends on the design
Further development of the blockchain or rules	Low flexibility, approval of at least 50% of computing capacity required for changes	High flexibility	Consensus within consortium necessary
Speed of transactions	Slow (based on proof of work)	Tends to be fast	Faster than public
Energy consumption	High (based on proof of work)	Tends to be low	Tends to be low
Operating costs for the entire system	High	Comparatively low	Medium to low
Operating costs of a single node operator	Low	Depending on scope: medium to high	Depending on scope: medium to low
Digital currency	As an incentive mechanism (as a rule)	Optional	Optional, but tokens are helpful

14. This is not an exhaustive overview. Other consensus mechanisms such as practical byzantine fault tolerance have not been listed so as not to exceed the scope of the explanation.

Today's most popular blockchains, such as Ethereum or Bitcoin, are "permissionless," in other words, public. Anyone can participate in the blockchain as a participant, node, or miner. Public blockchains are based mainly on the proof-of-work consensus mechanism for creating new data blocks (mining). In this case, the computers involved deliver a kind of proof of the work undertaken to generate a new block.

PROOF OF WORK
"I have worked to validate the transaction. I was faster and, therefore, better than my competitors. The solution is correct, and I get paid for it. Why should I create an invalid or manipulated block? Then I wouldn't earn anything from my work."

"Proof of authority is based on a dictator node that dictates what's right. It's very plain, very simple, and very efficient."[15]

Christoph Jentzsch, Slock.it

Developers are currently working at full stretch to find more resource-saving alternatives to the proof-of-work consensus mechanism. Alternative approaches, such as proof of stake, are intended to generate new blocks faster and less resource intensively. The concept saves resources by reducing the calculation effort needed to attach a new block to the chain. This is because (wealthy) participants are systematically contacted to confirm the transaction.

PROOF OF STAKE
"I have invested a great deal in this blockchain. Its continuity and functional capability are important to me, so you can trust me. I'll build you a new block and use my assets invested in this blockchain to vouch for its validity. If the block is incorrect or has been tampered with, I'll lose my investment."

With private (permissioned) blockchains, the participants in the blockchain are recorded by a central authority. Accordingly, the consensus mechanism can be structured differently. Generating new blocks is handled using the resource-saving proof-of-authority approach, where a single, previously specified participant (authority) generates new data blocks.

PROOF OF AUTHORITY
"When this blockchain was designed, I was specified as the authority. You know me, and you trust me. So why should I create invalid blocks?"

Consortium blockchains (also known as special-purpose blockchains) are, as semiprivate blockchains (shared permissioned blockchains), a compromise between public blockchains and private blockchains.

"Consortium blockchains may be an intermediate step. Perhaps they will have to open up again."[16]

Dr. Carsten Stöcker, Spherity

15. BDEW (2018).
16. BDEW (2018). Dr. Carsten Stöcker's quote was made during his employment at innogy. He is currently CEO of Spherity.

Comparison of Public, Private, and Consortium Blockchains

The various blockchain types offer associated advantages and disadvantages and are, therefore, ideally suited for different applications in the energy sector. For energy supply utilities, it is important to determine which type of blockchain fits which specific process, model, or service. Correspondingly, developers and users rate the potential of public, private, and consortium blockchains very differently. It is now widely agreed that the likelihood of a single type of blockchain dominating the market ("one blockchain to rule them all") is very low.

Public blockchains currently have considerable technical limitations (especially in terms of speed). Unrestricted access and governance issues (in other words, specifying and enforcing the regulatory framework) also deter some companies from using this type of blockchain. However, public blockchains are highly secure thanks to their architecture and number of participants. And participating in a public blockchain is relatively easy and involves lower initial investment.

In contrast, private blockchains are, by definition, limited when it comes to expansion, because subscribers must trust each other. This enables applications to be developed and used very quickly with known partners in private blockchains. However, the high level of efficiency in private blockchains also means that the number of connected computers and nodes that have to be attacked during manipulation attempts is smaller than in public blockchains. Establishing and operating proprietary private blockchains or licensing models also entails specific investments with a correspondingly greater financial risk than using existing solutions. With private blockchains, it is possible to "cut off" the blockchain and start again. This is useful, for example, if the blockchain is intended to keep an annual balance sheet or similar. At the beginning of the new year, the old blockchain is closed and a new one is opened. This new blockchain is, of course, faster, since it has to hold less data.

Private blockchains are well suited not only for use with in-house processes designed for high data throughput, for example, but also for applications requiring a high level of trust, which can be ensured by the blockchain.

> "At some point, computing power and storage cost money."[17]
>
> Dr. Michael Merz, PONTON

Consortium blockchains are limited with regard to the extent to which they can be extended: both the participating computers and the authorized applications require the approval of the entire consortium. On the other hand, this kind of approval, subject to checks, is very attractive for companies. Consortium blockchains will have to show how this can be combined with the counteractive limitations on expansion by focusing on specific individual applications on the one hand, and on the goal of achieving high appeal through the reach of the platform approach on the other. Some experts currently predict a promising future for the hybrid forms consisting of different blockchain types. Dr. Michael Merz of PONTON says, "The range of blockchains is essentially free, but neither of the ends is very realistic. Total openness is insecure, but too many rules blur the boundary between a blockchain application and a conventional database. So, hybrid solutions will win out."[18]

> "Consumers want someone who is responsible, a service contact. So far, this is available mainly in private blockchains, not in public blockchains."[19]
>
> Udo Sieverding, Verbraucherzentrale Nordrhein-Westfalen

17. BDEW (2018).
18. BDEW (2018).
19. BDEW (2018).

Another challenge to the rapid growth of applications that use a public or consortium blockchain arises from the fact that the business model can be copied. The classic data-based business model of Internet companies is to collect as much user data as quickly as possible and to gain added value by evaluating this data. However, in a public blockchain and generally also in a consortium blockchain, the transaction data is publicly visible. Even if the person or company behind a transaction is not known directly, all of the transactions can be assigned unique pseudonyms. In this case, it is impossible to prevent competitors from analyzing transaction data. The market entry barrier is, therefore, systematically lower than it is today. Reassessment will be required if there are breakthroughs in calculating using encrypted data (for example, ↑ zero knowledge proofs).

> “Analytics companies are becoming value creators.”[20]
>
> Kerstin Eichmann, innogy

In the future, the importance of interoperability between different blockchains (public, private, and consortium) is set to rise. It is also becoming increasingly useful to link blockchains from different sectors (energy, banking, insurance, health, and automotive industries, for example). Achieving this interoperability is regarded as one of the key success factors for blockchain technology (see the section “How Mature Is Blockchain Technology?”).

20. BDEW (2018).

Advantages and Disadvantages of Different Types of Blockchain

A **public blockchain** has the following advantages:

- Potential participation of computers that do not know each other without preliminary check
- Pseudonymity, or now even anonymity, of the participants
- Accessibility – participation by anyone that wishes to
- No need for a central authority to check the blockchain and new applications
- Open access in conjunction with an open source approach, promising high-speed innovation and further development through the large number of participants, as in the case of Ethereum; however, concentration of power and false incentives, as in the case of Bitcoin, can impede further development of the core technology of a blockchain
- High level of security

A public blockchain has the following disadvantages:

- Consensus mechanism (proof of work) is resource intensive; other consensus mechanisms have not yet been tested over longer periods.
- A large number of participants, with sufficient computing power and storage capacities, is required.
- It has low speed of transactions compared to other consensus mechanisms.
- Invalid transactions cannot be corrected.
- Pseudonymous systems guarantee anonymity only as long as login names cannot be associated with users. After this, all of the user's transactions are publicly traceable.
- No person is "responsible" in the legal sense for the operation and functionality of the blockchain.
- If access data for the wallet is lost, values, contracts, and verification are irretrievably lost.

A **private** (permissioned) **blockchain** has the following advantages:

- Restriction of access depending on use or by operator
- Control by the central authority or the operator
- Increased transaction speed and scalability of the blockchain
- Significantly lower resource requirements for the consensus mechanism (proof of authority)
- Option of regularly archiving data
- No financial incentives for mining necessary
- Easier to define responsibilities (in the legal sense)
- Adaptation of rules for operating the blockchain by the operator at any time
- Ability to correct transactions on the blockchain

A private (permissioned) blockchain has the following disadvantages:

- Restriction of access depending on use or by operator
- Transactions not anonymous and irreversible (depending on the particular design)
- Increased vulnerability to attacks and manipulation
- Possible charging of access fees by operator (restricted access for other competitors)

A **consortium** (special purpose, semiprivate) **blockchain** has the following advantages:

- Significantly faster transaction speed than in public blockchains thanks to optimized consensus algorithms or mechanisms
- No financial incentives for mining necessary
- Possibility of alignment with special requirements of the energy market (waiver of anonymity, increase in transaction volume)
- Adaptation of rules for operating the blockchain by the operator at any time

A consortium (special purpose, semiprivate) blockchain has the following disadvantages:

- Low flexibility when it comes to new applications
- Increased vulnerability to attacks and manipulation
- Possible charging of access fees by operator (restricted access for other competitors)

WHAT ARE THE CENTRAL PROMISES OF BLOCKCHAIN?

If we consider blockchain objectively, it might be assumed that – whether public, private, or consortium – it is simply a database. The only difference is that it is not stored on a single local computer or server but on many. However, this does not go far enough, because the basic functionality of a blockchain gives rise to advantages including the following: data sovereignty, disintermediation, process automation and associated cost reductions, security, transparency, and anonymity.

The Internet made it possible to share data worldwide at minimal cost for the first time. Large Internet companies came into being whose business models are still based on aggregating and evaluating large volumes of data. Using today's technologies, it is relatively easy not only to copy and share data anonymously but also to manipulate or illegally distribute it. Blockchain technology now promises critical added value by putting an end to wholesale copying and forwarding of data and by making it possible to control the use of data on the Internet.[21] For the energy sector, this new **data sovereignty** promises to enable information (data) about feeding electricity, gas, or heat in and out, for example, thereby allowing the flow of energy in networks to be tracked in a way that is cost-effective, tamperproof, and flexible. This makes energy more tangible by assigning it attributes, such as origin and time, making it a differentiable product (see the section "What Are Promising Use Cases in the Energy Sector?").

In addition to data sovereignty, blockchain technology promises another improvement. To date, end-to-end digitalization of processes has required the stakeholders to know and trust each other, or that a third party assumes liability. For example, a credit card company is responsible for authenticating the user and thus assumes the default risk in transactions between two parties. Likewise, institutions such as banks, lawyers, regulators, and brokers are still required as trustworthy intermediaries (trusted third parties) on the Internet.

A public blockchain makes it possible to process digital transactions directly and securely for the first time, including payment processes between two unknown stakeholders, with no need for an intermediary function (**disintermediation**). In public blockchains, trust is generated by the fact that all computers on the network (or nodes) check the correctness of transactions and confirm them. The decentralized community is, therefore, the body of trust. This presents both opportunities and challenges for the energy sector, and these are examined in greater detail in the following sections of this study.

The transactions recorded are not confined to barter. A blockchain can record both the operating sequence and the execution of a computer program with process logic within an organization (example: "Execute process B when process A is complete"). Other design options are enabled by integrating the smart contracts mentioned earlier. These are if-then contractual relationships that are set out in code and executed and monitored on the blockchain. Their **automated execution** is intended to reduce transaction costs and ensure greater contractual security as a result of the concatenation, because it is impossible or difficult to change actions subsequently. This enables new forms of organization that allow transactions to run automatically.[22]

Another advantage of blockchain-based automation is increased resilience. Unlike central databases, blockchain has no single point of failure. This means that the information is protected against server failures and attacks.

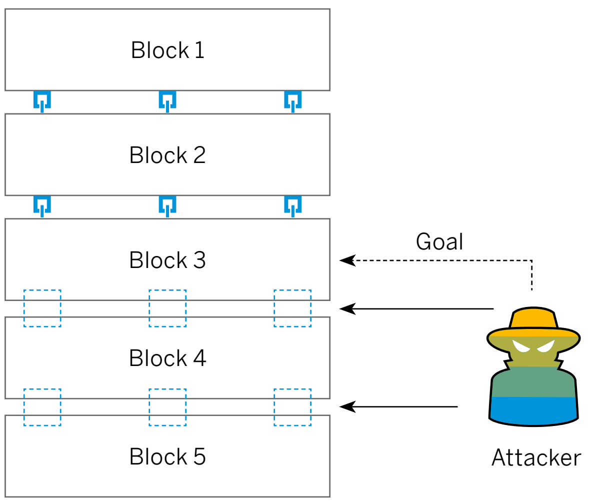
> "We in the energy sector can be the blockchain world champions; however, the technology is coming, with or without us."[23]
>
> Erwin Smole, Grid Singularity

21. Ito (2016).
22. Smart contracts can also create automated organizations, known as decentralized autonomous organizations, which map even complex rules and interaction patterns to smart contracts and use artificial intelligence for transactions between machines. Where devices make financial decisions autonomously, we are approaching the situation described by Slock.it founder Stephan Tual: "First we automated workers, now we're automating bosses." (The quote is a translation from the German language edition, "Blockchain in der Energiewirtschaft – Potenziale für Energieversorger" published by the BDEW).
23. BDEW (2018).

On the one hand, blockchain technology guarantees **security** because of its distributed storage of data. The data belongs to everyone, and everyone (every authorized person) can download the transaction history. It is virtually impossible to create fake entries, because this would require control over a critical number of computers (for proof of work) or asset shares (for proof of stake).

Additionally, cryptographic encryption and concatenation offer increased security. Each block is, figuratively speaking, placed on top of another block and "chained" to it. Once a block has been anchored and some additional data blocks have been attached, the block is considered secure because it (and therefore the transactions recorded in it) can no longer be changed or replaced. The following principle applies here: the longer a block has been bound in a blockchain, the less likely it is that an attacker will be able to generate the same hash value based on manipulated transaction content. This is, de facto, impossible. In the example in Figure 3, an attacker would have to manipulate the hash values of blocks 4 and 5 to get to block 3 and the transactions it contains in order to falsify them.

Figure 3: Representation of an Attack on a Blockchain



"The blockchain is an incorruptible digital ledger of economic transactions that can be programmed to record not just financial transactions but virtually everything of value."[25]

Don Tapscott, The Tapscott Group

Every change on the blockchain is visible, since every new transaction is recorded, checked, and saved on many computers. This **transparency** not only generates trust but also makes it possible to document processes and call them up at any time. This advantage can be decisive, particularly for different stakeholders who need a common data basis. The value of transparency in the blockchain is clearly illustrated by the following example: A producer and a supplier work together. With the help of a blockchain, they can both view their (shared) supply chain in real time. This enables them to plan reliably and gives them security when it comes to deadlines (producer) and purchase agreements (supplier).

Anonymity is a central factor in public blockchains and can also be implemented as needed in ↑ consortium blockchains. Strictly speaking, this is a conditional[24] "anonymity through pseudonymization." The transactions themselves are not anonymous; it is just that they cannot be readily assigned to real entities. But now there are also procedures for completely anonymous transactions. However, these may entail reductions in the speed and scalability of a blockchain. Anonymous transactions make it possible, for example, to acquire goods without competitors being able to track the purchases, despite the fact that the system is transparent and public.

24. On the one hand, conclusions can be drawn from only a few data points, and, in practice, many jurisdictions require compliance with certain know-your-customer requirements to prevent money laundering.

25. Tapscott and Tapscott (2015).

Blockchain in the Energy Sector

The energy production of today and tomorrow is increasingly shaped by decentralization, digitalization, and decarbonization. As a result, it is becoming increasingly granular,[26] the number of prosumers (consumers who are also producers) is steadily rising, and the number of distributed "energy resources" such as photovoltaic (PV) roof installations, batteries, and electric vehicles will continue to grow in the coming years. Like all types of loads in households and companies, they can increasingly be controlled through the Internet. The transition of the value chain to a two-way relationship between energy generation and consumers continues to make headway. At the same time, the economic pressure to make distributed resources available to the network and (local) market is constantly rising. Blockchain technology promises to enable the smallest energy flows and control signals to be organized and tracked very securely and with minimum transaction costs. As a result, blockchain fits seamlessly into strategies that put the customer center stage.

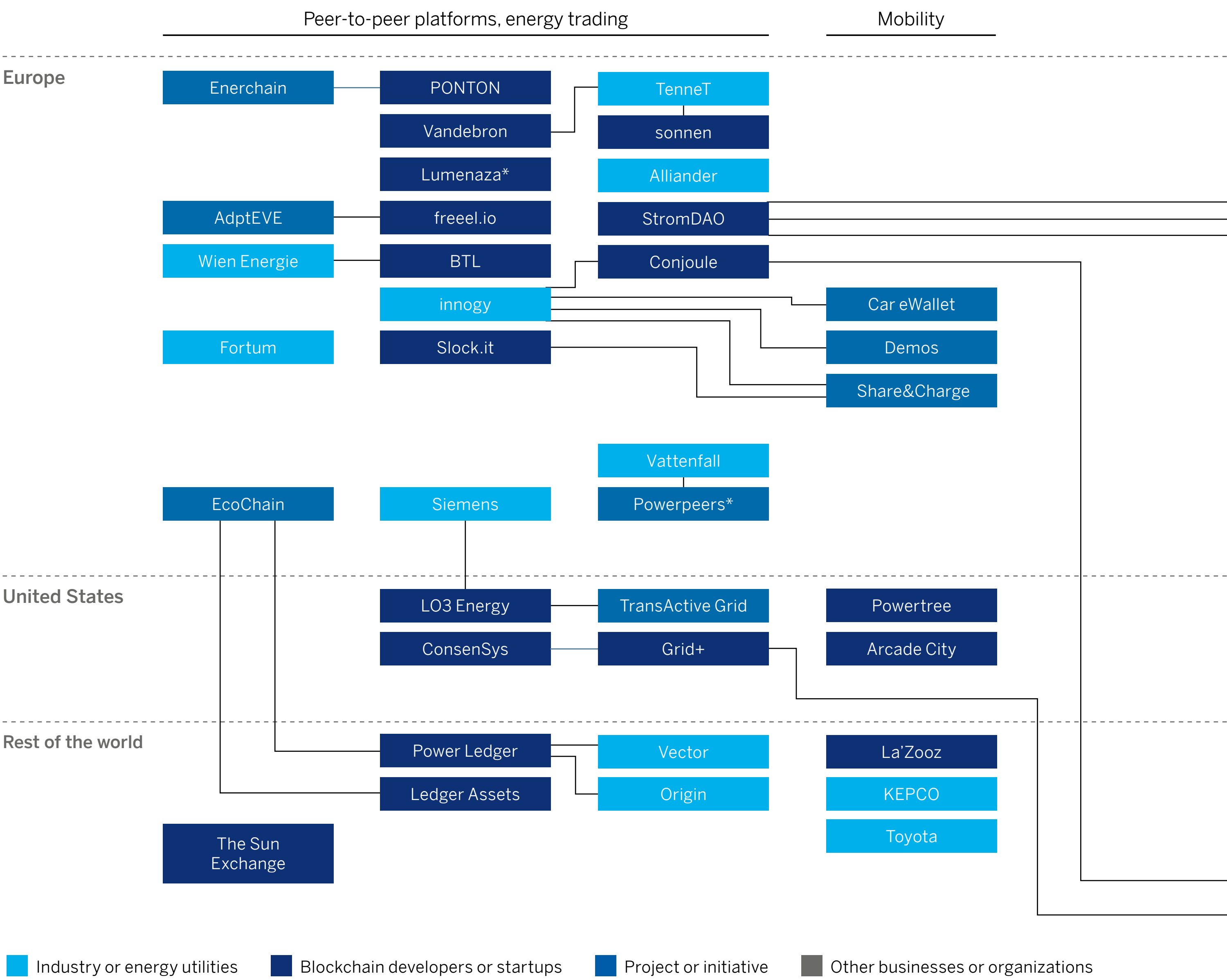
On the whole, processes and business models are increasingly determined by customers' changing needs. As a result, direct investments in generation plants, purchasing of very small quantities (including the associated processing and billing), and flexible delivery, are making the energy system as a whole much more complex. Blockchain technology promises to help master this emerging complexity through controlled use of data (data sovereignty) and direct interaction between players (disintermediation).

Potential applications of blockchain technology in the energy sector are the subject of intense discussion. In 2016, for example, dena[27] conducted a study to investigate the potential of several applications. Considerable potential was identified primarily in direct transactions between customers, including financial settlement, as well as in the area of clearing and settlement, and proof of origin (see the section "What Are Promising Use Cases in the Energy Sector?"). A study conducted by PwC has also examined potential for consumers.[28]

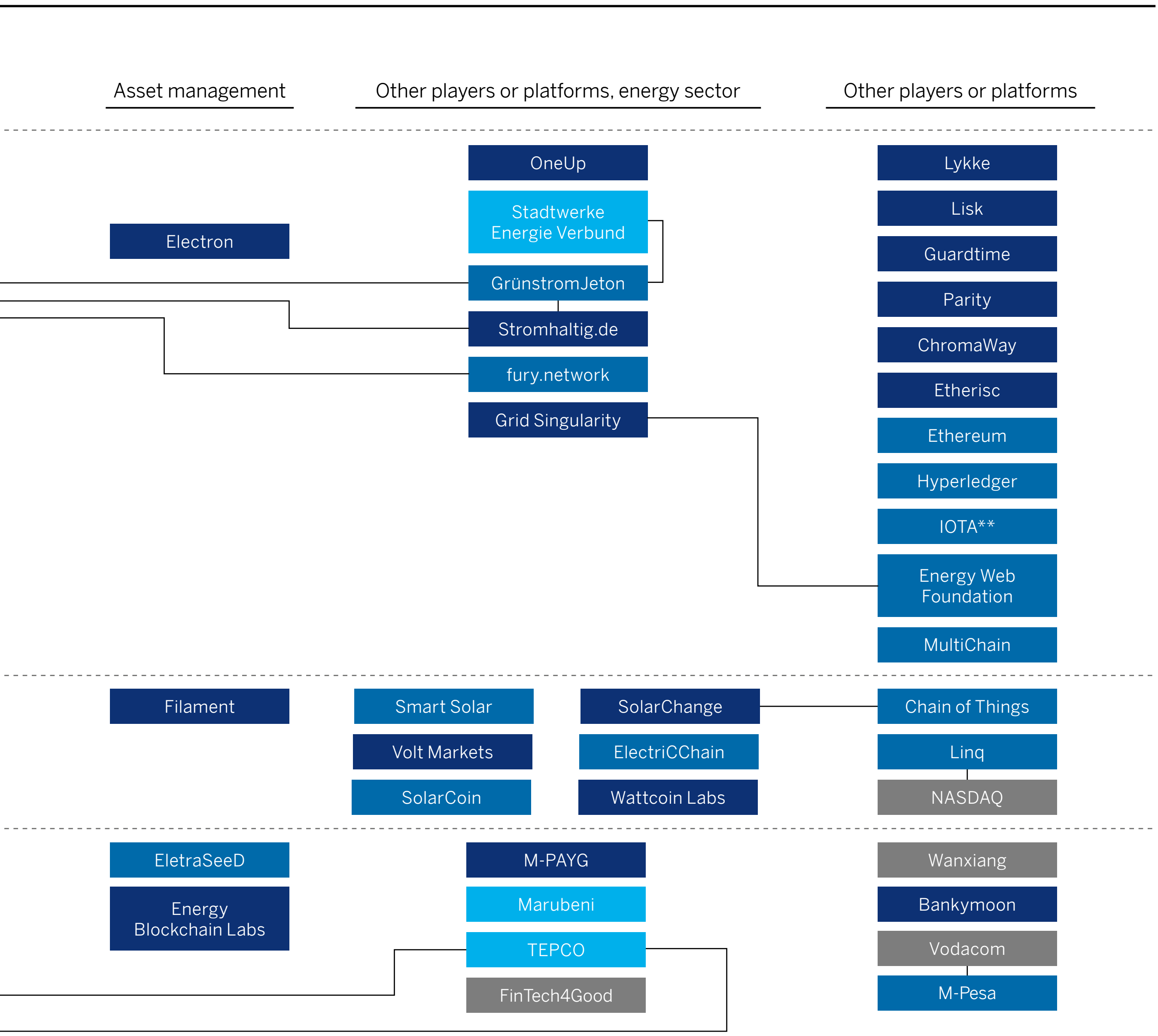
The continuously updated "Blockchain-Radar from BDEW and PwC"[29] provides an up-to-date market overview of blockchain applications in the energy sector and the companies behind them. Figure 4 provides an overview from a recent "Blockchain-Radar" showing various companies that focus on different topics.

26. At the end of 2016, for example, more than 1.5 million PV systems were installed in Germany (BDEW 2017c). Electricity generation by cogeneration plants of less than 1 MW increased by 4 TWh to 24 TWh between 2003 and 2016 (BDEW 2017a).
27. dena & ESMT (2016).
28. PwC (2016).
29. BDEW (2017d).

Figure 4: Blockchains and Companies Behind Them



*Notable peer-to-peer model, without use of blockchain
**Not based on blockchain but on a distributed ledger that, by its own reports, overcomes the limitations of blockchain technology



No warranties for correctness and completeness

DOING THINGS EFFICIENTLY WITH BLOCKCHAIN

The decreased need for intermediaries (disintermediation) enables many processes, such as changing electricity suppliers or organizing ancillary services (see the section “What Are Promising Use Cases in the Energy Sector?”), to be simplified and potentially organized more cost-effectively. Blockchain could also be used to implement automatic payment of taxes, levies, fees, or remuneration. Complex documentation processes can be eliminated or reduced for all players involved. For example, SAP regards the options offered by blockchain in the energy sector as “an evolution as fundamental as the transition from paper-based processes or even customer-specific accounting using ERP software,” according to Henry Bailey.[30]

Accelerated processes usually have the effect of reducing variable costs. Commenting on the use case of electricity trading, Dr. Michael Merz of PONTON says, “Blockchain promises to significantly reduce costs, especially for small-scale market participants.”[31] Another example of process cost reductions through the use of blockchain is billing within a virtual electricity community, the effect of which Claudia Bächle of sonnen eServices considers to be substantial: “In some areas, this could save up to 80% of operating costs.”[32]

It should be noted here that the distinction between optimizing existing processes and designing new processes is fluid. In addition, these changes require extensive organizational adjustments.

> “Processes are not simply changed by a medium like blockchain. Bad processes remain bad processes. In such cases, changes have to start at the organizational level.”[33]
>
> Matthias Postina, EWE

30. BDEW (2018).
31. BDEW (2018).
32. BDEW (2018).
33. BDEW (2018).

DOING THINGS DIFFERENTLY WITH BLOCKCHAIN

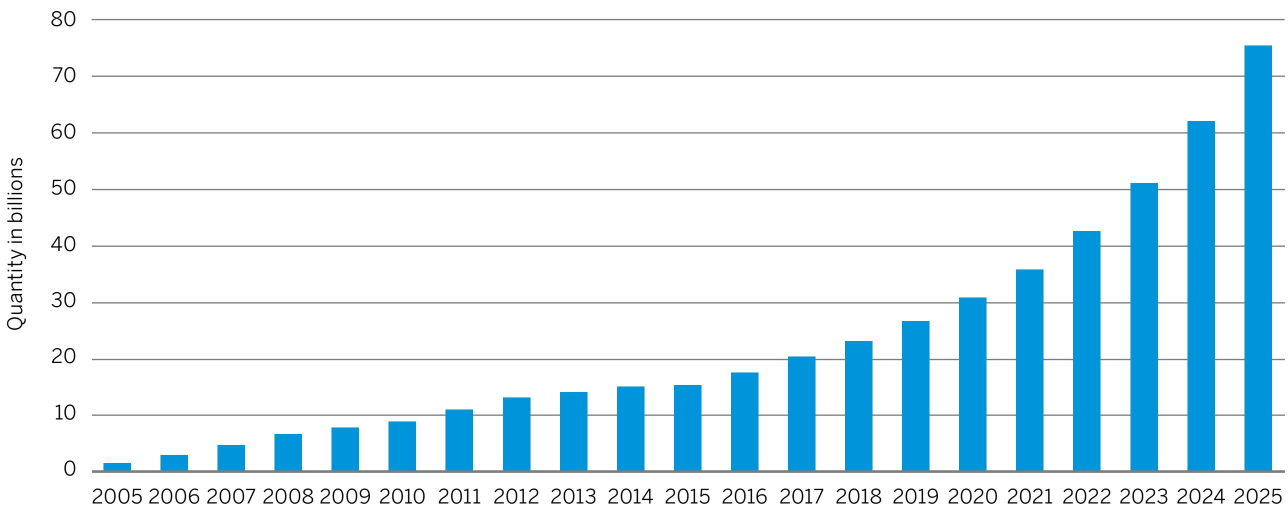
In addition to distributed generation, there is a rapidly increasing number of loads of all kinds that can be controlled over the Internet, such as production machines, lighting, ventilation, vehicles, heating systems, and so on. (See Figure 5.)

Quite apart from the question of a suitable market design, it is urgently necessary to integrate these IoT resources into the electricity system as active market participants. Unused capacities and (long-term) storage facilities are opportunity costs. Direct interaction with devices promises to significantly improve the utilization of networks and the allocation of flexibilities.

In a real-time energy sector of this kind, millions of devices coordinate their behavior based on signals from the market and the network. However, if these microtransactions are to become a reality, they must be performed securely and efficiently and made traceable. Blockchain technology promises to make a key contribution here.

If operation schedule management becomes possible in (IT) real time, this may give rise to new degrees of freedom in the design of balancing group management (see the section "What Are Promising Use Cases in the Energy Sector?").[35] If small amounts of electricity fed into and out of the grid can be traced cost-effectively, it is also possible to differentiate products by type, location, and time (for example, verification of local green wind power; see the section "What Are Promising Use Cases in the Energy Sector?"). As a result of increasing self-sufficiency, neighborhood electricity supply, and more widespread use of electric cars, the typical 4,000 kWh German household will no longer be in the majority in the future. Resulting growth in the percentage of prosumers and ongoing electrification of the heat and transport sector are expected to create considerable pressure for a changeover to local networking of supply and load.[36] This also applies to the expansion of Internet-capable systems that consume and generate electricity. The discussions about peer-to-peer energy trading and landlord-to-tenant electricity supply models point the way forward here (see the section "What Are Promising Use Cases in the Energy Sector?").[37] Ultimately, the pace of these developments will have a major impact on the scope for deploying blockchain technology.

Figure 5: Estimated Number of IoT Devices Worldwide 2005–2025[34]



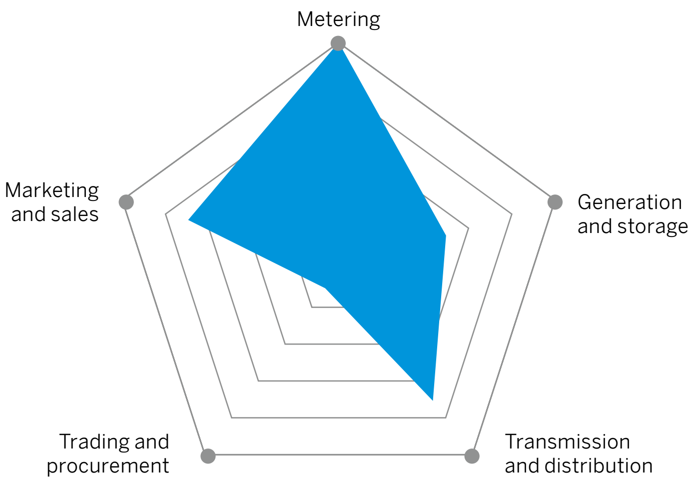
34. Approximated on the basis of data from Statistica (2017).
35. See, among others, PONTON's Gridchain project, PONTON (2016a).
36. Agora Energiewende (2017).
37. The "Winter Package" of the European Commission (2016) contains the "Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (Recast)." In section (53), this provides for empowerment of tenants with regard to collective private consumption. The aim is to put them on an equal footing with consumers who own their homes (European Commission 2017).

What Are Promising Use Cases in the Energy Sector?

Many energy providers and startups are currently working on testing blockchain solutions such as Ethereum, Hyperledger, and Tendermint. The focus is usually on optimizing energy sector processes such as billing and master data management and procedures for changing electricity suppliers. The classic stages of the energy sector value chain are increasingly becoming mixed, and new applications can no longer be assigned exclusively to one area. The following sections demonstrate selected application areas and outline their impact on the classic stages of the value chain. The figures at the beginning of each subsection give a rough approximation of the relevance of the applications for the various stages.

CHARGING INFRASTRUCTURE FOR ELECTROMOBILITY

Figure 6: Relevance of Applications for Charging Infrastructure



The use of electromobility requires a nationwide charging station infrastructure. A highly decentralized structure and a large number of different operators stretch today's billing processes to their limits. For example, the process for identifying users during authorization at a charging station may currently be delayed because of the large number of requests sent to different authorities.

Processing speed can be increased significantly by using a blockchain procedure for identifying the vehicles, for communication, and for billing the electricity purchased. The consumer at a public charging station could be identified and billed immediately. This not only increases convenience for the customer and reduces costs for the provider, but it also enables detailed billing of the electricity actually purchased and its origin. In addition, customers remain in control of their mobility data at all times.

One example of a project in this area is Share&Charge, which was initiated by innogy and Slock.it[38] and is now run by MotionWerk. The project involves blockchain-based tracking and billing of electricity purchased for electric cars. In addition, it enables participants to make their private charging stations available to other e-car drivers. Payment and billing are handled automatically using blockchain-based ↑ smart contracts.

In Germany, there are more than 1,000 registered users and some 1,250 active charging stations. In cooperation with Electric Motor Werks (eMotorWerks), owners of charging stations in California were last year able to share their charging stations with others through the Share&Charge system and have billing performed automatically.[39]

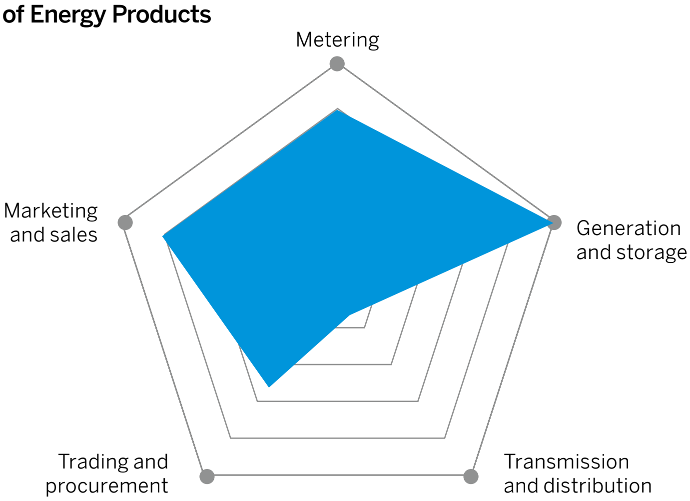
Case study: Share&Charge

Blockchain	Objective	Advantage
Ethereum (as of 2017)	• Improve transaction between charging station and customer through smart contracts • Promote expansion of the charging infrastructure	• Automated processing • Detailed billing • Technological support for provision of private charging stations for public use • Cost reduction for providers

38. Kanneberg, Axel (2017).
39. Share&Charge (2018).

CERTIFICATION OF ENERGY PRODUCTS

Figure 7: Relevance of Applications for Certification of Energy Products



Tamperproof distributed storage of data in a blockchain enables transparent and, therefore, comprehensible documentation of transactions that can be viewed by all users. This shows particular promise in the field of certification. For example, certificates for renewable and regional electricity production can be documented and traded in a blockchain even at the generation stage. This enables development of products such as green and regional power, which can be clearly attributed to a source and cannot be duplicated. It is also conceivable that the approach could be applied to tradable emission or CO_2 products. IBM has been working for some time with the Chinese company Energy Blockchain Labs on developing a green asset management platform for emissions trading in the Chinese market.[40]

Generation facilities such as PV roof systems or combined heat and power (CHP) units can document the quantity of the electricity generated directly into a blockchain through a terminal device connected to the Internet. This provides tamperproof documentation of any electricity fed in or consumed. However, it is also necessary to ensure the system on the ground is correctly authenticated (generation facility, measuring device) and that incorrect values are not immutably written to a blockchain. For example, a PV system must actually feed in electricity, and the infeed must be billed using a calibrated meter.

In France, ENGIE, in cooperation with industrial gas company Air Products and Chemicals, will use a blockchain-based solution to enable green electricity and its origin to be certified for Air Products' production facilities. This will make it possible to prove that the electricity comes from sustainable sources.[41]

GrünStromJetons ("green electricity tokens") are a solution that is already available on the German market from startup StromDAO.[42] The tokens evaluate the electricity consumption of a household using the relevant postcode area's share of green electricity in the regional energy mix at the time when power is consumed. This is known as the green electricity index (based on the regional generation structure, grid topography, weather forecast, and load profile). Participating households receive units of the tradable GrünStromJeton cryptocurrency, depending on the amount of green electricity they purchase. The more electricity they buy, the more green electricity tokens they receive. The tokens provide information on the sustainability of individual households' electricity purchases or (indirectly) on the positive contribution of consumption patterns to the grid. In addition to the criteria of when and where electricity is consumed or generated, integrating appropriate sensors enables differentiation by contribution to voltage regulation as a criterion for the positive contribution to the grid and as the basis for corresponding electricity tariffs. These examples can also be applied in the heating and gas market.

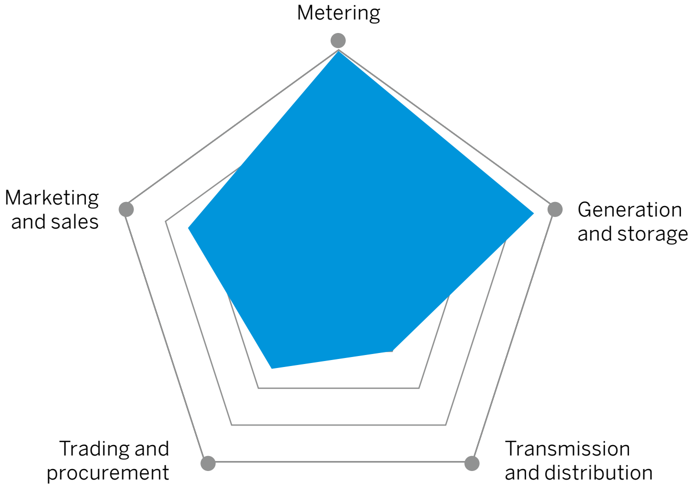
Case study: GrünStromJeton

Blockchain	Objective	Advantage
Ethereum and semipublic special chain (fury.network)	Green electricity and regional certification of electricity	• Differentiation of electricity products • Precise proof of electricity consumption from renewable sources • Evaluation of consumption behavior that positively contributes to the network

40. IBM (2018).
41. ENGIE (2018).
42. GrünStromJeton (2016).

PEER-TO-PEER ENERGY TRADING AND MICROGRIDS

Figure 8: Relevance of Applications for Community Business Models and Migrogrids



The ability to carry out secure transactions between players without intermediaries, to bill these transactions accurately, and to use ↑ smart contracts offers new options for landlord-to-tenant electricity and community business models as well as for new energy products. The Brooklyn Microgrid[43] in New York City attracted a great deal of media attention in 2016. Blockchain startup LO3 Energy is implementing a peer-to-peer electricity exchange platform (direct exchange between private participants without intermediaries) for electricity. The general design of this project's microgrid is considered to be an efficient microgrid energy market.[44]

LO3 Energy is now collaborating closely with Siemens. Interest is focused on the market for peer-to-peer electricity solutions, especially for companies. "We believe that ↑ microgrids and distribution networks in particular are increasingly becoming transactive grids, which will take into account network-specific requirements and restrictions even before trading. Because of the link with blockchain technology, this creates the conditions for transparent and efficient energy trading between a large number of participating systems and a wide variety of players, particularly in systems comprising many decentralized units. As a result, the efficiency of the overall system can be increased, resulting in cost benefits for our customers as well as opportunities for new business models," says Constantin Ginet from Siemens Digital Grid.[45]

The shared basis for landlord-to-tenant electricity supply and neighborhood power grids is the fact that the energy quantities are recorded using intelligent measuring systems and written into the blockchain, where the transactions between the participants are executed and documented automatically. Smart contracts are decentralized and self-managing to ensure that electricity is requested, for example, when prices fall below a price threshold or when green electricity or local power is available. Billing is also automated.

Another microgrid, namely, Stone Edge Farm, demonstrates the added value of local energy autonomy. During a forest fire, the microgrid was cut off from the grid but continued to operate autonomously and supplied power to run the farm while other electricity consumers in the vicinity were affected for more than a week. In this case, blockchain-based software developed by Omega Grid controls the microgrid, calculates the optimum power flow and location-based prices for each asset, and controls the total load.[46]

A useful alternative business model is to operate a local donation network that supports providers in generating regional renewable energy. To this end, the Conjoule[47] pilot project brings together private PV systems and local customers in a separate balancing group on the basis of blockchain. The project also offers the opportunity to operate energy management for households automatically using smart contracts. Flexible consumers bring forward their demand, use it in the future, or store cheap, local, or green electricity. Under certain circumstances, it is also possible to participate actively in other markets, such as the market for balancing power.

43. Berkeley Lab (2017).
44. Mengelkamp et al. (2017).
45. BDEW (2018).
46. Microgrid Knowledge (2017).
47. Conjoule (2017).

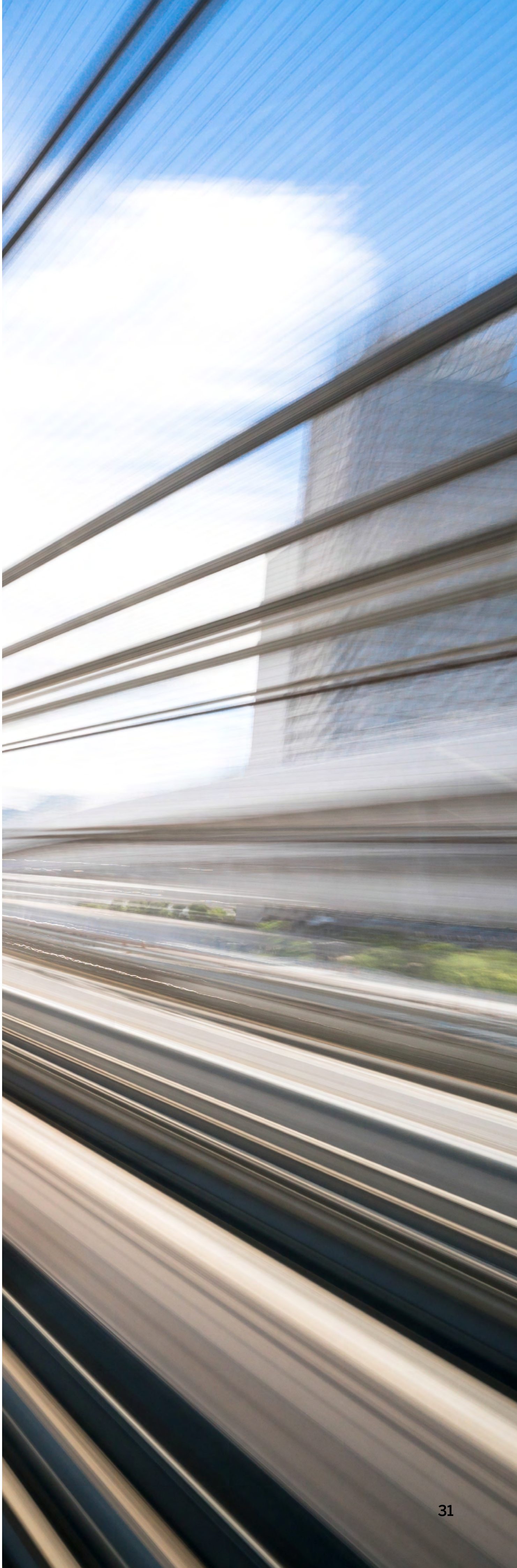
International utilities are now showing great interest in blockchain solutions of this kind. Alongside innogy, Tokyo Electric Power Company Holdings (TEPCO) also invested €3 million in Conjoule as part of a €4.5 million round of financing in mid-2017.[48] There are now similar (pilot) projects throughout Europe, Australia, Asia, and the Americas.[49]

Case study: Brooklyn Microgrid/TransActive Grid (LO3 Energy)

Blockchain	Objective	Advantage
Ethereum[50]	• Establishment and operation of a neighborhood power grid/microgrid • Peer-to-peer electricity trading (private to private)	• Flexibility of electricity consumption according to market signals or other defined criteria • Electricity purchased from the district • Electricity trading without intermediaries

Case study: Conjoule

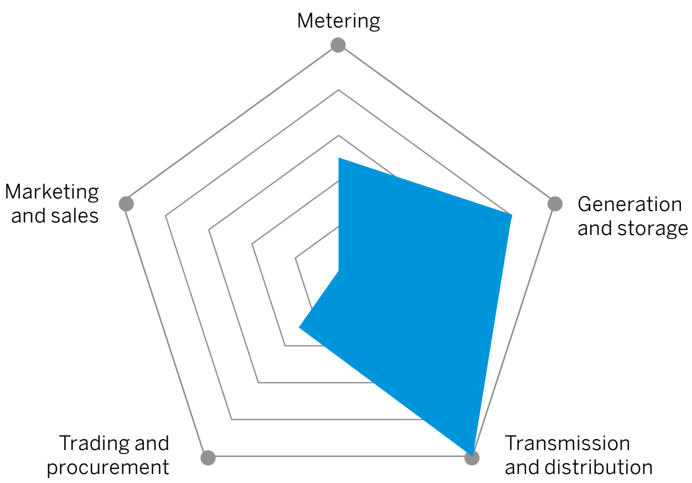
Blockchain	Objective	Advantage
Ethereum	• Establishment and operation of a microgrid • Peer-to-peer electricity trading	• Flexibility of electricity consumption according to market signals or other defined criteria • Electricity purchased from the region • Electricity trading without intermediaries



48. TEPCO (2017).
49. See, for example, Greentechmedia (2018).
50. Since the cooperation of LO3 with Siemens, a private blockchain has been used. Mengelkamp et al. (2017).

ANCILLARY SERVICES

Figure 9: Relevance of Applications for Ancillary Services



The expansion of renewable energy systems naturally leads to greater fluctuations in the electricity grid and a change in demand for ancillary services. Blockchain technology makes it possible to use a large number of decentralized microsystems to provide ancillary services. It offers the opportunity of including a large number of systems in congestion management with the highest levels of precision. The advantages of a blockchain solution are the high level of security and the low cost of the transactions. Otherwise, it is not possible to generate very small amounts of energy and participate actively in the market.

Recent examples include PONTON's Gridchain project and the solution presented by transmission system operator TenneT and energy utility and storage producer sonnen eServices for reducing the need for redispatch measures by using home battery storage. Approximately 6,000 private battery storage facilities can store or release excess power in a matter of seconds, helping reduce transport congestion in the grid and calling up emergency measures to stabilize the grid.[51, 52]

Another TenneT pilot project, in which the batteries of electric cars are used to stabilize the grid, was launched in 2017 in the Netherlands in collaboration with electricity trader Vanderbron. The evaluation phase of the sonnen and TenneT pilot project is due to be completed in the second quarter of 2018, but some regulatory obstacles still need to be overcome before the project can be made commercially viable.[53, 54]

Leapfrog Power Inc. (Leap)[55] uses smart contracts to facilitate transactions in a marketplace for demand response and allows power consumption to be reduced at peak load times with a remuneration concept. Users with free electricity storage capacity are given a financial incentive to adapt their total electricity consumption to the electricity supply. This can balance the load on the power grid more evenly and reduce the risk of failure, without having to step up electricity production. Intelligent energy storage systems could thus contribute significantly to stabilizing the grid and prices in the future. Decentralized trading exchanges can be used to communicate the offer structure for load reduction, while cooperation with other users enables trading of interruptible loads.

Case study: sonnen and TenneT pilot project

Blockchain	Objective	Advantage
IBM Hyperledger	• Reduction of emergency grid-stabilization measures (redispatch, grid reserve, feed-in management) • Stabilization of power grid operation	• Blockchain as a basis for congestion management tools • Linking, control, and transparency of decentralized battery storage • Participation of decentralized flexibility

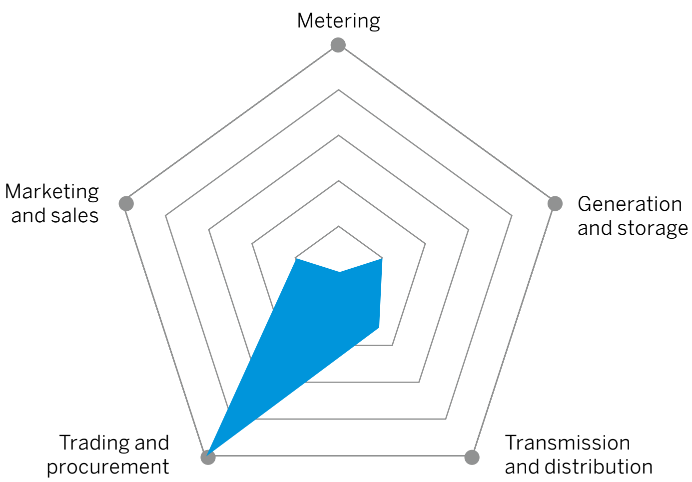
Case study: Leap

Blockchain	Objective	Advantage
Stellar Lumens	• Demand response–oriented charging of electric cars using smart contracts • Smarter utilization of the power grid	• Automated processing • More balanced utilization of the power grid • Cost reduction for customers

51. PONTON (2016a).
52. TenneT (2017a).
53. TenneT (2017b).
54. Montel (2018).
55. Leap (2018).

ELECTRICITY WHOLESALE

Figure 10: Relevance of Applications for electricity wholesale



The advantages of blockchain open up considerable potential in electricity trading. Blockchain technology promises direct, anonymous trading of various products in the electricity market without the need to involve a marketplace or intermediary. This is mainly because blockchain enables trustworthy transactions between players who do not know each other. One way of putting this idea into practice was presented in November 2016 in the form of the blockchain application Enerchain, which is now being implemented by around 40 European utilities in a pilot project. The proof of concept phase began in September 2017. At EMART 2017, the first P2P trades were presented to the public live in the Enerchain network: a gas transaction between Wien Energie and Neas and an electricity transaction between ENEL and E.ON.[56]

Future expansion to include balancing group management is also conceivable. This could make the transmission of relevant information more efficient (see the subsection "Doing Things Efficiently with Blockchain" in the section "Blockchain in the Energy Sector") and improve the load and generation forecast by integrating a large number of small, connected devices. The actual consumption and production figures can be automatically recorded, compared with the forecast, and billed. While the technology enables the size of the balancing group to be reduced to final consumers or end devices, responsibility for the balancing group raises a number of unresolved questions (for example, organization of residual current supply).

Case study: Enerchain

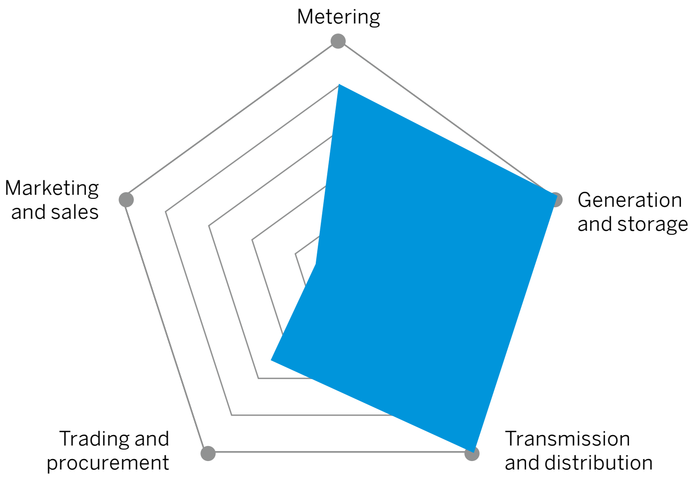
Blockchain	Objective	Advantage
Tendermint	Development and operation of a platform for wholesale electricity trading without intermediaries	• Recoding of trading data (including supply, demand, price, quantities, and purchasing) on the blockchain, resulting in transparency, security, and efficiency • Trust-based transactions • No intermediary (cost reduction and speed gains)

> "Using the technology in electricity wholesale makes sense. This enables the number of checks to be reduced dramatically."[57]
>
> Erwin Smole, Grid Singularity

56. PONTON (2016b), PONTON (2017).
57. BDEW (2018).

ENTERPRISE ASSET MANAGEMENT

Figure 11: Applications for Enterprise Asset Management



The installed measurement technology and data transfer to the blockchain can be used for asset management. Monitoring and documenting asset statuses enables these assets to be managed efficiently. This gives operators, regulators, investors, and insurers accurate and reliable information on the status and condition of assets and their ownership structures. This can be used to design predictive maintenance cases for assets. Other applications include verifying the availability of wind turbines in the event of reduced feed into the grid due to congestion, tamperproof and distributed storage of ownership structures and their transactions, and efficient auditing.

Cost reductions can be achieved here primarily through disintermediation and process acceleration, as well as more resilient asset monitoring and control thanks to the system and decentralization.

Because distributed assets are presented as a portfolio, private investors can acquire a fraction of an asset using blockchain-based tokens, as in ↑ initial coin offerings (ICOs) crowdfunding. This enables consumers to cofund a highly efficient and sustainable power supply system without having to own the entire network of assets.

The overlaps between the applications described here support the earlier statement regarding the role of new technologies in breaking down the boundaries between the traditional stages in the value chain. Just as the individual economic sectors of mobility, energy, and communication are converging, the application of innovative technologies such as blockchain is blurring the boundaries between the subsectors of traditional utilities. As a result, there is a need to redesign and rethink conventional corporate structures.

How Mature Is Blockchain Technology?

The maturity of blockchain technology for processes in the energy sector depends not only on technical criteria such as speed, energy consumption, economic viability, IT security, and reliability, but also on its profitability and acceptance.

> "Public blockchains are today limited by their speed and energy consumption for many applications. The developments that can currently be seen lead me to believe that these restrictions can be overcome."[61]
>
> Dr. Volker Rieger, Detecon International

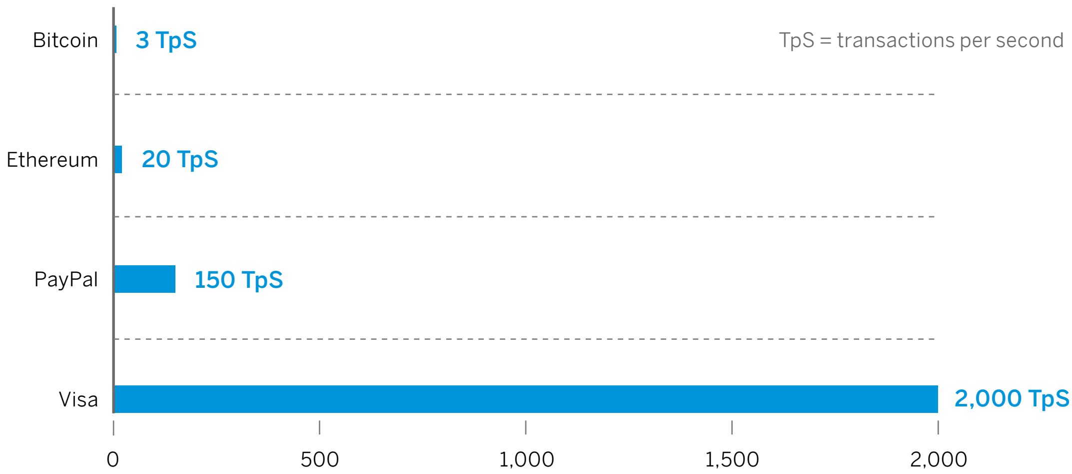
SPEED

↑ Private blockchains have no technology-specific restrictions on transaction speed. Because all the nodes in the network are known and, therefore, trustworthy, they can easily validate transactions (↑ proof of authority). The number of transactions that can be achieved per second (TpS) of ↑ public blockchains is already sufficient for less-time-critical transactions, such as creating certificates of origin for energy or the accounting for community business and landlord-to-tenant electricity supply.

However, the limited transaction speed of public blockchains is an inhibiting factor for widespread use of the technology. See comparisons in Figure 12. Ethereum currently allows only about 10–30 TpS. By comparison, the Visa network has a capacity of 56,000 TpS and handles an average of 2,000 TpS and a maximum of 4,000 TpS per day. And PayPal achieves an average of 155 TpS. Architectures such as the Energy Web Foundation's test network Tobalaba can achieve up to 2,500 TpS. Raiden Network, a ↑ state channel network, is expected to reach speeds of up to 1,000,000 TpS in the next few years.[58, 59, 60]

The low speed is attributable to the ↑ proof-of-work procedure used to validate transactions. In the medium term, the public blockchain Ethereum intends to focus (Serenity Release, 2018) on the less computationally intensive and thus faster ↑ proof-of-stake process (known as "Casper"). The changeover to proof of stake promises to accelerate transaction speed tenfold. Copublished by Ethereum founder Vitalik Buterin in August 2017, the white paper "Plasma: Scalable Autonomous Smart Contracts" offers the promise to apply the MapReduce procedure, familiar from Big Data calculations on computer clusters, to ↑ proof-of-stake consensus building (including between different blockchains). The authors envisage improved scaling to potentially billions of transactions per second and also economic conformity of incentives.[62, 63]

Figure 12: Transaction Speeds of Public Blockchains and Established Transaction Systems



58. Smole (2016), BitcoinBlog (2017).
59. Mougayar (2016), Visa (2015), Vermeulen (2017).
60. Rocky Mountain Institute (2017).
61. BDEW (2018).
62. The expected date is the end of 2018 (BitcoinBlog 2017).
63. plasma.io (2017).

The state channel mentioned above is another concept. Here, only the result of bilateral communication is recorded in the associated blockchain. Individual transactions take place between the respective stakeholders. After a predefined period has expired, the current state at that time is recorded on the blockchain. This not only brings a vast increase in transaction speed, but it also prevents detailed billing from being publicly visible in the blockchain. The ↑ sharding concept also promises to significantly accelerate the Ethereum blockchain.

ENERGY CONSUMPTION

Energy consumption in public blockchains is the result of the calculation effort required to implement the proof-of-work consensus mechanism. Consumption can be calculated only approximately, since not all the information about the machines involved in public blockchains is actually captured. An approximation for the Bitcoin blockchain, for example, may serve as a reference value. Here, too, the actual energy consumption can be determined only approximately. The various approaches[64] deliver different results concerning the total power consumption of all the computers involved. However, the order of magnitude is evident. For the Bitcoin network alone, this is around 65 TWh[65] (as of May 15, 2018) and is, therefore, equivalent to the total annual consumption of countries such as the Czech Republic or Austria. Although the performance and energy efficiency of the mining hardware are improving continuously, this does not impact the total power consumption, because electricity costs are almost the only variable cost factor in mining. As a result, the total power costs of mining are always slightly below the value of the coins calculated. Electricity consumption, therefore, directly follows the exchange rate in the medium term.[66]

This also raises the issue of the "pollution haven" hypothesis. In principle, mining can take place anywhere in the world. This means that the associated energy consumption, as a significant cost factor in the mining process, is primarily in areas with low-cost electrical energy. According to estimates, mining in the Bitcoin blockchain is currently profitable only with electricity prices of up to 6 cents per kWh. In some cases, this is associated with concerns that mining could be relocated to countries with low or marginal environmental standards.

At present, more than 80% of the Bitcoin mining pools are in China. In locations with particularly favorable conditions for mining, this can significantly impact the power supply capacity and has already prompted corresponding government responses. In Venezuela, for example, there have been repeated waves of arrests of miners who allegedly "steal" state-subsidized electricity. In China, the state grid monopolist was forced to make it clear that direct contracts between power plants and mining farms, bypassing the public electricity grid, were illegal, because they would distort competition to the detriment of the public electricity supply.[67, 68, 69, 70, 71]

The proof-of-stake process, by contrast, consumes much less energy because fewer participants are needed to complete and confirm a transaction. For private and ↑ consortium blockchains, the energy consumption of the consensus mechanism is even lower, as the processes are executed on a very small number of nodes or using cloud solutions.

> "Decentralized computing power poses an ethical problem: We're cutting transaction costs by burning coal in China."[72]
>
> Matthias Postina, EWE

64. Energy consumption can, for example, be calculated using the average ↑ hash calculations (checksum calculations; see the section "The Blockchain Promise") performed to find the required ↑ hash value and an assumed average energy consumption per hash. Calculating the power per gigahash per second multiplied by the number of hashes yields the estimated total power consumption.
65. Digiconomist (2018).
66. Vranken (2017).
67. With proof-of-authority blockchains, the governance structures are specified explicitly (that is, by the authority). With proof-of-work blockchains, governance is implicit (in other words, in the countries with the lowest price per kWh).
68. Cryptocompare.com (2017).
69. buybitcoinworldwide.com (2017).
70. Washington Post (2078).
71. Financial Times (2018).
72. BDEW (2018).

ECONOMIC VIABILITY

Unlike a private blockchain, a public blockchain does not involve fixed costs for purchasing, implementing, licensing, or maintaining software. Additional computing power is added by participating ↑ nodes. This can be beneficial for rapid scaling of business models. With public blockchains, on the other hand, fees per transaction are seen as a major obstacle to the continued spread of the technology. Private and consortium blockchains allow the total costs to be controlled by dimensioning the infrastructure in a similar way to classic database or cloud computing solutions. Because of the proof-of-authority validation process, openly accessible consortium blockchains such as those of the Energy Web Foundation promise to reduce transaction costs (and increase transaction speed). Furthermore, the selection of the validating nodes in this model enables computing capacity to be systematically ensured, as in cloud computing services.

Blockchain transactions are already inexpensive compared to existing payment service providers (for example, a PayPal transaction costs around €0.35 plus 1.9% of the transaction volume).[73] Transactions using public blockchains are, therefore, already economically viable. A simple Ethereum transaction without the ↑ smart-contracts option costs about 21,000 gas (about 3 to 5 cents).[74] This figure can be roughly halved by combining transactions. In the context of microtransactions, however, these costs are still too high. For example, a new refrigerator consumes an average of approximately 12 cents per day (150 kWh/a x 29 cents/kWh).[75] Small-scale, flexible purchases of electricity from different sources (for example, from a neighbor with a PV system or a neighbor with a battery) and with multiple transactions each day are, therefore, currently not economically viable (using public blockchains).

Using payment channels (state channels) is a pragmatic approach deployed by Grid+. In the same way as in a restaurant, orders are initially taken as transactions, but only the final total is stored as a transaction on the blockchain. Similar approaches are used, for example, by StromDAO and Powerledger.

IT SECURITY

According to current knowledge, the proof-of-work process is secure. "So far, the actual blockchain has not been hacked, only the applications in it," says Udo Sieverding of Verbraucherzentrale Nordrhein-Westfalen.[76] However, there is as yet no proof of the security of the proof-of-stake procedure. In terms of security, private and consortium blockchains are located between public blockchains and the use of non-blockchain-based methods.

One general vulnerability could be the low number of developers.

> "Only a few developers program these algorithms, and very few check them again – although everything is open source."[77]
>
> Sebnem Rusitschka, freeel.io

However, to guarantee resilience and, therefore, long-term security of supply in the energy sector, the system as a whole (that is, the blockchain application and other parts of the system such as the smart meters and gateways) must withstand security testing.

> "The DAO hack has shown that there is too little structured testing of attack scenarios."[78]
>
> Jan-Peter Kleinhans, Stiftung NV

73. PayPal (2017).
74. Gas is Ethereum's internal unit of account for remunerating transactions.
75. Energy price estimation from the German language edition "Blockchain in der Energiewirtschaft – Potenziale für Energieversorger" published by the BDEW.
76. BDEW (2018).
77. BDEW (2018).
78. BDEW (2018).

ACCEPTANCE AND QUALITY MANAGEMENT

The issue of acceptance is closely related to the issue of security but goes beyond it. For example, the Bitcoin blockchain application has shown that peer-to-peer electricity trading transactions can be carried out safely but still has to contend with acceptance problems. Trust in the technology is necessary, especially when it comes to the Internet of Things and smart homes. Using blockchains can ensure this. "Currently, however, there is a lack of additional projects to demonstrate the possibilities of the application and confirm the technology," according to Claudia Bächle of sonnen.[79]

Further problems are caused by the right to erasure, as enshrined in the EU's General Data Protection Regulation, and data portability, which, according to Oliver Süme of Fieldfisher, will be difficult to implement in a public blockchain (see the section "How Are Blockchain and the Internet of Things Connected?").[80] One potential pragmatic solution, at least for private and consortium blockchains, is the regular truncation of the transaction history, which makes it more difficult to actively access personal customer data. A cut of this kind must also be considered because of the costs and the speed issues mentioned above.

On the other hand, at the point when vast transaction volumes of several terabytes are reached, technologies may already have been enhanced through innovative mining and validation concepts, such as ↑ IOTA or ↑ sharding. In sharding, the blocks are broken down into different shards for parallel processing during validation. This approach enables each transaction to be optimized according to either security, speed, or cost, depending on requirements. As Christoph Jentzsch of Slock.it puts it: "If Ethereum introduces sharding, then an infinite number of transactions is possible . . . but we'll be working with different levels of security." Sharding is not expected to be implemented until two to three years after the introduction of proof of stake.[81]

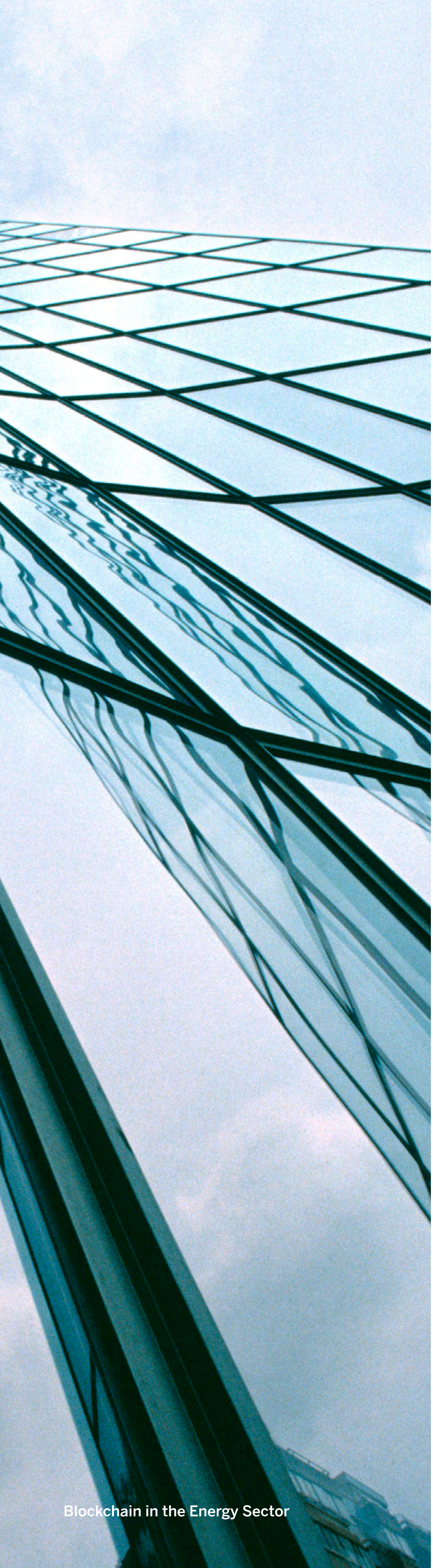
Another method is a block-free ↑ distributed ledger network of the kind used by IOTA, in which participants' peer-to-peer energy trading transactions are validated without participants being remunerated in a cryptocurrency. To perform a transaction over the network, each participating device must verify two preceding transactions. This rule ensures that adequate resources are always available for verifying transactions. The typical blockchain cryptographic concatenation is not used. Instead, a directed acyclic graph, here known as a tangle, is used.[82]

INTEROPERABILITY OF DIFFERENT BLOCKCHAINS AS A CRITICAL SUCCESS FACTOR

Recently, the question of how different blockchains can cooperate with each other has become increasingly important. Just as the user benefit of LinkedIn, Facebook, or WhatsApp depends on the number of participants in the networks (network effect), the value of a blockchain is determined by the number of network users. Consequently, the more blockchains that can interact, the greater the potential user benefit. The central challenge is that assets on one blockchain cannot be transferred directly to another blockchain but must be exchanged through an intermediary.

The Cosmos project "Internet of Blockchains,"[83] in conjunction with the Tendermint consensus protocol,[84] aims to track ↑ tokens in connected blockchains and allow direct exchange. The Polkadot,[85] Plasma,[86] and MultiChain[87] concepts aim to achieve similar goals. Another contribution to this and to interoperability and data exchange between different users, applications, and systems using blockchain and distributed ledger technologies was initiated by the International Organization for Standardization (ISO) through the establishment of a technical committee (ISO/TC 307) in 2016.[88]

79. BDEW (2018).
80. BDEW (2018).
81. BitcoinBlog (2017).
82. IOTA, Ethereum, and Hyperledger are compared in Red (2017).
83. Interchain Foundation (2017).
84. Tendermint (2017).
85. Polkadot (2016).
86. plasma.io (2017).
87. Greenspan (2015).
88. International Organization for Standardization (2016).



What Is the Legal Framework for Blockchain?

The use of blockchain applications raises a multitude of legal questions. These are increasingly being addressed and analyzed in jurisprudential literature.[89] The legal issues can be clustered into various topic areas, which can be roughly classified under general contract law, data protection and IT security law, and energy law.

GENERAL CONTRACT AND DATA PROTECTION LAW

↑ Smart contracts (self-executing contracts) are practically relevant options for deploying blockchain applications. However, the term covers more than just contracts in the strict civil law sense of the term. It goes further by including the use of software that controls and/or documents a legally relevant activity or even triggers it (for example, within the context of existing contractual relationships).[90] Smart contracts can therefore themselves be contracts or simply a functional annex to a contract.[91] Smart contracts are code based and are processed by software applications. On the basis of specific defined conditions, the software automatically checks whether the predefined conditions apply and performs the legally relevant activity (matchmaking).

However, there will be areas where smart contracts can "probably never replace a comprehensive contracts," remarks Oliver Süme of the international law firm Fieldfisher. In any case, complex contracts are characterized "by a certain degree of openness, which can be interpreted by experienced lawyers on a case-by-case basis."[92]

There are generally various contractual principles that set limits for transactions using smart contracts. These limits ultimately define the characteristics required by transactions that it makes sense to handle using smart contracts.

> "Permissionless blockchains are the 'Wild West.' The legal framework is far too vague for B2B processes."[93]
>
> Michael Merz, PONTON

89. See, for example, Scholtka and Martin (2017), Schrey and Thalhofer (2017), Jacobs and Lange-Haustein (2017), Kaulartz and Heckmann (2016).
90. Schrey and Thalhofer (2017).
91. Jacobs and Lange-Haustein (2017).
92. BDEW (2018).
93. BDEW (2018).

If blockchain is used to conclude the contract itself, it is necessary to consider that general civil law makes no provision for an unchangeable transaction history. Examples here include invalidity of contracts, voidability of contracts, restitution following rescission, or the provisional invalidity of contracts with minors pending approval by their legal representative. In these cases, a reverse transaction might be necessary.[94] In the analog world, the associated normative issues require the involvement of lawyers and, in the event of disputes, even the courts. Consequently, transactions using **smart contracts** should be designed to be as unsusceptible as possible to such performance risks.[95] The smart contract should be capable of handling malperformance at the program level.[96]

It is evident that the legal requirement to make value judgments and weigh various factors conflicts with the use of smart contracts. Since value judgments and weighing are inherent in the law, smart contracts must be deployed to make use of areas that are largely free of value judgments and weighing.[97] This requires the subject of performance and the means of execution to be defined as specifically as possible.

Remaining shortcomings regarding the enforceability of the law must be dealt with. The problem of the enforceability of the law arises most clearly where open, anonymous blockchains are used.

Because public blockchains accept anonymity and lack a central authority, there is no control mechanism inherent in the system, apart from the blockchain structure itself with its repository function. In this context, it could also be argued that a large-scale validation network offsets the need for law enforcement. However, this argument will reach its limits in many areas (for example, where large-scale transactions or general consumer protection are involved). In some cases, using a programmed arbitration board is also proposed as a solution to the problem.[98]

The question of who is liable in the event of defective performance or nonperformance if this is due to a (technical) system error in the blockchain also remains unresolved. For cases of this kind, it would be necessary either to find a liability rule[99] or to accept that no liability can be assigned.

Enforcement is more manageable within the framework of ↑ private blockchains because, in this case, all the participants in the network are known. A municipal utility could set up a controlled blockchain and assume responsibility for legally compliant storage of the smart contracts. However, this may also require manual intervention in the blockchain. Another hypothesis is that the reasons for litigation in the case of smart contracts are declining generally. “If it is possible to change supplier at any time, and the bill is transparent, then this should give rise to legal disputes in only a few isolated cases,” says Jochen Grewe of Stadtwerke Energie Verbund.[100] That could be true at least for “simple” legal transactions, where changing contractual partners is faster and more efficient than a legal dispute with an uncertain outcome. This requires contracts that can be terminated at short notice, which is likely to become increasingly important as digitalization gains ground.

Another relevant topic that defines limits for blockchain applications is data protection law. This applies where personal data is processed and stored on the blockchain. Relevant legislation includes the right to rectification,[101] the right to erasure (“right to be forgotten”),[102] the right to data portability,[103] and others rights as stipulated by the EU General Data Protection.[105] In a

> “The right to be forgotten does not exist in blockchain.”[104]
>
> Oliver Süme, Fieldfisher

94. Schrey and Thalhofer (2017).
95. Jacobs and Lange-Haustein (2017).
96. Kaulartz and Heckmann (2016).
97. Jacobs and Lange-Haustein (2017).
98. Kaulartz and Heckmann (2016).
99. Current regulatory concepts for the prevention of noncompliant behavior range from voluntary control obligations to various whitelisting and blacklisting approaches (Pesch and Böhme, 2017).

100. BDEW (2018).
101. Article 16 EU GDPR 2016.
102. Article 17 EU GDPR 2016.)
103. Article 20 EU GDPR 2016.
104. BDEW (2018).

blockchain, an individual's data can neither be removed nor transferred once and for all. Some blockchains allow the historical data sets to be removed entirely at regular intervals.

Further consideration is necessary to determine how data protection requirements relating to personal data can be implemented in the blockchain.

Last but not least, IT security regulations must be complied with. Where personal data, network status data, and master data from advanced metering infrastructure are exchanged, the German meter operation act states that the high technical and cryptographic requirements of the smart meter guidelines of the German Federal Office for Information Security (BSI) apply. The Federal German Network Agency BNetzA formulates corresponding requirements for business processes and market communication. Finally, operators of critical infrastructures are also obliged to implement IT security standards, which are monitored by the BSI.[106]

ENERGY LAW

Blockchain technology enables, among other things, direct handling of the trade in the smallest quantities of electricity (and heat) between households and companies at low transaction costs. However, there are various legal requirements that must be met in this area.

The requirements of the German energy sector legislation, the electricity grid access regulation (StromNZV), and the associated specifications of the responsible regulatory authority (Federal German Network Agency – BNetzA) are definitive for market access and the exchange of energy through a public grid. The electricity grid access ordinance regulates the conditions for feeding electrical energy into feed-in points in the electricity supply networks and for the associated simultaneous extraction of electrical energy at extraction points at remote locations in the electricity supply networks. To use the networks and exchange energy, a power network access contract and a balancing group contract must be concluded and the rights and obligations set out in these contracts complied with. The balancing group contract is concluded between the transmission system operators and the party responsible for the balancing group. It regulates the rights, obligations, necessary exchange of information and data, liability provisions, and rules on the provision of collateral, as well as rules on termination.

These obligations apply to the exchange of energy between market parties, irrespective of the instruments used to agree on this (bilateral transactions, brokerage, stock exchange transactions, or blockchain technology).

Access to the balancing power market is regulated by the provisions of the electricity grid access ordinance so that the use of blockchain technology represents a new instrument for control and billing. Prequalification is required for the systems for the balancing power market and for participation in the transmission system operators' tenders. Moreover, physical feed-in and billing are represented through the schedule management in the balancing group contract for electricity. As a result, exclusive provision of balancing power to the transmission grid operator also requires a balancing group contract to be concluded. In addition, the rules of the electricity grid access ordinance for the provision of balancing power by final consumers (keyword: aggregators) must be complied with. In the future, this will enable microsystems and consumers to participate in the balancing energy market. To this end, the Federal German regulatory authority is working toward a definition, the key points of which were the subject of consultation in Spring 2017. As a result, the provision of balancing power can be offered through a blockchain only in specific balancing zones.

105. Regulation (EU) 2016/679 of the European Parliament and of the Council of April 27, 2016, on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation) (EU GDPR 2016).
106. BSI (2018).

Compliance requirements for transactions in the wholesale market also apply to energy traded using blockchain technology. At the European level, for example, the Regulation on Wholesale Energy Market Integrity and Transparency (REMIT) makes it obligatory to report transaction data for energy wholesale transactions.

When a trading system for energy is established using blockchain, the rules of financial market regulation (MiFID II) may apply in addition to REMIT. In Germany, these rules are essentially set out in the German Banking Act (KWG) and the German Securities Trading Act (WpHG). To decide whether the associated requirements are applicable, it is necessary to check whether transactions concluded through a blockchain are financial instruments as defined by the KWG.

According to the German energy sector legislation, EnWG, providing energy to household customers entails the obligation to report this activity to the regulatory authority.[107] To enable the Federal German Network Agency BNetzA to fulfill its legally assigned supervisory tasks, a postal address is required for administrative purposes if blockchain is used in a way that is relevant for the supervisory regulations. In its latest report on digital transformation, BNetzA takes a cautious position on the subject of blockchain.[108] The agency states that it is necessary to await developments regarding energy requirements and computing power and to review these in light of the security of supply that must be guaranteed.[109]

Energy supply contracts must also meet specific legal requirements. Examples include the obligation to incorporate provisions on contract duration, price adjustment, cancellation dates and periods, the customer's right to withdraw from the contract, liability and compensation provisions in the event of noncompliance with contractually agreed services, and information on the rights of household customers relating to resolution procedures available to them in the event of a dispute.[110]

At a minimum, these requirements would have to be met by means of a framework agreement as a basis for processing individual electricity deliveries using smart contracts.[111]

The provisions for changing suppliers could also prove problematic[112] if contract partners in the blockchain change. These provisions do not yet support changes in a matter of hours or minutes. To introduce such changes at such short notice, it will be necessary to adapt the legal and regulatory requirements for market communication. However, this is the case regardless of whether blockchain or another technology is used to implement changes of this kind. In view of all this, a totally decentralized model for electricity trading based on blockchain technology appears impossible at present.

However, it is conceivable that peer-to-peer energy trading could be incorporated into the existing legal framework in the form of a service model. In this case, the service provider (for example, an energy utility) provides end customers with blockchain-based technical applications that comply with the regulatory and legal requirements set out in the contract.[113] The members of a blockchain network (household customers with or without generation facilities) could then be connected to each other and to the public grid through the service provider. They could then conclude smart contracts; for example, by matching ("if-then" setting with the content "always buy or sell electricity whenever a certain price signal occurs"). The service provider could then also assume responsibility for balancing group management. Time will tell whether other models will be developed.

If prosumers are producing electricity from renewable sources and wish to market the electricity they generate by means of subsidized direct marketing, it should also be noted that their claim to the market premium is forfeit[114] if the relevant balancing group also accounts for electricity that is not marketed directly using the market premium. In this case, a "market premium balancing group" would have to be managed as a subbalancing group.[115]

107. EnWG, Section 5 (2005).
108. Jacobs and Lange-Haustein (2017).
109. BNetzA (2017).
110. EnWG, Section 41 (2005).
111. Scholtka and Martin (2017).
112. EnWG, Section 41 (1) No. 5 (2005).
113. Scholtka and Martin (2017).
114. EEG (2017), Section 20 (1) no. 4 (a).
115. Scholtka and Martin (2017).

In addition, the German Renewable Energy Sources Act (EEG) requires that the full so-called EEG levy be paid for deliveries to final consumers in blockchain models[116] and that the corresponding quantities be recorded and reported correctly. The electricity used for self-sufficiency must be recorded separately.[117] If blockchain is to be used to simplify internal company processes, there are greater legal freedoms, because no legal relationships with third parties are involved. But questions will also arise here; for example, how to ensure control of the processes and how to deal with errors.

Overall, it should be noted that existing legal requirements still present obstacles for blockchain applications in some cases. However, there is currently no targeted regulation of the technology. Whether the regulatory framework should be adapted at individual points to allow digital innovation is a question that should be examined carefully and with a view to potential applications. Legally supported "innovation sandboxes" in which applications can be tested are also conceivable. To achieve this, it is necessary to first identify fields of application that could be tested under simplified legal conditions.[118] Ongoing dialogue between the worlds of business and politics on the latest developments appears to be imperative.

116. EEG (2017), Section 60 (1).
117. EEG (2017), Section 61h.
118. Professor Lavrijssen of Tilburg University argues that it may be necessary to create regulators with interdisciplinary competencies in competition law, consumer protection, and data protection (Lavrijssen and Carrilo 2017).

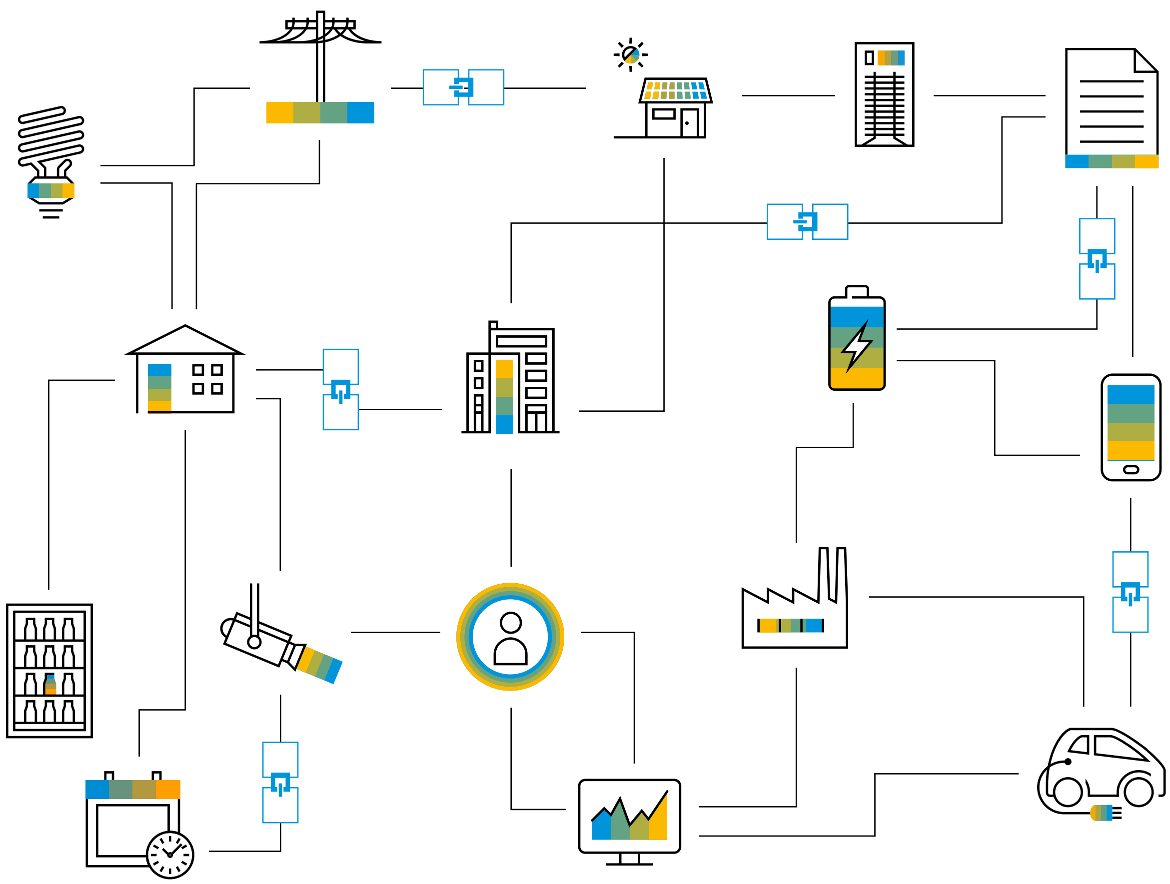
How Are Blockchain and the Internet of Things Connected?

Blockchains enable a real-time delivery and payment process for digital goods because transactions can be executed immediately and in a manner that is transparent for all parties. Since the advent of the Ethereum blockchain, it has also been possible to represent and execute complex rules and interaction patterns verifiably using ↑ smart contracts.[119]

In view of the emerging Internet of Things ecosystem, blockchain now promises considerable added value. If sensors and devices interact over the Internet, the integrity of the data exchanged becomes more relevant for a smooth process flow.[120] Blockchain, or general distributed ledger technologies (DLT), provides this documentation for a theoretically unlimited number of devices that do not know or trust each other, enabling them to communicate with each other. If possible, the computing power required for this purpose would have to be provided by the devices themselves (maximum security), by locally linked devices, or by cloud solutions.

As the number of IoT devices and their transactions with each other grows, a scalable solution is becoming increasingly important (see Figure 13). For example, ↑ IOTA promises precisely this scalability, as well as free transactions and encrypted data transmission. Moreover, the provision of hashing services is distributed across many end devices.[121] Each participant that sends a transaction to the network must confirm two previous

Figure 13: The Internet of Things



119. World Energy Council (2017).
120. Hwang (2017).
121. Red (2017).

> "In the blockchain, every transaction between machines becomes executable."[122]
>
> Robert Schwarz, Pöyry Management Consulting

transactions selected at random. The participant's own transaction is deemed confirmed as soon as it has been verified by two other transactions. As a result, no financial incentive is required to validate transactions. This enables a large number of microtransactions as well as secure, data-intensive exchanges of information between IoT devices. Furthermore, the IOTA network is not subject to the typical limitations of a blockchain such as predefined block size or block times. This is referred to not as a blockchain but as a tangle, a directed acyclic graph (DAG). IOTA's supporters position it as an important platform for the constantly growing Internet of Things and machine-to-machine payments.

For example, if a smart-home solution uses the blockchain to track the data flow between the battery storage in the garage and a neighbor's PV roof system and performs optimizations based on predefined consumption and cost preferences, this lends itself to the use of self-executing contracts (smart contracts).[123] The crucial factor here is interoperability (see the section "How Mature Is Blockchain Technology?"), in other words, communication between each individual system and all the others. Added to this is the option of unconditionally entering into secure, reliable, and tracked transactions with any participating stakeholder. In ↑ public blockchains at least, anyone can potentially participate. Only in this way is an integrated Internet of Things possible.[124]

A large number of systems and devices can be connected to a blockchain, where they can manage all access and usage rights independently, provided they have the necessary intelligence. If local intelligence of this kind has "write" permission – in other words, if a device is intended also to conclude contracts itself – it is advisable to additionally implement ↑ private keys in the devices.

If a critical mass of devices is connected (application dependent) with each other over blockchains, this enables better utilization of the full synergies of decentralized organization and artificial intelligence (AI). Locally available devices can then use their computing power to identify specific behavior patterns and send data that has already been evaluated for further processing, or possibly for sale, through the blockchain.

Because both decision-making and financial compensation are performed exclusively through communication between the devices and an authority at the energy provider (or a number of local neighborhood suppliers), this opens up new opportunities for demand-side management, where consumers' habits are optimized without their being aware of this. The data collected does not necessarily have to be stored on the blockchain itself. This also enables hybrid solutions in which the blockchain merely administers the rights of external databases. In these scenarios, devices manage themselves to such a great extent that assets (such as a PV system) literally pay their own way through autonomously generated surpluses.

A large number of intelligent autonomous device require correspondingly large resources. According to Dr. Carsten Stöcker of Spherity: "In addition to local intelligence, intelligence must be available at a hierarchically higher, central level"[125] to coordinate the herd behavior of a mass of machines acting individually. In demand-side management (for example, coordinating charging points for electric cars), it is necessary to avoid new peaks in electricity demand. Algorithms of this kind can also be implemented via applications on the blockchain.

> "Blockchain enables interoperability between assets that do not know each other and can immediately execute transactions with each other."[126]
>
> Dr. Carsten Stöcker, Spherity

122. BDEW (2018).
123. Grid+, for example, develops hardware and software for connecting IoT devices to the Ethereum blockchain and the Raiden Network. The gateway is intended to register cryptocurrencies and payment processes in real time. The agent-based software is designed to buy, sell, and optimize the use of energy for the household (Gridplus [2017]).
124. Lewis (2017).
125. BDEW (2018). Dr. Carsten Stöcker's quote was made during his employment at innogy. He is currently CEO of Spherity.
126. BDEW (2018). Dr. Carsten Stöcker's quote was made during his employment at innogy. He is currently CEO of Spherity.

When Will Blockchain Happen?

Since the publication of the white paper "Bitcoin: a Peer-to-Peer Electronic Cash System" in 2008, blockchain technology has developed rapidly. In just a few years, Bitcoin has shown that transactions between strangers without intermediaries can be automated and reliably executed via a blockchain. By incorporating automatically executable contracts (↑ smart contracts), the ↑ public blockchain Ethereum has proven that agreements can be executed in complex business processes without an intermediary.

Nevertheless, blockchain technology is still in its infancy, both technologically and in business terms. The majority of the applications identified in the energy sector to date[127] are currently in the conceptual design phase and are still a long way from commercial deployment. As pioneers of sustainable business models, however, they will quickly contribute to making blockchain's potential to reduce and generate revenue more tangible and quantifiable. The number of business opportunities for these applications is growing steadily, and the emergence of ↑ ICOs as a funding option[128] has given them additional impetus. In 2016, blockchain organizations had already succeeded in raising US$200 million through ICOs,[129] but in the following year the figure rose to $5.6 billion.[130] For blockchain projects in the energy sector alone, US$324 million has already been invested, 75% of which comes from ICOs.[131]

> "The pace of innovation has never been so high (as it is with blockchain). So, it's more likely to be two to five years."[132]
>
> Fabian Reetz, Stiftung NV

127. BDEW and PwC (2017).
128. Jurisdiction is increasingly examining financing options within the framework of cryptocurrencies. The U.S. Securities and Exchange Commission, for example, has decided that, from a regulatory perspective, the ICOs of the DAO must be classified as securities (SEC 2017a) and has published a guide for investors on how to deal with ICOs (SEC 2017b). There is currently no regulation of ICOs under tax law. For example, while the exchange of cryptocurrencies in the EU is tax exempt, Lacore warns against opportunity costs and explicitly recommends not to apply this approach to ICOs (Lacore 2017).
129. Tapscott and Tapscott (2017).
130. Fabric Ventures and TokenData (2018).
131. gtm research (2018).
132. BDEW (2018).

Figure 14: Potential Sectors Affected by Blockchain and Expected Investment Risk

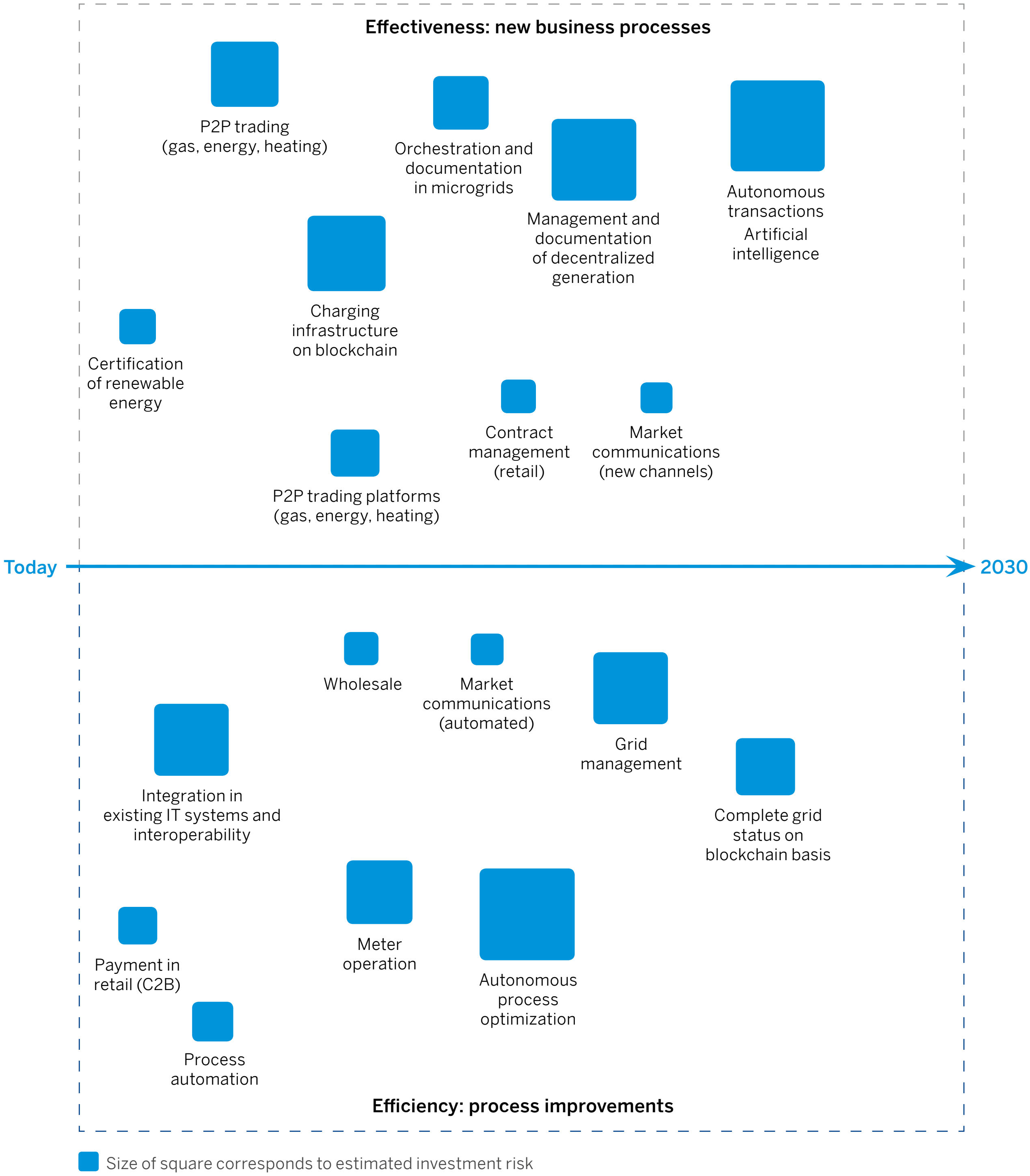


Figure 14 shows the time frame and the expected investment risk of the use cases discussed in the section "What Are Promising Use Cases in the Energy Sector?"[133] The potential of some applications (such as product differentiation or metering) and the low investment risk involved already appear sufficiently promising to anticipate the implementation of robust business models in the near future. Other applications, such as coordinating a large number of autonomous AIs with a blockchain (for example, in the mobility sector[134]), are still a long way off. The figure also provides an overview of potential future business segments that will be transformed by blockchain and includes an estimate of the current investment risk. Because the technology is developing rapidly, the forecasts reflect only the current status.

WHAT IS TO BE DONE?

It is already possible to implement blockchain applications in various use cases. However, the actual implementations are likely to depend heavily on the size and strategy of a particular company. In any case, it is important to gain and further develop knowledge within the company. "It's all about standardizing the processes to keep them up to date and knowing the current framework conditions and regulatory changes," explains Uwe Metz of Stadtwerke Uelzen.[135]

When companies deal with blockchain in-house, the question arises as to whether applications should be developed, implemented, or merely evaluated. The expertise required differs according to the range of applications and tasks involved (in other words, the type of blockchain used: public, private, or consortium) and issues associated with the specific cases. Irrespective of the type of blockchain, integration into standard industrial processes is essential if blockchain technology is to become widespread. As Henry Bailey of SAP puts it: "Integration into standard business processes is very important. Processes using conventional software, the IoT, and public clouds are necessary to deliver or demand data in smart contracts. Smart contracts designed in this way provide the innovation required for true end-to-end simplification with blockchain technology."[137]

> "Development of blockchain applications themselves is likely to be outsourced."[136]
>
> Claudia Bächle, sonnen

PERSONNEL REQUIREMENTS AND EXPERTISE

Using the cryptocurrency Bitcoin in sales activities may be a promising way for utilities to gain initial experience with blockchain technology.

> "The introduction of Bitcoin as an additional payment method has led to a corresponding increase in know-how among the employees involved."[138]
>
> Thomas Schrader, enercity

However, to design blockchain applications that go beyond a pure payment function, employees need a basic understanding of IT and of the blockchain concept. Knowledge of database technologies, security, and cryptography is particularly helpful. Experienced developers who are proficient in object-oriented programming can easily learn Solidity (Ethereum's smart contract language), as smart contracts are similar to objects in common languages such as Java. An understanding of business is required to include business potential and cost parameters in the development of an application. Sebnem Rusitschka of freeel.io explains this as follows: "There are too few good developers."[139]

Similarly, in a white paper published in June 2017 by World Economic Forum, Brian Behlendorf of Hyperledger estimates that there are only between 1,000 or 2,000 developers who know how to program blockchain applications.[140] This shortage was further exacerbated by the ICO boom in 2017. Many startups

133. Weighting and classification of the use cases are based on the interviewees' assessments.
134. Toyota Research Institute (2017).
135. BDEW (2018).
136. BDEW (2018).
137. BDEW (2018).
138. BDEW (2018).
139. According to Sebnem Rusitschka, a growing number of universities are adapting their curriculums, and many of Ethereum's open source projects – such as bug bounties for white-hat hackers, smart contract audits by established security companies, and coding festivals for young developers – are having a positive impact on the number of blockchain developers. See BDEW (2018).
140. Tapscott and Tapscott (2017).

that are now looking for developers for their blockchain designs, which still exist only on paper, have received an extraordinary amount of capital. Today, blockchain bonuses of US$25,000[141] are paid for software developers with relevant experience. One positive aspect of this is that the basic development completed to date makes it easier to build designs on an existing blockchain. For example, the IBM Hyperledger is a modular principle for frequently used program components. Existing programming languages are increasingly being integrated for blockchain application development.

Even large municipal utilities usually commission experts to implement blockchain applications, since this calls for many years of experience in software development. The knowledge required includes how blockchain applications are integrated into the existing IT landscape and how data can be extracted.

> "Because the technology is so new, highly specialized staff are not as helpful as interdisciplinary staff."[142]
>
> Dr. Carsten Stöcker, Spherity

This calls for an overview of the whole company. However, it is not expected that each supplier will implement their own solution. Instead, they will be able to choose from existing application elements and integrate them into their own applications.

Since one-sided specializations could rapidly become obsolete due to the rapid development of the technology, it is advisable to train personnel in blockchain on a broad basis. What is needed are agile "all-rounders" who can work using an interdisciplinary approach. It will be necessary to ensure integration of various components (IoT, system architecture, and smart contracts) into the system while adopting a mind-set that marries entrepreneurship and technology. This applies in particular when designing new internal processes. "All too often, the evaluation of new technology for existing business models fails because of a lack of understanding of the interfaces between different aspects of the new technology," explains Dr. Carsten Stöcker of Spherity.[143]

141. Computerworld.com (2018).
142. BDEW (2018). Dr. Carsten Stöcker's quote was made during his employment at innogy. He is currently CEO of Spherity.
143. Dr. Carsten Stöcker's quote was made during his employment at innogy. He is currently CEO of Spherity. BDEW (2018).

As a result, the following is conceivable: on the one hand, IT experts and data scientists who can think in terms of business models and processes, and on the other hand, project managers and business evangelists who have an implicit feel for technical interdependencies. Furthermore, it would be feasible for municipal utilities, above all for small and midsize utilities, to network. For example, various companies can form a knowledge community to exchange experiences, thereby saving costs.

> "In human resources, we have cut the Gordian knot. We thought about how roles in the company had to change and then got this across to our employees."[144]
>
> Uwe Metz, Stadtwerke Uelzen

Is the Energy Sector Ready for Blockchain Technology?
The application of blockchain technology is a challenge for various areas of energy providers' business, such as sales. In extreme cases, sales could be eroded by direct electricity trading between prosumers or partially replaced by automated processes. One strategy to counteract such developments would be to try to leverage the blockchain and its characteristics for the energy provider's own business processes. According to Robert Schwarz of Pöyry Management Consulting, companies should "understand and anticipate the disruptive nature of blockchain technology" before being disrupted themselves.[145]

A successful strategy for the future goes beyond merely safeguarding day-to-day business. "Investing in the future means replacing old solutions, especially in IT," says Uwe Metz, Stadtwerke Uelzen.[146] However, it is not yet possible to predict which particular blockchain applications will win out against established processes. "We need more use cases. There is currently no killer application," says Oliver Süme of Fieldfisher.[147]

If we turn our attention away from Central Europe, we can see that blockchain applications in pilot projects in India and African countries already fulfill the functions of an energy provider. Through its use in developing countries with fragmented grid infrastructures and without trustworthy public and private intermediaries, blockchain technology can demonstrate its applicability also to European markets. In particular, public blockchains are used not only because of their high degree of standardization but also for the generally smaller number of transactions.

In the local energy supply in Germany, consortium blockchains make sense: even though they have higher development costs, they can be tailored precisely to meet specific requirements. This allows a higher number of transactions to be processed and enables utilities to implement their own applications.

The liberating effect of the technology can tilt the balance of power in customers' favor, turning prosumers (for example, in cooperation with consulting startups) into direct competitors of established suppliers. Systematic deployment of blockchain technology could change the classic intermediary functions. These would be filled quickly by new intermediaries, such as the operators of ↑ consortium blockchains. New marketing options would be based to a much lesser extent on traditional business models and would instead implement the "business philosophy" of the 21st-century in the sense of the sharing economy (Uber and Airbnb)[148] and the machine economy (the IoT and AI).

Blockchain can create trust through transparency and deliver cost reductions through efficiency. Ultimately, consumers decide who they trust and which offers they accept. Energy utilities already enjoy trust, and this could be a key factor here.[149] These offers do not necessarily have to consist of conventional electricity or gas supply but can also include consulting and other services.

144. BDEW (2018).
145. BDEW (2018).
146. BDEW (2018).
147. BDEW (2018).
148. Löbbe and Hackbarth (2017).
149. Results (BDEW 2017b).

The focus will also be on handling new tasks for the customer that were either previously unheard of or difficult to perform. These include, for example, end-to-end optimization of a customer's household using analysis software, with subsequent billing through the blockchain. In the long term, the provider could also become a data intelligence manager and evaluate and market the value of the data available in customers' households on behavior or device flexibility. It should be noted that "blockchain itself is only a tool that initiates the changes," says Uwe Metz of Stadtwerke Uelzen.[150]

In addition to the vertical and horizontal elements of increasing competition in Germany described above, a global component should also be taken into account. For some time now, Chinese industrial conglomerates have been involved in buying up and cloning blockchain startups to implement, test, and establish them in smart city projects in China. The following enterprises plan to invest in blockchain technology: Wanxiang Group, US$50 million; Credit China, US$30 million; and Huiyin Group, $20 million.[151] The energy sector is protected only to a limited extent against outside companies using the expertise gained in these projects on the German market. This can be countered by actively investing in innovative technologies in conjunction with perhaps the most important advantage that regionally established suppliers can mobilize: customer confidence as an investment in the future.

> "The Chinese are already purchasing the technology of the Fourth Industrial Revolution."[152]
>
> Dr. Carsten Stöcker, Spherity

150. BDEW (2018).
151. Rizzo (2015), Reuters (2017), Faife (2016).
152. BDEW (2018).

Conclusion

Blockchain technology holds great promise for the energy sector. Initial applications clearly show its enormous potential for automating processes in the energy sector and the resulting scope for developing new business models.

The distributed blockchain system architecture is ideally suited to an increasingly decentralized energy sector. Greater IT security, efficiency gains, potential cost reductions, and transparency are major arguments in favor of blockchain technology, which utilities should use to their advantage. New blockchain-based business models and applications are currently being developed at a rapid pace. The maturity of blockchain technology in terms of speed, energy consumption, IT security, reliability, governance, interoperability, and profitability is also developing rapidly. However, it should be noted that almost all blockchain applications and projects are still a long way from high market penetration.

Blockchain technology will not become an integral part of the day-to-day business of the energy sector until important questions regarding the regulatory framework have been answered. In addition to fundamental challenges concerning data protection or liability law, specific energy industry issues currently remain open. Blockchain applications allow existing and new energy sector processes to be automated and presented in a tamperproof and transparent manner. Especially when it comes to integrating and orchestrating decentralized devices, systems, and storage facilities, blockchain can be used to enable real-time communication (for example, charge conditions of storage facilities), to document these assets in a legally admissible form, and to make them available as a basis for further applications. One key criterion for success will be the integration of blockchain applications into existing standard energy processes and software. Once interoperability has been improved, penetration should increase rapidly.

In addition, peer-to-peer models based on blockchain technology are being developed in the energy sector. Here, it is becoming increasingly important for utilities to evolve from pure commodities into integrated systems service providers. Peer-to-peer electricity trading models are currently difficult to implement in Germany because of the regulatory requirements for ensuring security of supply. Here, energy providers have the opportunity to act in a new capacity, for example, as service providers who ensure decentralized private plants are integrated into the overall energy sector system in accordance with regulations and who also offer additional services. Blockchain technology enables utilities to utilize a tamperproof and transparent architecture to achieve this integration.

In addition, new and existing blockchains must overcome the present limitations of the technology. Besides the level of maturity in terms of speed, energy consumption, IT security, reliability, and governance, interoperability between blockchains is a factor that can significantly extend the reach and importance of blockchain technology. For energy providers, this also involves networking with companies from other industries that use other blockchain systems, for example. The cross-industry use of blockchain applications also holds potential and promises benefits for everyone involved, for example, through documented cross-industry supply chain management of multiple players on the basis of a blockchain.

Blockchain will increasingly demonstrate its importance in the energy sector. In principle, utilities have no end of opportunities to develop or test blockchain-based applications to determine their suitability, thereby becoming first movers. By getting into the market early, companies can achieve good positioning and ensure their competitive edge. At the same time, however, investment costs are rising. Not everything that is currently possible using a blockchain is suitable for every company in the energy sector, nor does it generate the same added value in all areas. Existing systems that are not based on blockchain often outperform blockchains when it comes to user-friendliness and, above all, integration into existing standard systems. But this can change rapidly, depending on the circumstances. When companies implement entirely new processes, they should discuss the advantages of a blockchain-based system architecture.

Utilities can also wait until market-ready applications are developed in the next few years. But then it may be more difficult and costlier to implement these solutions. It is advisable to play an active part in shaping the development of applications, standards, and the regulatory framework. The question of allocating roles (in other words, which stakeholders will ultimately operate a blockchain or blockchain application) still remains to be answered. Trials in this area can range from collaboration in associations to cooperation with other suppliers or startups right through to stakeholders' own projects and can uncover new opportunities.

Blockchain As a Service and Integration into the Utility System Landscape

INTRODUCTION: MESSAGE FROM RAIK AND STEFAN

Dear Utilities Community,

Utilities and their IT departments are challenged by two disruptions at the same time – the energy revolution and digital transformation.

The energy revolution changes the classical business models for utilities and, as a result, requires agile adaptations of IT system landscapes with flexible IT software. It is a business model transition away from selling energy to offering comprehensive bundles of energy products and nonenergy services. Utilities are in a transition from delivering energy to consumers to participating in a partnership with prosumers and the electromobility ecosystem. A trustful relationship with customers becomes more important than ever. Utilities are no longer the commodity energy provider; they are the partner for the transition and the required services for the future.

Digital transformation accelerates and enables utilities to become intelligent enterprises. They can anticipate and use new disruptive technologies such as blockchain, machine learning, the Internet of Things, Big Data, and in-memory analytics, among others, to meet market challenges. Each disruptive technology is fast moving in accelerated repetition rates. IT departments in utilities are stressed by following and evaluating all the new technologies. Therefore, they require strong IT partners that help them consume disruptive technologies in a manageable way and integrate them in to relevant existing business processes. Utilities' IT departments cannot dive in to the huge variety of new technologies in detail. Therefore, they expect qualified and easy-to-consume technologies at the same time they need end-to-end solutions from the IT industry that embed new technologies continually. Utilities need IT partners that they can rely on to help them to become intelligent enterprises. Intelligence includes the ability to adapt to change – to new business models and to new underlying, end-to-end IT processes – and agility is more relevant for utilities than ever.

The previous sections in the white paper presented some insights about one of these disrupting technologies: blockchain. SAP partnered with BDEW and Prof. Jens Strüker at Fresenius University to share the state of the art with the international utilities community. We received the permission to translate the German study **"Blockchain in der Energiewirtschaft – Potenziale für Energieversorger"** and to append the SAP-specific point of view in the following pages. We hope that our joint white paper opens the perspective into how the utilities industry will adopt blockchain.

Thank you for your interest, and we look forward to your thoughts and our journey together.

Raik Kulinna
Global Lead for Blockchain
for Utilities and Waste,
SAP SE

Stefan Wolf
Vice President Solution Management,
Industry Business Unit Utilities,
SAP America Inc.

“We envision a real-time digital energy network. Blockchain promises to become the missing link to automate energy transactions between the utilities within this digital network. Therefore, utilities must start now to understand how blockchain will impact their IT landscape.”

Stefan Wolf, SAP America Inc.

“Utilities are in a ‘decathlon’ of new business models and new underlying technologies. Blockchain is one discipline, and we hope that utilities will gain a competitive advantage thanks to ‘trainers’ from BDEW, Fresenius University, and the SAP ecosystem.”

Raik Kulinna, SAP SE

BLOCKCHAIN AS A SERVICE: LOW ENTRY INTO BLOCKCHAIN INNOVATIONS

Blockchain projects are challenged regularly by:

- Too-high transaction costs, in practice, in ↑ public (permissionless) blockchains with ↑ proof-of-work consensus (↑ mining)
- Too-high costs for the setup of their own ↑ private or ↑ consortium blockchain
- Many "off-chain" development tasks such as user interface, security for use in companies, and integration into existing system landscapes
- Maturity of a young, fast-evolving technology and the prediction of the leading blockchain variant as very challenging

Blockchain as a service (BaaS) is a new technology deployment concept that focuses on solving such challenges and, in general, aims to significantly improve the ease of use of blockchain technology in enterprises.

Blockchain technology is deployed by technology companies on top of platform as a service (PaaS) to lower the barrier for developers to develop blockchain solutions, on one hand, and to simplify the integration into the existing infrastructure of enterprises, on the other hand. Application management is done by the technology provider so that blockchain projects in utilities' innovation departments, at innovative partners, and in startups can focus more on the blockchain innovation itself. The following table provides an overview of various deployment options of blockchain technology into enterprise landscapes.

	Blockchain on custom infrastructure	**Blockchain on infrastructure as a service (IaaS)**	**Blockchain on platform as a service (PaaS)**	**Blockchain on multi-cloud (PaaS)**	**Blockchain as a service (BaaS)**	**Blockchain software as a service (SaaS)**
Blockchain (instance)	Custom	Custom	Custom	Custom	Custom	Specific blockchain offered like an **SaaS**, that is, it is managed by the provider; partially includes enterprise landscape integration
Integration in business IT	Custom	Custom	Custom	Custom	Partially included integration	
Blockchain technology	Custom	Custom	Custom	Custom	**BaaS**	
Software or platform	Custom	Custom	**PaaS** on one infrastructure provider	**PaaS** with an a la carte infrastructure provider		
Infrastructure or hardware	Custom	**IaaS**				

A cloud platform (PaaS) is, in most cases, the underlying basis and provides the underlying hardware and software platform as well as general integration technologies. BaaS reuses such services and adds vendor-selected blockchain technology on top. The technology provider adds application management services such as testing, release changes, health monitoring, and security.

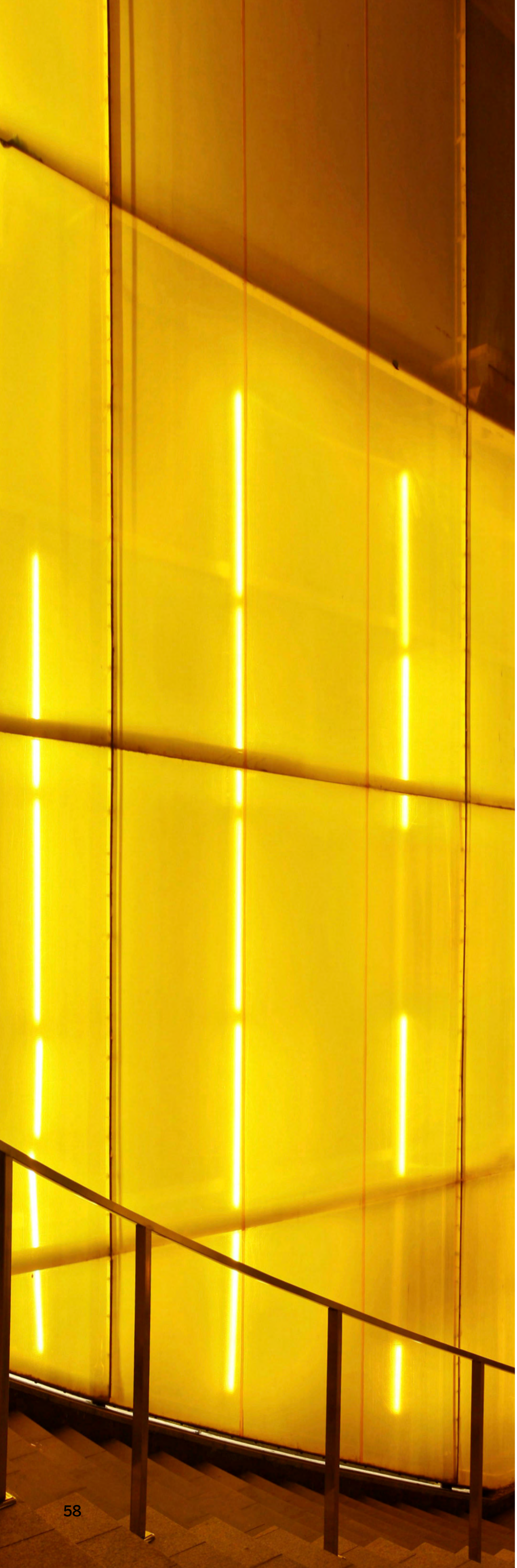
Because the target group of BaaS includes enterprises and IT consulting companies, current offerings focus on what are often called "enterprise blockchains," that is, private (permissioned) and consortium blockchains. In most cases, BaaS providers use open source blockchain technology. Integration into the existing enterprise IT landscape is typically in scope, while ↑ token-economics incentives are less in focus in these scenarios. Various BaaS providers differentiate in the offered blockchain technology, in the value-adding services on top of such open source technology, and in the underlying cloud platform capabilities.

BLOCKCHAIN IN SAP® CLOUD PLATFORM

SAP's blockchain as a service is offered on SAP® Cloud Platform.[153] This platform is also the basis for SAP's cloud road map with the SAP Customer Experience portfolio as well as the SAP Cloud for Energy solution. The blockchain service focuses today on the integration of permissioned blockchains into the existing SAP solution landscape. As of 2018,[154] MultiChain, Hyperledger Fabric, and Quorum (enterprise-focused version of Ethereum) are ready-to-use open source blockchain services. Customer demands and maturity of the blockchain open source technology drive SAP's selections for open source blockchain technologies. Application management services for the technology are added on top so that users can focus on the blockchain innovation. As blockchain is a fast-changing technology, the application management services offered by SAP help keep the technology at the latest innovation level, enabling the focusing of all capacities on the new blockchain business models.

> "Our partnership with SAP is a very important factor in our startup company strategy for scaling our blockchain solution. SAP Cloud Platform is a powerful integration option for connecting existing enterprise business processes and data with blockchain platforms. We expect a lot of support in the SAP enterprise community for field testing and rollout of blockchain solutions through sound integration of SAP systems. Machine economy and cross-utility automation on top of blockchain and SAP systems as an important backbone is the path that we follow."[155]
>
> Dr. Carsten Stöcker, Spherity

153. See www.sap.com/blockchain.
154. See https://cloudplatform.sap.com/capabilities.html#2.13.
155. Quote provided by Dr. Carsten Stöcker to SAP.



SAP Cloud Platform follows a multi-cloud strategy;[156] that is, SAP enables customers to individually select the infrastructure from various infrastructure providers including SAP's own data centers, Microsoft Azure, Google Cloud Platform, and Amazon Web Services. The platform is based on open source container orchestration (OpenStack, Cloud Foundry, and Kubernetes) and, therefore, supports custom deployment of blockchain technology and the integration of such nodes into public blockchain networks. SAP-managed permissioned (consortium and private) blockchains as well as currently customer-managed or partner-managed blockchains are enabled to use the underlying SAP Cloud Platform (as a PaaS) as well as the secure standard integration into SAP solutions.

SAP's strategy in its BaaS offering is to keep the open source blockchain technology unchanged so that SAP-managed blockchain nodes can integrate to external non-SAP-managed nodes on third-party BaaS offerings or on-premise blockchain nodes in customer or partner data centers (new network extensibility services for externally operated nodes). That means decentralization will be achieved by following these two principles: interoperability and openness to the outside plus a multi-cloud strategy.[157]

SAP believes in the disruptive potential of blockchain. We are committed to harnessing the value of enterprise blockchain to solve the challenges faced by our customers in the utilities industry. On the one hand, SAP is a member of various initiatives and consortia. The experts in 25 industries and various cross-industry solutions are supporting such activities. On the other hand, SAP engages with leading partners to develop new blockchain innovations as well as to co-innovate with partners using SAP-managed technologies.

156. See https://cloudplatform.sap.com/enterprise-paas/cloudfoundry.html.

157. Future scope, subject to change. As of summer 2018, the SAP Cloud Platform Blockchain service is not enabled yet for multi-cloud operations. See https://cloudplatform.sap.com/capabilities.html#2.13 for current availability.

Unique in SAP's blockchain services are the capabilities of SAP Cloud Platform underneath as well as blockchain-specific value-adding services on top of the open source technology, such as the application enablement capabilities inside the SAP Cloud Platform Blockchain service[158] and the adapter for the SAP HANA® Blockchain service.[159]

Integration Between Blockchain and Cloud or On-Premise Systems

One differentiating capability of SAP's blockchain as a service is the integration into existing SAP and third-party IT landscapes. In addition to the capabilities for application enablement provided by SAP Cloud Platform Blockchain and the adapter for the SAP HANA Blockchain service, embedding blockchain into existing end-to-end processes is enabled by the underlying SAP Cloud Platform Integration service. Examples of typical required integration into existing IT systems in the utilities industry are energy data management systems (including SAP Cloud for Energy), accounting and finance, enterprise asset management, and customer experience solutions for customer portals and commerce, marketing, sales, billing, and service. Using already-available SAP solutions helps reduce the development scope of blockchain projects, lower the development cost, and speed up time to market, all of which help utilities gain experience quickly. Existing business processes and the IT landscape can later be changed more easily with that early feedback and quick learning.

In addition to the integration of utilities' IT landscape into blockchain, there are other data integration demands, such as "off-chain" data storage. Scenarios could be found in technical performance limitations of the blockchain, such as the processing of Big Data, and in legal requirements, such as data privacy regulations.

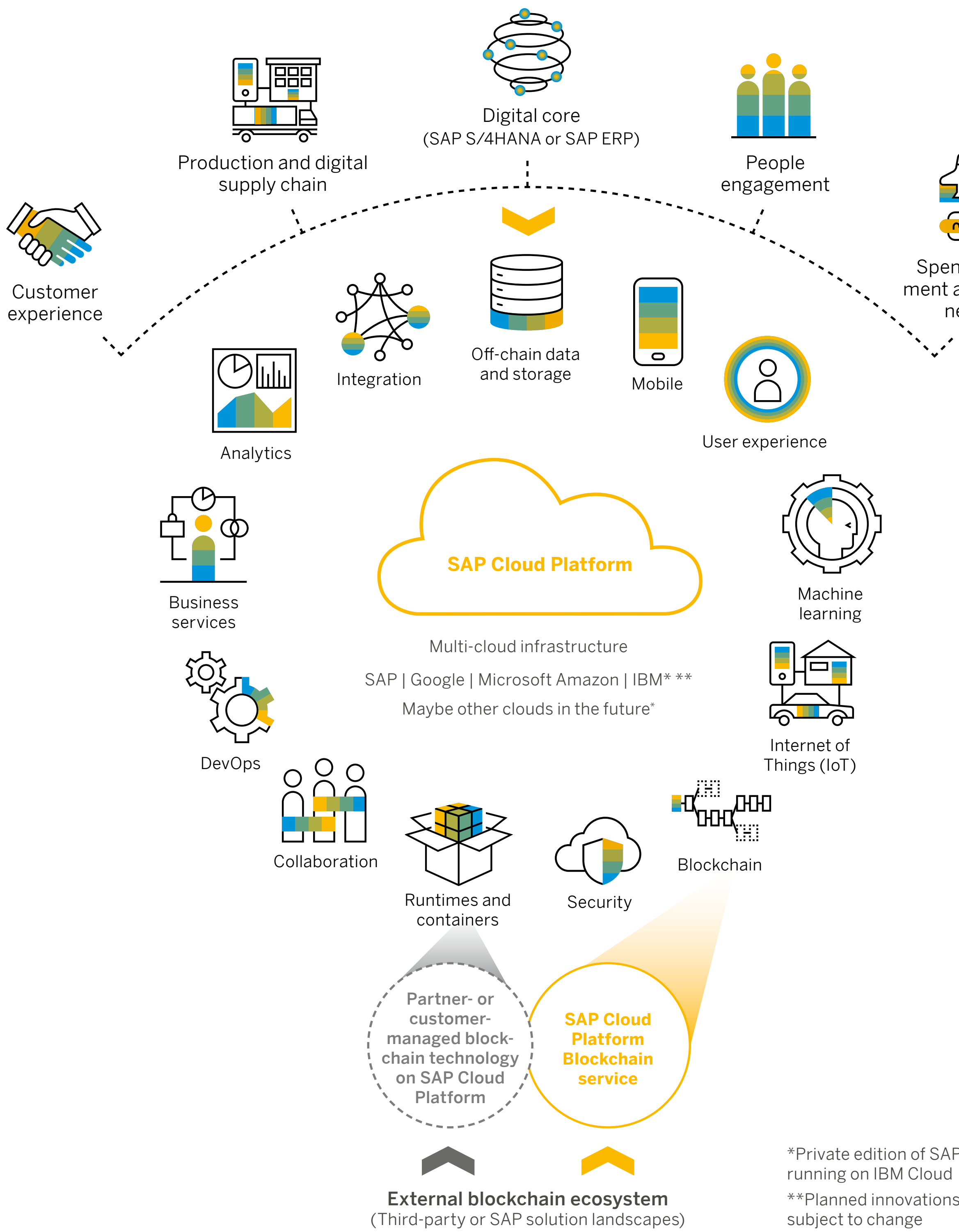
The main use cases for hybrid data storage strategies – in integrated systems or in off-chain data storage – involve the use of:

- Existing off-chain data as a data ↑ oracle[160] in blockchain. In this case, such external off-chain systems are integrated, for example, because of better processing speed, cheaper data storage, or as mutable storage for personal data, such as that needed for company-internal drafts and for compliance with GDPR.
- Existing IT solutions to offer value-adding services[161] on top. In this case, the integrated systems provide new value to the blockchain and solve customer needs while working with the blockchain in daily life. In many cases, these services are started to simplify the usability for nontechnical users or to solve specific demand for enterprises. Value-adding services often connect blockchains with other blockchains or with the off-chain services.
- Classic data storage and classic systems. These are used to reduce complexity, lower development and operations cost, mitigate risk, or decrease time to market of the blockchain scenario.

Blockchain-as-a-service offerings typically provide access to the underlying cloud platform and, therefore, access to off-chain data processing already established in nonblockchain use cases. SAP's platform intrinsically enables access to all other services in SAP Cloud Platform for blockchain innovation scenarios. A quick look into real-world blockchain projects shows that a large percentage of development effort is going into nonblockchain topics. Such topics are Web and mobile user interfaces and integration with or a solution for off-chain data storage to comply with legal requirements. SAP Cloud Platform below the blockchain technology reduces such development costs because of established platform services[162] such as award-winning SAP Fiori® user experience technology for Web and mobile app users, the secure connector into on-premise SAP systems, off-chain Big Data and in-memory storage, IoT capabilities, analytics, and machine learning (see Figure 15).

158. See https://help.sap.com/viewer/p/BLOCKCHAIN_APPLICATION_ENABLEMENT.
159. See https://help.sap.com/viewer/p/SAP_HANA_BLOCKCHAIN_ADAPTER.
160. See the section "The Blockchain Promise" for a discussion of oracles.
161. Such value-adding (commercial) services in the Bitcoin blockchain are, for example, cryptocurrency exchanges for other fiat and nonfiat currencies and online wallets with respect to integration into online bank accounts or previously existing mixing services.
162. See all services at https://cloudplatform.sap.com/capabilities.html.

Figure 15: End-to-End Software Landscape for Utilities



*Private edition of SAP Cloud Platform running on IBM Cloud

**Planned innovations or future direction, subject to change

Application Enablement with SAP Cloud Platform Blockchain
The second differentiating capability is application enablement inside SAP Cloud Platform Blockchain, which provides an abstraction layer on top of all the managed open source technology. Standard templates for typical blockchain development tasks are provided to simplify and speed up the development.

The following technical services are being planned.[163]

The **time stamp service** stores, on request, a time stamp to prove that the specific key was known at a specific time. This service can be used for scenarios in which object states require the verification of a time stamp; for example, when you want to prove that a document, such as an asset inspection document, existed in a specific state at a specific moment in time. The consuming application builds a hash function, effectively a unique digital fingerprint, over the complete content of the document, and then the calculated hash value is saved to the blockchain with the time stamp service. In the future, anyone who receives the same document can compute the hash value again and validate the time stamp for this hash value with this service. Any changes to the document result in a new hash value. This proves that the document existed in the specific state at the specific moment in time.

Proof-of-state service stores data (JSON formatted) that is passed through an API call in a complete state to a given key. This service can be used for scenarios in which the complete state of an object is stored (usually once). For example, the service can be used when a public equipment safety certification is stored on the blockchain. The records can be stored using the proof-of-state service in a complete state on the blockchain by each inspection organization using its own organization-specific ↑ private key.

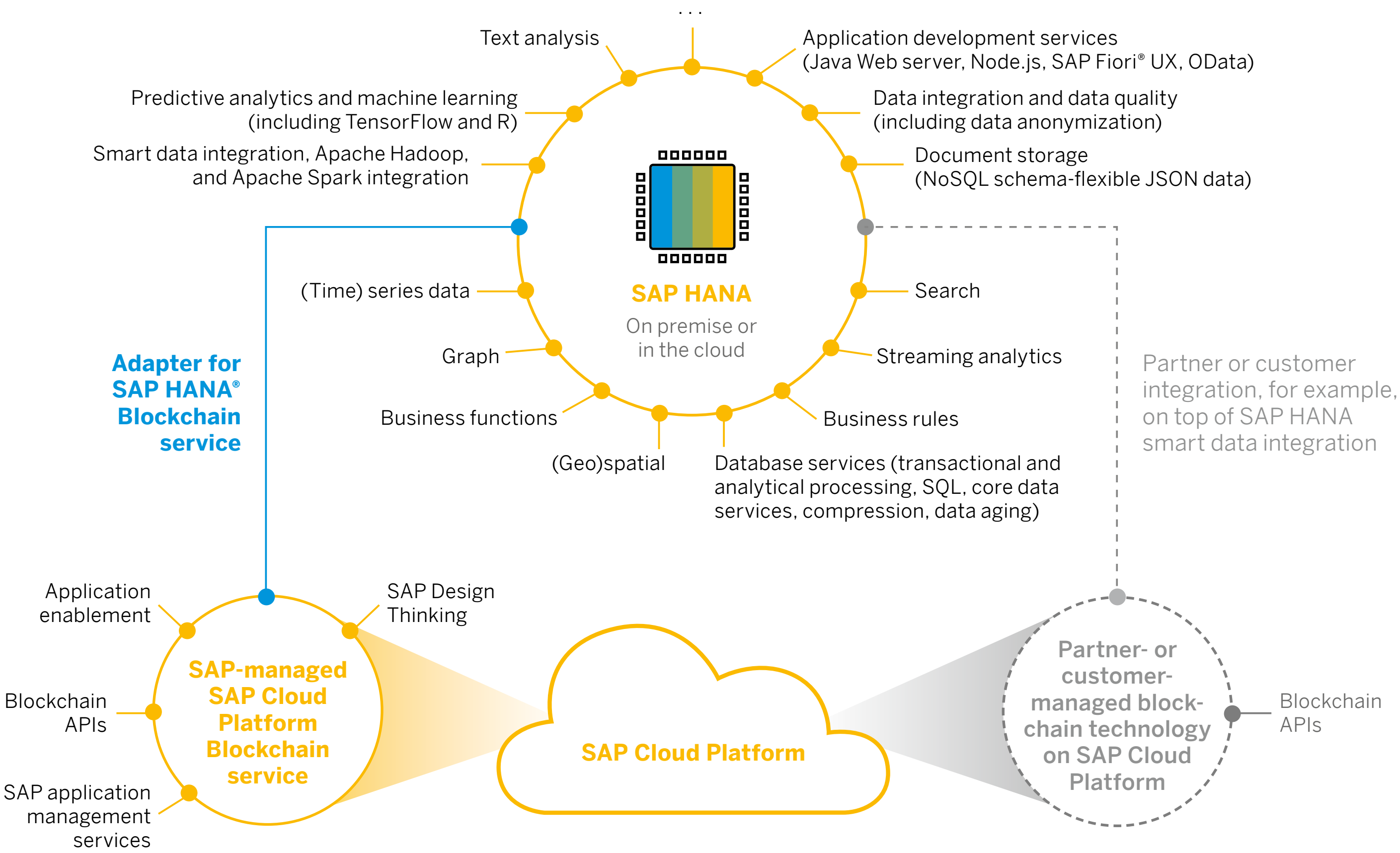
Proof-of-history service records updates or changes to a business object's attribute (JSON-formatted storage) for a specified key and recalls the history of those changes on request. This service can be used for scenarios in which you want to keep a record of delta updates to an object. For example, the service can be used when device management, including software versions, should be recorded for assets such as smart meters. Each time an attribute of the smart meter is changed in the smart meter, it can be protocoled and stored on the blockchain. If an error occurs in billing or in a security review, the audit trail (the details of the revisions to the attributes of the smart meter) can be retrieved and reviewed.

At a conceptual level, all blockchain technologies support the same application enablement capabilities provided with SAP Cloud Platform Blockchain. That makes it easier for developers to switch between the supported open source blockchain technologies if new requirements come up. However, applications on top might need to be adapted to the different blockchain technologies as interactions with those technologies can differ.

Adapter for SAP HANA Blockchain
Third in the list of differentiating capabilities is the planned[164] adapter for the SAP HANA Blockchain service, which will enable access to blockchain data over the SAP HANA business data platform (database management system, in-memory platform, analytics, and so on). The blockchain is replicated in real-time into SAP HANA database tables, enabling the access of SQL database interfaces and all other capabilities of SAP HANA. See Figure 16.

163. See https://help.sap.com/viewer/0a3ff4e76504461f91d0a6319904b8ca/BLOCKCHAIN/en-US.
164. Future scope, subject to change.

Figure 16: Adapter for SAP HANA Blockchain



Benefits include:

- Real-time in-memory analytical processing (OLAP) with low-cost IT operations added for blockchain data
- Enablement of the blockchain with fast in-memory engines such as predictive analytics and machine learning, text analysis, geospatial processing, graph analysis, (time) series data, document storage (JSON), data streaming analytics, business rules engine, and data anonymization services
- Easy mashup of data stored in blockchains with off-chain transactional data
- Use of existing development training for blockchain innovations (blockchain-specific programming model stays unchanged in parallel so that the customer can choose between the two options)

Of course, in-memory engines can be used by anyone with the free express edition of SAP HANA as well as the commercial editions. The blockchain adapter is planned to provide standard integration into the SAP Cloud Platform Blockchain service so that such integration efforts are done centrally by SAP.

In the blockchain community, there are many service providers and analytical applications for detailed insides such as Blockchain.info, Etherscan, and services of exchanges. SAP HANA, as an in-memory platform, can help developers fulfill the market demands specific for each blockchain.

BLOCKCHAIN – A NEW ADDITIONAL DIGITAL TWIN

The term "digital twin" refers to a digital representation of a physical asset, and the related additional software-supported functionality provides new value for physical assets. Various technologies are using the term to market its specific digital representation. For example, it is used by IoT and engineering platform vendors to market innovative Big Data processing, simulation of the physical environment, and analytics capabilities such as predictive maintenance. In that specific focus area, the digital twin describes new, innovative (IoT), sensor-related business processes with a digital visualization and simulation of the physical environment of real-world things. As an example, SAP Predictive Engineering Insights is an innovative solution with such specific capabilities.

The term "digital twin" is not universally standardized, and it is also used in other ways. Such a recent example is the newly occurring use of digital twin by the blockchain community. The term in this context describes the mirroring of object status and corresponding state changes of real-world things into distributed ledger technologies. It markets the specific, unique digital representation of assets inside the blockchain technology, that is, immutable asset states without infinite reproducibility and the distributed protocol for state changes.

Additionally, relationships and communication between things as well as ownership can be defined in a unique, trusted way. The term "digital twin" is used in the blockchain community in business processes that require trustful data sharing among multiple parties without intermediaries. Typical use cases of digital twins in blockchains are track and trace, proof of provenance, machine-to-machine trading, identity management, access control, and certificate of ownership.

In addition to these examples, there are "classic" digital twins that also contain a digital representation of physical assets with information of the asset state and object behaviors. Modern implementations provide analytics and predictive capabilities so that specific simulations of physical, business, or other environments are possible, specific to the type of systems. The following table summarizes all various potential digital twins of physical assets so that the full picture becomes clear.

The digital twin inside . . .	1. Engineering system	2. Transactional processing (OLTP)	3. Analytical processing (OLAP)	4. Internet of Things or operational technology system	5. Distributed ledger
Business capabilities	• Computer-aided design • Computer-aided engineering, simulation, finite element analysis • Geographic information system • Project management or product lifecycle management • Digital asset management (asset information)	• Strategic asset management and compliance • Asset supply chain (acquisition, installation, certification, device management, asset inventory and logistics) • Asset operations, such as maintenance planning and scheduling, field services, inspections, decommissioning • Asset accounting • Asset-related integrated management systems such as quality management, environment, health and safety • Assets in customer engagement	• Asset performance management and analytics, predictive maintenance • Asset vendor evaluation and analytics • Predictive maintenance and service • Reporting and dashboarding	IoT and Big Data processing (data aggregation, pattern analysis or disaggregation, asset and system health, pattern benchmarking or usage comparison, forecasting)	• Digital distributed single truth or distributed digital trust • Open sharing of aggregated data • Proof of provenance • ID management and access control • Blockchain-based network collaboration • Machine economy or machine-to-machine economy or formalized open legal contracts and automated open order management • Automated data commercialization
Technologies	• Special software system • Often file data storage with special domain-specific processing engines • Sometimes special databases such as geospatial or document databases	• Mutable SQL database with ERP systems on top, enabled for drafts, internal workflows, GDPR, and so on • With in-memory SQL: analytical processing on top of transactional data storage	• Business intelligence systems with analytical data storage • In-memory SQL database with analytical processing capabilities • Data hub or data lake	• Real-time message ingestion, stream processing (Lambda architecture components) • Big Data store, data lake • Time series (in-memory) processing • Analytical processing on top of Big Data storage	• Blockchain (immutable open data storage, decentralized, self-executing business logic [↑ smart contracts]) • Integration with "off-chain'" storage and off-chain data processing and hardware (data ↑ oracles)

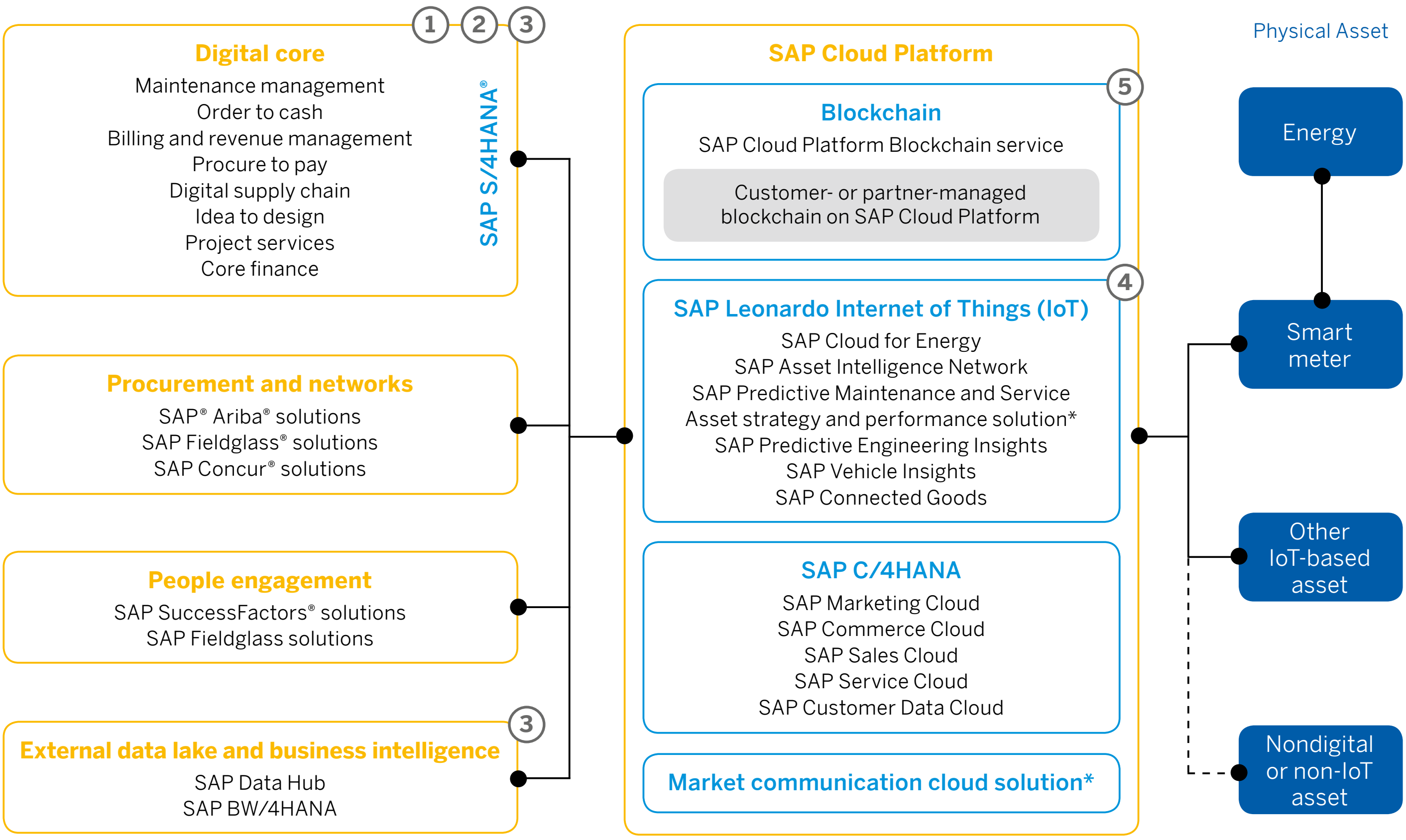
As you can see in the table, all representations of a physical twin in IT systems have their special technology with their special processes and their special software optimizations. For example, a smart meter in an end-to-end system environment consists of the IoT-enabled meter hardware and hardware infrastructure, the special IoT platforms for smart meter data processing (such as SAP Cloud for Energy), and integration into the digital core (such as SAP S/4HANA®). Blockchain technology can be integrated with all these systems, that is, on the meter hardware as a so-called hardware oracle, on the IoT platform, and on the digital core as the backbone of the utility.

All integration points are valid by default, and all integration points can be seen across various blockchain proofs of concept in the utilities industry. It is expected that utilities will select the blockchain integration points that are the most cost-efficient for the scenario. For example, an additional hardware blockchain oracle on a smart meter is probably a competitive disadvantage compared to integration into the IoT platform for smart meter data processing (smart meter analytics with benchmarking or usage comparison).

Our recommendation to utilities is to start with the full digital twin in the future IT landscape and select for the blockchain digital twin the most competitive (the cheapest) point for integration of the blockchain technology. BaaS and custom blockchain technology PaaS simplify such integration tasks, increase security, and reduce integration and development costs. Figure 17 shows the two new digital twins – IoT and blockchain – as well as the classic physical twins inside the SAP system landscape for utilities. The numbers in Figure 17 refer to the categories in the previous table.

Blockchain technology is in the center of the landscape. Blockchain end-to-end processes in utilities are created by the technology itself and SAP solutions or the direct integration with hardware (↑ oracles).

Figure 17: Multiple Digital Twins in the SAP Solution Landscape for Utilities



(1) Engineering system (2) Transactional processing (3) Analytical processing (4) Internet of Things (5) Distributed ledger

*Planned innovations or future direction, subject to change.

WIPRO AND SAP SHOWCASE: GREEN ENERGY TRACKING AND DISTRIBUTION

One of the most typical blockchain scenarios in the energy sector is certifying energy products by ↑tokenization of renewable and regional energy on a fine-grain level and managing the distribution from the generation to the consumers over a distributed ledger (see the section "What Are Promising Use Cases in the Energy Sector?").

SAP partnered with Wipro to showcase the typical business benefits of this scenario, such as:
- Full auditability and transparency from green-energy generation to consumption without manual transactions and without double spending
- Automated transparency for consumers regarding the source of green energy in detail
- Reduction in handling costs, resulting from, for example, manual processes, manual audit steps, and fees paid to intermediaries

Furthermore, it was developed to visualize the following IT-specific benefits in contrast to other implementations already done in the utilities industry:
- Secure and low-effort integration of new blockchain innovations into existing SAP system landscape (on-premise and cloud solutions)
- Elimination of the need for additional hardware ↑oracles on the prosumer and consumer side by integrating blockchain with the SAP for Utilities solution portfolio (the SAP Energy Data Management application)
- Reuse of existing SAP solution landscape for full end-to-end processes including energy data management and customer experience solutions
- Efficient, low-cost, and robust development thanks to the SAP Cloud Platform Blockchain service, user interface technology of SAP Fiori, SAP Cloud Platform Integration, and other services
- Demonstration of the partnership between SAP and a partner as a template for blockchain innovations in the utilities industry
- Starting point for SAP customers in the utilities sector for new blockchain-enabled business models such as local renewable energy tariffs, blockchain-based loyalty programs, renewable energy marketplaces, and blockchain-powered demand and supply optimizations

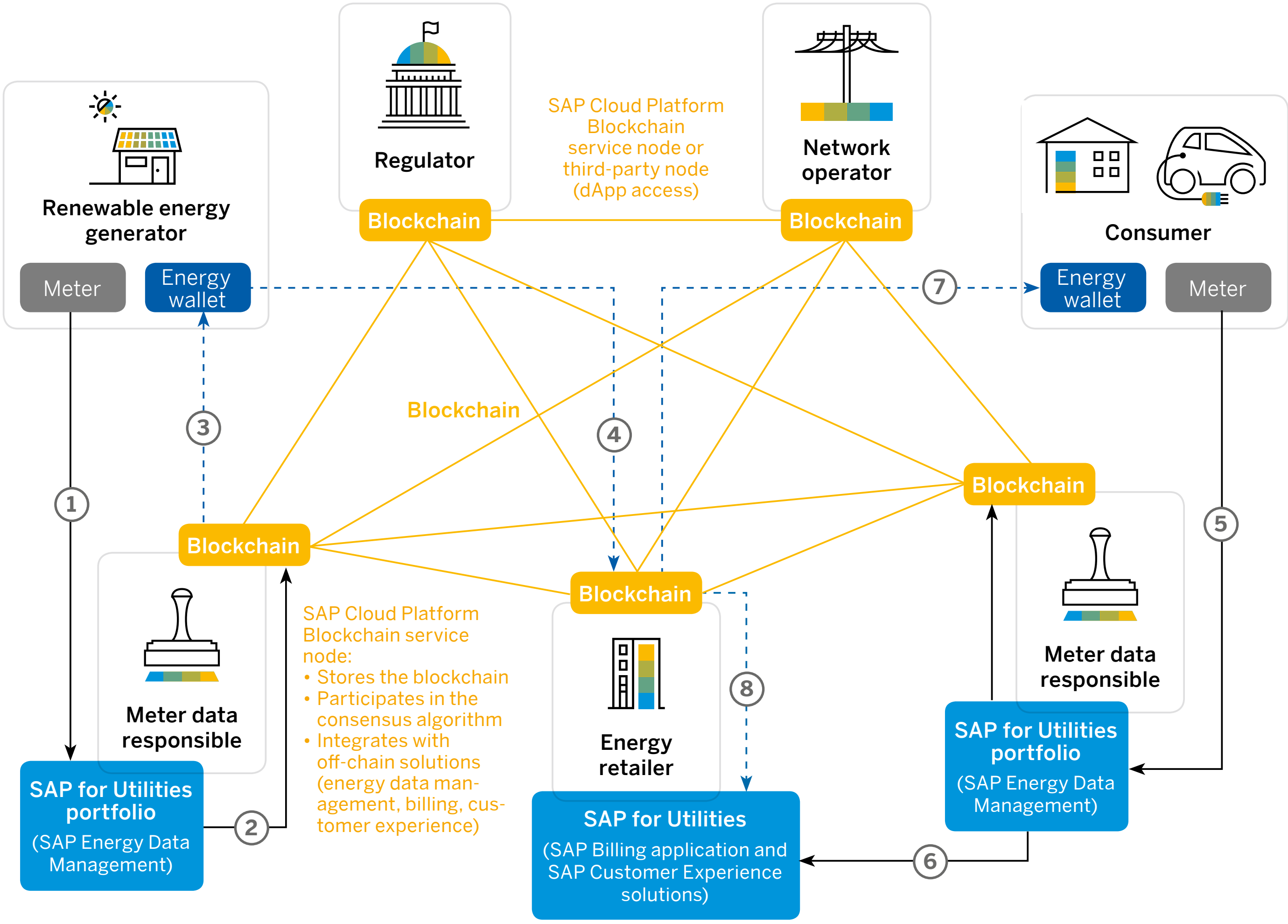
Figure 18 on the next page visualizes the results with the integration into the existing enterprise landscape.

The blockchain implementation in this showcase is a vendor-neutral implementation; that is, non-SAP blockchain nodes can be added and also third-party utilities business software systems can be integrated. The blockchain was designed in an open way so that regulators, standardization organizations, and consortia can use it as a blueprint for standardization of such processes in their specific area of responsibility.

The optional blockchain hardware ↑oracles (smart meter with specific security-certified blockchain clients) are a differentiating feature of this showcase, in contrast to several other published implementations of this specific blockchain scenario.

> "The solution has received huge interest from energy retailers and distribution companies worldwide. The solution showcases Wipro's competency to implement new blockchain-based innovations for utilities with faster time to market. The SAP Cloud Platform Blockchain service coupled with SAP Cloud Platform capabilities and integration services for SAP S/4HANA helps us to implement end-to-end scenarios quickly and cost-effectively."
>
> Shivanand Hiremath, Wipro

Figure 18: Results of Integration of Blockchain into SAP Solution Landscape



1 5 6 Off-chain meter data integration

3 Blockchain-based 1:1 renewable certificate issued and visible in the energy wallet

4 Consumption of tokenized energy certificates by retailer

7 Consumer receives renewable energy certificates

8 Energy wallet as an app or consumed inside SAP Customer Experience solutions

Utilities save additional hardware cost for blockchain hardware oracles[165] as well as additional service cost for installing blockchain oracle hardware in the infrastructure. Fraud is also minimized because the established, secured infrastructure and the fraud prevention processes inside the meter data responsible for detecting fraud are reused in the blockchain scenario – you can say that the meter data "signs with its name" that the physical (off-chain) energy world is valid. The meter data responsible guarantees that no energy fraud happens by risking the loss of repetition in the market as well as to be excluded from accessing the blockchain.

SAP Cloud Platform provides integration with existing SAP for Utilities solutions as well as with customer experience solutions such as customer portals and marketing. That simplifies the access for generators and consumers – they can access their "energy wallet" through the known customer portal without any additional apps (mobile apps, dApps, and so on). The customer experience is simplified, and typical technology hurdles for nontechnical consumers are removed.[166]

In addition to the inherent benefits inside the IT landscape, there are synergies with other innovation scenarios. If utilities want to support consumers to analyze and benchmark their energy consumption, then meter data has to be streamed into special energy data analytics systems such as SAP Cloud for Energy. Such solutions are specialized to support analytical tasks, and they have the capabilities to provide aggregates and cleansed data that is typically required by public and consortium blockchains. On the other hand, blockchain can be used to securely save ↑ hash values (unique digital fingerprints) of data. Blockchain could help to validate that the data is unchanged in the energy data management and smart meter analytics systems – also without replicating the complete data into the blockchain.

All in all, consuming data inside the established infrastructure and IT landscape helps to reduce hardware and complexity and lower total cost of ownership for blockchain innovations. It is recommended to discover the fully end-to-end processes as well as overlapping processes to choose the most competitive landscape architecture and project setup.

SUMMARY FROM SAP

SAP is committed to blockchain technology and supports customers and partners in the innovation scenarios and the development of new business models. We offer blockchain technology in an easy-to-consume blockchain-as-a-service offering on SAP Cloud Platform. Other blockchain technologies can be offered by partners in a similar way to utilities in the SAP community and ecosystem. SAP helps utilities leverage their existing utilities IT solutions to innovate faster and to focus on the unique benefits of the new technology: distributed immutable collaboration and automation between multiple utilities and other businesses.

> "Wipro's partnership with SAP for SAP Leonardo puts us at the forefront in the global consulting market. It helps us gain early insights into the latest developments and provides us a direct channel for feedback. Most importantly, the partnership provides our clients with best-in-class technology and domain expertise."
>
> Ameekar Charan, Wipro

165. This benefit becomes obsolete if blockchain clients are delivered out of the box, security certified, hardware vendor independent, and sold without additional total cost of ownership. Until then, it is a competitive advantage to integrate blockchain innovations inside the IT landscape of the utilities.

166. Access to decentralized applications, known as dApps, is not prevented by SAP Cloud Platform. If utilities find this beneficial, then such access could be offered.

Glossary of Terms (↑)

consortium blockchain: As a semiprivate blockchain (shared permissioned blockchain), a consortium blockchain (or special-purpose blockchain) is a compromise between ↑ public and ↑ private blockchains. Only verified participants are permitted to validate blocks. Optimized consensus algorithms allow significantly faster transactions than public blockchains. A digital currency is not required to perform transactions, but ↑ tokens may be helpful as an incentive. Overall, consortium blockchains have the potential to be tailored to the specific requirements of the energy market, for example, by waiving anonymity or increasing the transaction volume, depending on the application.

decentralized autonomous organizations (DAOs): DAOs are one form of ↑ smart contracts. They represent an organization or community on the basis of smart contracts, which are self-organizing and require no human intervention initially. Governance rules are formalized, automated, and implemented by software. The rules of procedure are defined immutably in the code. The specified tasks are therefore confined to requirements that can be clearly described mathematically. Decisions that go beyond the procedures defined in the code are made by the holders of voting rights in accordance with predetermined criteria stored in the program code. The voting rights are proportional to the number of ↑ tokens held. This is usually the freely tradable equivalent of the financial investment made in the DAO. As a result, a DAO has no physical address. All rules for ensuring the operation of this digital organization and its entire financial transaction history are tracked on a blockchain and are therefore distributed and cannot be precisely located.[167, 168]

distributed ledger: Distributed ledger is the consistent result of duplicated and shared data. There is no higher-level administrator and no central data repository; the data is distributed across many computers, countries, and institutions. Although a peer-to-peer network and a consensus mechanism are required, a distributed ledger does not automatically constitute a blockchain. Only when the data is stored using concatenated blocks is this known as a blockchain. A blockchain is only one possible form of distributed ledger.

hash, hash value: A hash is the unique identification of a block and is comparable to a checksum or a digital fingerprint. It is formed by a hash function that creates a relatively short character string based on various input data. The correctness of the hash value or the checksum can be checked easily if the initial values are known, but it is not possible to uniquely determine the initial values (inverse mapping). This means that the identity of two blocks can be verified easily by comparing their hash values.

initial coin offering (ICO): The advance sale of a project-internal cryptocurrency or ↑ tokens to finance the project concept is known as an ICO. The investors – traditional investors as well as small-scale supporters (crowd) – count on the exchange rate rising if implementation is successful. This may also involve a transfer of voting rights. Unlike traditional capital market financing, this type of corporate financing is not currently subject to any regulatory mechanisms.

IOTA: IOTA is a blockchain without block generation. In IOTA, transactions are stored not in a chronological chain but in a large number of decentralized database strings. The cryptographic concatenation typical of blockchains is not used; instead, a directed acyclic graph (DAG), known as a tangle, is used. The transactions are, therefore, interlinked. Each participant or participating device that sends a transaction must participate in consensus building. This ensures that sufficient resources are always available to verify transactions, without having to pay for external resources for transaction verification. Before a transaction can be recorded, the relevant participant must verify two randomly selected preceding transactions. This is done using a simple (in other words, less CPU intensive) ↑ proof of work. The result is a network of verified transactions. Over time, these are indirectly attributable to all new transactions (here known as tips). The confirmation level of your own transactions can be set. This means that a transaction is considered to be a consensus in the network if a percentage of the tips, predefined by the transaction partners, can be attributed to the transaction. In principle, a small percentage of tips ensures faster implementation, and a high percentage of transaction-confirming tips (up to 100% is possible) ensures a high level of security. Although this is not, strictly speaking, a blockchain, as it has no blocks and no chain, the decentralized IOTA peer-to-peer network is expected to be compatible with all other blockchain technologies in the medium term.

167. Jentzsch (2016), Buterin (2013).
168. P2P Foundation (2016).

microgrid: Microgrids are electrical distribution networks that contain both (controllable) loads and distributed generation capacities. A microgrid can also include power storage. The participating resources can be operated in a controlled and coordinated manner. The system can be operated both with a connection to the regular power grid and as a stand-alone solution.[169]

mining/miners: Mining denotes the work performed by the computers involved in the block creation process. All transactions carried out during predefined time intervals are combined to form a block and attached to the existing blockchain at these intervals. To achieve this, the participating computers (miners) in the network must validate these blocks (that is, confirm and enter their correctness). This is done using the ↑ proof-of-work mechanism. If the block is generated successfully, the computers involved are compensated for this in the blockchain's own cryptocurrency.

node/full node: A (full) node is a participating computer in the peer-to-peer network that stores the entire blockchain history. It checks (but does not calculate) and forwards every transaction that reaches it. A node does not do any ↑ mining, but a miner is usually also a node. Nevertheless, the peer-to-peer network must have a sufficient number of nodes. Unlike mining, this activity is not remunerated. An incentive to provide a node is given by the fact that this is an opportunity to participate directly in the network, to have a say in the development of the network, and to possess data from the blockchain.

oracle: An oracle is a source of information that is defined in a ↑ smart contract and considered to be a trigger of events. It defines the "if" in the if-then relationships. An oracle can be defined both inside and outside the blockchain. While an internal oracle provides the same security standards as transactions in the blockchain, trustworthiness and reliability for integration of external oracles are crucial. External oracles make it possible to link transactions in the blockchain to the occurrence of many real-world events. Selecting a suitable oracle is key. This is why there are oracle service providers who act as "notaries," bringing information from the real world into the blockchain and confirming its validity.

private (permissioned) blockchain: A private (permissioned) blockchain grants access only to preselected participants who can read and/or write depending on their access rights. The blockchain is under the complete control of the operator, who knows all participants from the outset. In contrast to ↑ public blockchains, the characteristics of anonymity and irreversibility are therefore removed, but not necessarily. In principle, the operator can reset processes in the blockchain. However, the chosen design is very important in this respect. Waiving both ↑ proof of work as a decentralized consensus mechanism and immutability can radically increase the speed and scalability of the blockchain. It is thus possible to validate individual blocks with significantly fewer resources, because not all participants have to compete to solve an algorithmic puzzle. The alternative used in this case is known as ↑ proof of authority, in which a single participant generates new data blocks.

private key: While a public key is used as a target address when executing transactions, the private key enables access to and insight into the currency units and ↑ smart contracts of the relevant blockchain participant. Each transaction is signed using the private key, allowing a third party who knows the key to perform transactions. The private key also serves as the basis for the public key, which is derived mathematically from the former. It is very difficult to reconstruct this and derive it by backward induction.

proof of authority: In the proof-of-authority process, a single central network participant is responsible for verifying transaction blocks. This participant is defined in advance and is responsible for managing the network.

proof of stake: In contrast to ↑ proof of work, the proof-of-stake consensus mechanism does not involve performing work (↑ mining). Instead, the trustworthiness of the validating node is the result of depositing a stake (in other words, a monetary deposit). Only some of the participating computers are randomly selected to validate the block or the transactions it contains. The likelihood of being selected rises as ownership of the blockchain's currency increases. It is assumed that this approach could boost transaction speed up to tenfold.

169. Marnay et al. (2015).

proof of work: Proof of work is a validation procedure for adding new transactions, aggregated over a certain period of time, to a blockchain in the form of blocks. The work involved is the artificial computational effort required to generate a ↑ hash value. All the computers involved in the network compete to solve an algorithmic puzzle by trial and error. The winner receives the hash value, thus generating the next block, and is rewarded for this in the underlying digital currency. The validity of the solved puzzle and the integrity of the entire blockchain are verified by all the servers involved. The puzzle is based on the previous hash value and other predefined conditions such as block content and time. This ensures that the transactions stored on the blockchain are immutable in practice. To change a block, all the following blocks would have to be changed, which entails very high calculation effort. In addition, 51% of the computing power used in the network would have to agree to the changed chain of blocks. Because the blocks should always be generated at approximately the same time intervals, the difficulty of the puzzle must increase as the computing capacity within the network increases.

public (permissionless) blockchain: In principle, a public blockchain is accessible to everyone – provided there is a suitable infrastructure. Participants are usually displayed to all other participants anonymously by means of random IDs such as personal addresses. In the first instance, there is no central operator who monitors ongoing events on the blockchain. A public blockchain is mainly based on the ↑ proof-of-work consensus mechanism. This sophisticated validation procedure means that trust is no longer necessary between individual market participants in a transaction, because the majority of all participants monitor the validity of the blockchain. Computing power and storage capacity are provided by the participants.

sharding: This concept provides for the splitting of the space that can be represented in the blockchain into "shards." Under the consensus mechanism, these shards are randomly assigned nodes of the network for validation. The assignment can be made, for example, using the initial digits of the individual participant's address in the network. This enables transactions to be verified in parallel, increasing the speed and number of verifications accordingly. To date, this concept exists only in the form of a white paper by Vitalik Buterin.[170] However, it is planned to develop it together with ↑ proof of stake as an integral part of Ethereum. There is still a need for solutions, particularly when it comes to transactions between participants from different shards. The aim is to find a procedure that guarantees the correctness of the transaction history of each individual shard for all other shards.

smart contract: A smart contract is a self-executing agreement that is mapped and monitored directly on the blockchain as a computer program. Its automated execution is intended to reduce transaction costs by cutting out middlemen. A high degree of contractual security is ensured by the fact that subsequent changes to actions are either impossible or made more difficult. In addition, implementing the contract content can be accelerated significantly by the possibility of near-real-time execution. In principle, complex rules and interaction patterns can be verifiably mapped and executed; a smart contract always functions according to the if-then principle. This makes possible totally new forms of organization for designing automated transactions. These can be executed independently between intelligent objects and require no human intervention. For example, a direct supply contract can be concluded between a photovoltaic system and a neighboring small-scale consumer. When current is collected, the system automatically checks whether it is generating electricity at present and whether this electricity is already being sold elsewhere. If the response is positive, a financial transaction is credited automatically to the directory of the photovoltaic system.

170. Buterin (2013).

state channel: State channel is a concept, not a technology. The exact design, therefore, depends on the particular implementation and the blockchain used. A state channel is designed to significantly increase scalability and privacy protection for normal blockchain transactions. For transactions between two participants or between a participant and a service (that is, a machine), the transactions are pooled and recorded only as a result in a ↑ smart contract. They are recorded, for example, after a predefined time, after a defined monetary amount is reached, or after manual confirmation by both participants. To avoid discrepancies, all communication is signed with the ↑ private key and a time stamp. Because of the low effort involved in this two-way communication outside the blockchain, transactions can be implemented quickly and cost-effectively.

token: A token usually denotes the currency unit on which a cryptocurrency is based. From a technical perspective, tokens are an entry in the distributed database; from a practical perspective, they are essential for operating ↑ public blockchains. They incentivize the individual participant to take part in the validation. However, the function of tokens can go beyond this. For example, user-defined data of any kind, objects, and relationships – such as voting rights, ownership structures, and identities – can be stored in blockchain tokens and transferred in this form.

zero-knowledge proof: Zero-knowledge proof is a verification procedure in which no knowledge is transferred. The proofer convinces the verifier without providing the solution to the puzzle or the password. However, a great deal of communication is required to demonstrate with sufficient probability that the proofer knows the secret without actually mentioning it. This makes it difficult to use this method in practice. In contrast, most cryptographic methods are based on the exchange of a symmetrical (shared-secret method) or an asymmetrical key. This can be exploited by third parties stealing and misusing the key.

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Methodology of the German study: 27 interviews with experts (March through August 2017)

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