Blockchain – an opportunity for energy producers and consumers?

Table of contents

This is a study conducted by PwC on behalf of Verbraucherzentrale (consumer advice centre) NRW, Düsseldorf

Executive summary

Efficient peer-to-peer transaction platform

Blockchain is a special technology for peer-to-peer transaction platforms that uses decentralised storage to record all transaction data.

The first blockchain was developed in the financial sector to serve as the basis for the cryptocurrency "Bitcoin". More and more new applications have recently been emerging that add to the technology's core functionality – decentralised storage of transaction data – by integrating mechanisms that allow for the actual transactions to be effected on a decentralised basis. These mechanisms, called "smart contracts", operate on the basis of individually defined rules (e.g. specifications as to quantity, quality, price) that enable an autonomous matching of distributed providers and their prospective customers.

Lower costs, faster processes and greater flexibility

Blockchain technology changes the way we transact, with the underlying transaction model shifting away from a centralised structure (banks, exchanges, trading platforms, energy companies) towards a decentralised system (end customers, energy consumers). Third-party intermediaries, whose services are needed today in most industries, are no longer required in such systems – at least according to the blockchain theory – given that transactions can be initiated and carried out directly "from peer to peer". This can cut costs and speed up processes. As a result, the entire system becomes more flexible, as many previously manual work tasks are now carried out automatically through smart contracts.

Current barriers hindering the implementation of blockchain applications

In theory, blockchain systems no longer require either intermediaries or a central authority. Conflicts are to be resolved using "swarm" principles, i.e. based on the collective opinion of all parties involved. But it is still difficult today to put such models into practice. In addition, there are a number of legal and regulatory requirements that blockchain projects must also comply with. In any case, the actual technology behind blockchains has not yet reached maturity and is therefore still being developed.

Some level of maturity in financial services but concepts only in energy and other sectors

An entire eco-system of companies has sprung up around Bitcoin that build on the virtual currency and its underlying technology. Other financial use cases of the technology are currently being developed and trialled by many major banks and start-up companies.

Other industries are only just starting out on blockchain development. Some start-ups are currently entering the market with blockchain projects. In the energy sector, a small number of pilot projects are trialling the technology, some of them funded by large energy companies. In New York in April 2016, for instance, decentrally generated energy was sold directly between neighbours via a blockchain system for the first time. The goal is to establish a fully decentralised energy system in which energy supply contracts are made directly between energy producers and energy consumers (without involving a third-party intermediary) and carried out automatically.

Opportunities for prosumers

Blockchain technology strengthens the market role of individual consumers and producers. It enables prosumers, i.e. households that not only consume but also produce energy, to buy and sell energy directly, with a high degree of autonomy. The current legal and regulatory framework for consumers and prosumers in the energy sector is clearly defined and provides protection on many levels to consumers in particular. However, in the medium to long term, this framework will probably have to be adjusted to reflect the requirements of decentralised transaction models.

Wide range of energy use cases

Blockchain technology shows a lot of promise. Other than being used to execute energy supply transactions, it could also provide the basis for metering, billing and clearing processes. Other possible areas of application are in the documentation of ownership, the state of assets (asset management), guarantees of origin, emission allowances and renewable energy certificates.

Blockchain technology has the potential to radically change energy as we know it, by starting with individual sectors first but ultimately transforming the entire energy market.

1 IEA, World Energy Outlook, 2015.

1. Blockchain:

introduction, definition and development history

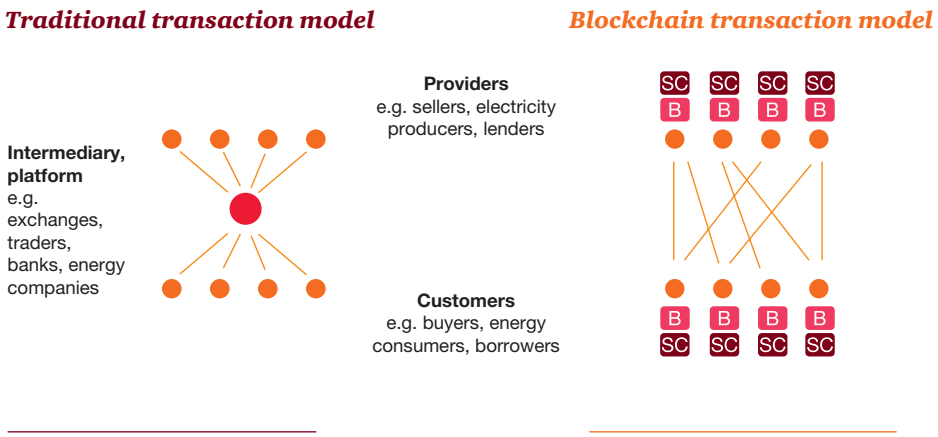
Blockchain is a technology that enables so-called "peer-to-peer" transactions. With this type of transaction, every participant in a network can transact directly with every other network participant without involving a third-party intermediary.

The blockchain innovation is that transactions are no longer stored in a central database, but distributed to all participating computers, which store the data locally. The first relevant blockchain application was Bitcoin, a so-called "cryptocurrency". Over recent years, Bitcoin has become the basis for other blockchain applications, most of which are currently being developed in finance. A number of businesses and initiatives have recently been launched that apply the blockchain principle to other industries, among them the energy sector. Blockchain applications are generally considered to be a very promising technology but they are still at an early stage of development.

What is blockchain?

The aim of this study is to analyse the potential impact of blockchain technology on the energy sector and to explore what opportunities it may hold for energy customers and energy consumers. Born as a niche product on the fringes of the market, blockchain has for some time now been garnering the attention of experts in various industries, and has increasingly been in the spotlight of the media. Yet many decisionmakers, e.g. in the financial sector, are unsure how to respond to this trend: in a survey conducted by PwC in March 2016, 57% of respondents said so.[1]

Figure 1: How blockchains change the way we transact



- Multi-tiered transaction model relying on a central authority
- Transaction data is primarily stored by the central authority (●)

- Transactions are carried out directly between providers and their customers
- All transaction data is stored on a distributed blockchain B, with all relevant information being stored identically on the computers of all participants
- Ideally, all transactions are made on the basis of smart contracts SC, i.e. based on predefined individual rules concerning quality, price, quantity etc.
- Largely automated, decentralised transaction model with no need for third-party intermediaries

1 PwC Global FinTech Report, March 2016

In many cases, this uncertainty can be explained by an insufficient understanding of how blockchains work. Essentially, a blockchain is a digital contract permitting an individual party to conduct and bill a transaction (e.g. a sale of electricity) directly (peer-to-peer) with another party. The peer-to-peer concept means that all transactions are stored on a network of computers consisting of the computers of the provider and customer participating in a transaction, as well as of the computers of many other network participants. Traditional intermediaries, e.g. a bank, are no longer required under this model, as the other participants in the network act as witnesses to each transaction carried out between a provider and a customer, and as such can afterwards also provide confirmation of the details of a transaction, because all relevant information is distributed to the network and stored locally on the computers of all participants.

Figure 2: The blockchain process

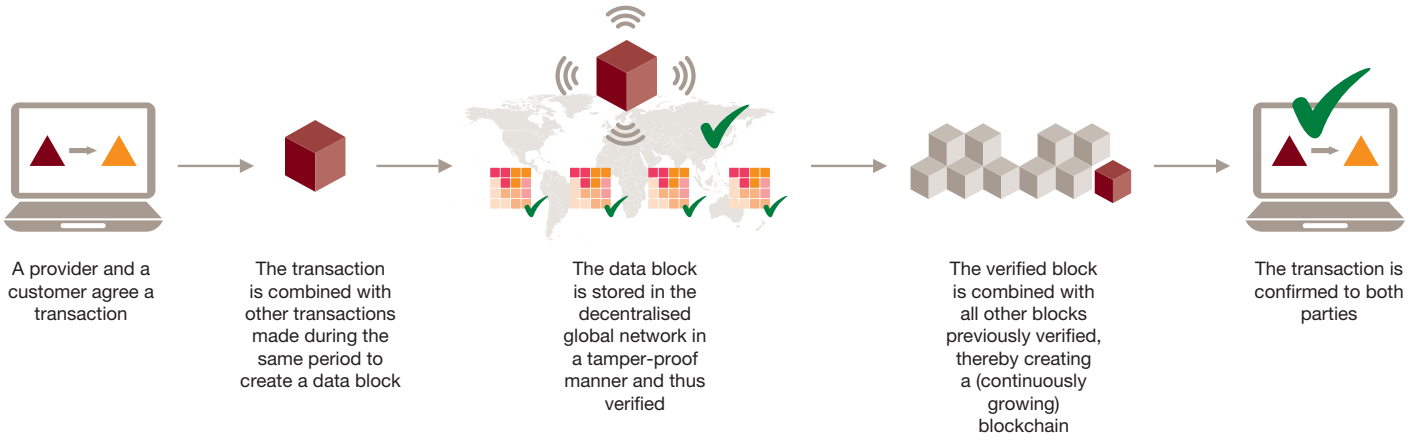
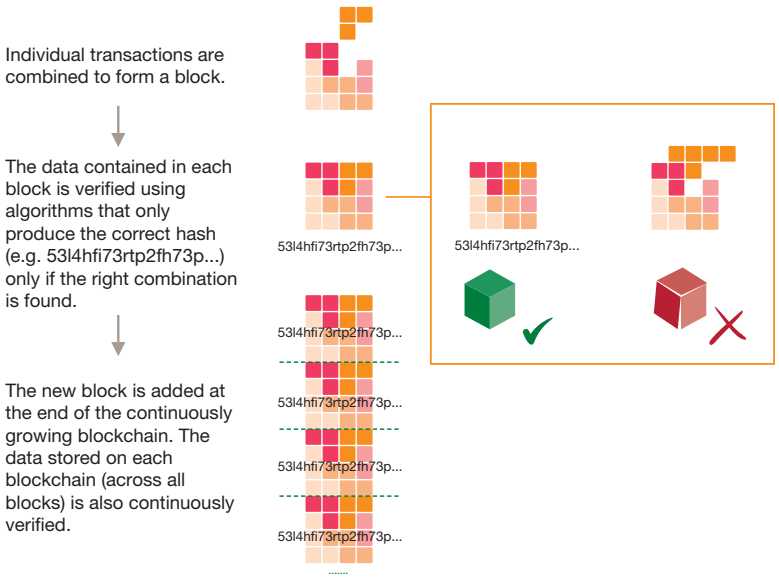


Figure 3: The verification process



How does a blockchain work?

Where a provider and a customer agree to enter into a transaction, they determine the variables of this transaction by specifying the recipient, the sender and the size of the transaction, among other things. All information relating to an individual transaction is then combined with the details of other transactions made during the same period to create a new block of data. This is comparable to sending emails, which are also split into separate data blocks. Blockchains are different in that this process relates to a single standardised transaction.

Each transaction is encrypted and distributed to many individual computers (peer-to-peer), each of which stores the data locally. The members of the network automatically confirm (verify) the transactions stored on the individual computers.

The data stored in a block is verified using algorithms, which attach a unique hash to each block. Each such hash is a series of numbers and letters created on the basis of the information stored in the relevant data block. If any piece of information relating to any transaction is subsequently changed as a result of tampering or due to transmission errors, e.g. the exact amount of the transaction, the algorithm run on the changed block will no longer produce the correct hash and will therefore report an error.

All number/letter combinations are continuously checked for correctness and the individual data blocks are combined to form a chain of individual data blocks – the blockchain. Due to the interlinking of these number/letter combinations, the information stored on the blockchain cannot be tampered with (at least this would require a great deal of effort). This continuous verification process (called "mining") is performed by the members of the blockchain, who are rewarded for this service according to the computing power they contribute.

The verification process ensures that all members can add to the blockchain but no subsequent revisions are possible. This enables direct, peer-to-peer transactions between persons or organisations that used to require the services of an intermediary in order for their transactions to be legitimately recorded. For example, while a bank is currently needed as an intermediary to effect a financial transaction between two parties, the same transaction can be executed and documented directly between the two parties if a blockchain is used.

What is the blockchain development history?

Today's blockchain applications can be divided into three broad categories based on their stage of development, namely stages 1.0, 2.0 and 3.0. The category **"Blockchain 1.0"** comprises virtual (crypto)currencies such as Bitcoin that can be used as an alternative to real currencies (e.g. the euro or the dollar). To this day, Bitcoin continues to be the blockchain application best known to the general public, and becoming more so. However, despite the fact that more and more users are adopting the currency, with traded volumes on the rise, the absolute share of Bitcoin transactions in the international foreign exchange markets is still minimal. At present there is no indication that Bitcoin may ever come close to reaching the dimensions of other international currencies.

The next stage of development is to enable smart contract models, which are collectively referred to as **"Blockchain 2.0"**. A "smart contract" represents a digital protocol that automatically executes predefined processes of a transaction without requiring the involvement of a third party (e.g. a bank). Returning to the example given at the start of this chapter, it would for example be possible to create a fully automated smart contract between an energy producer and a consumer that autonomously and securely regulates both supply and payment. If the customer were to fail to make payment, the smart contract would automatically arrange for the power supply to be suspended until payment has been received, provided the parties had previously agreed to include such a mechanism in their contract. This development poses a threat to the traditional business models of banks, which may be in danger of being excluded from the market segment of payments.

Companies and developers may decide to build their applications on either public or private blockchains. On a public blockchain, the identity of all participants remains anonymous. Bitcoin and Ethereum are examples of this. In private blockchain systems, all participants are known and identified before being given access. Some advantages of private blockchains are that they allow for simpler governance structures and that they can be operated at lower cost compared to public applications. Banks and payment service providers are therefore bound to use private blockchains for their existing business models, among other reasons because this will allow them to retain some degree of control as well as revenue potential.

The next blockchain generation, referred to as **"Blockchain 3.0"**, remains a vision for now. Blockchain 3.0 is the stage where the smart contract concept is developed further so as to create decentralised autonomous organisational units that rely on their own laws and operate with a high degree of autonomy.

"Today's blockchain applications can be divided into three broad categories based on their stage of development, namely stages 1.0, 2.0 and 3.0"

How the blockchain works in detail

Each blockchain is essentially a so-called "DApp" (decentralised application) operating on the basis of a peer-to-peer protocol and coming with the special feature that it provides distributed storage functionality for storing transaction data.

DApps are open-source applications which represent a contract between a network and its users and which run on a distributed register (the so-called "ledger"), such as the Bitcoin or Ethereum blockchains. What makes this type of application special is that no single organisation controls these contracts or holds a legal claim over them, but that all decisions (e.g. on protocol adaptations) are taken by consensus between the users on the basis of computer code.

In order for an application to qualify as a genuine decentralised application, both its protocol and data must be stored on a public, decentralised blockchain (to avoid a central point of failure) and validated using a decentralised verification mechanism (e.g. "proof of work").

Properly decentralised applications ensure that a reliable record can be kept of all transactions and business deals, even in the event that key websites and interfaces go offline. Also, no one can subsequently revise or erase the ledger.

DApps can be classified as follows:

- Type 1: decentralised applications that have their own blockchain
  - Examples: Bitcoin, Altcoin, Litecoin
- Type 2: decentralised applications that use the blockchain of a type 1 DApp
  - Example: Omni Protocol (a software layer built on top of the Bitcoin blockchain)
  - Type 2 DApps are protocols and use their own tokens
- Type 3: decentralised applications that use the blockchain of a type 2 DApp
  - Example: the SAFE Network, which uses the Omni Protocol to issue "safecoin" tokens. [2]

The proof-of-work and proof-of-stake concepts

The purpose of the verification process is to achieve consensus on the content of the distributed ledger. Consensus-based verification is a decentralised (i.e. embedded on the blockchain itself) and automated process.

The following two mechanisms are most commonly[3] used to establish consensus:

Proof of Work

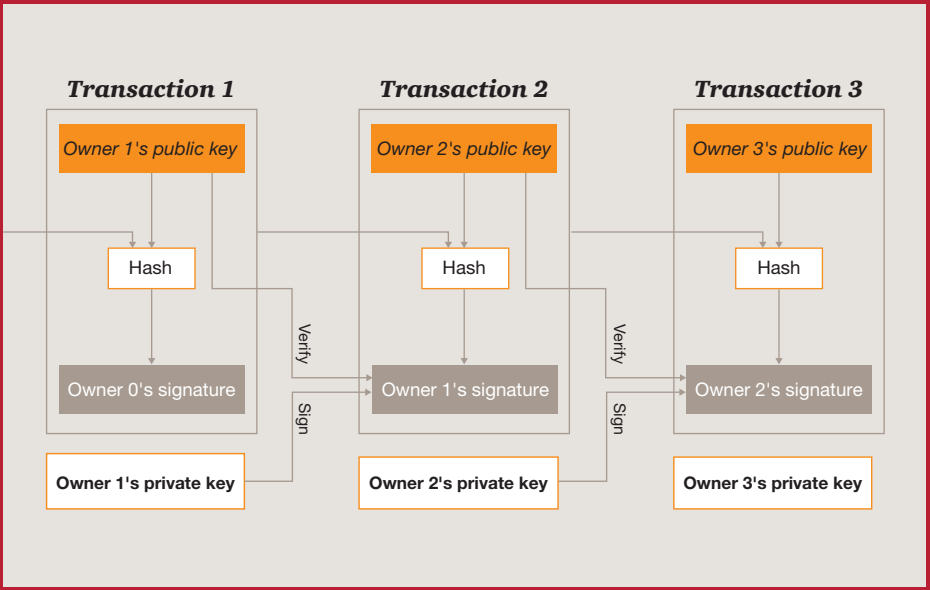
The proof-of-work concept is the consensus mechanism most frequently used in conjunction with blockchain technology, and relies on so-called "miners". Each block is verified through mining before its information is stored. The data contained in each block is verified using algorithms which attach a unique hash[4] to each block based on the information stored in it. These hashes can be either ordinary hashes or cryptographic hashes. The complexity of this task lies in finding a specific hash corresponding to the block's content. The level of complexity (difficulty) adjusts flexibly in response to the computing power available on the miners' network, so as to ensure that new blocks can be hashed at predefined intervals (Bitcoin: 10 minutes, Ethereum: 10 seconds). Even if only a single piece of information relating to any transaction is subsequently changed, for example if the amount of a transaction is altered as a result of tampering or due to transmission errors, the algorithm applied to the block will no longer produce the correct hash. The hashes computed for the same block, which was stored many times around the decentralised network as described above, are compared so that changed blocks can be identified and declared invalid. The verified, correct version of a block is identified by the majority of participating computers and added to the other blocks previously verified, thereby extending the blockchain. Once the block which contains the initial transaction is added to the blockchain and this addition has been stored by a sufficient number of network participants, the transaction is confirmed to both parties.

2 Source: David Johnston/Decentralized Applications

3 Other consensus mechanisms: federated Byzantine agreement (FBA), deposit-based consensus, Byzantine fault tolerance

4 Hash algorithms are used to convert data of an arbitrary length to a fixed length, thereby creating a hash. The hash value represents a checksum which is used to encrypt a message of variable size using a hash function. No two encrypted messages may be based on the same hash value, nor will the hash value provide any clues as to the message content.

Figure 4: Peer-to-peer transactions[5]



The mining process can also be used to take decisions on changes to a DApp. Decisions made in accordance with the proof-of-work principle are taken on the basis of the amount of work the individual stakeholders have performed to verify a block.

Proof of stake

The proof-of-stake approach simplifies the mining process where a large number of tokens need to be verified. While under the proof-of-work principle, a large group of distributed users are continuously verifying the hashes of transactions through the mining process in order to update the current status of the blockchain assets, the proof-of-stake concept requires users to repeatedly prove ownership of their own share ("stake") in the underlying currency. Where the proof-of-stake method is used, the work required to carry out the verification process is allocated between the individual members based on their stake in percent. For example, if a user owns a 10% share of the total outstanding blockchain assets, the user will have to carry out 10% of the required mining activity. This approach reduces the complexity of the decentralised verification process and can thus deliver large savings on energy and operating costs.

What are tokens?

The term "token" may refer to several things: a token can be used to grant users access to a (de-)centralised computer application, act as a key for the execution of digital transactions or represent a currency unit (e.g. bitcoins).

DApp tokens must be generated and distributed according to a standard algorithm or set of criteria. Tokens constitute the basis for using an application, and are also a reward for contributions by users. Yet tokens do not represent any assets, nor do they give rights to dividends or equity shares. Although the value of a DApp token may increase or decrease over time, it would be a misconception to think of them as a type of security.

What mechanisms are used to distribute tokens?

There are three general mechanisms DApps (e.g. Bitcoin, Ethereum) can use to distribute their tokens (e.g. bitcoins, ethers): mining, fundraising and development

- Mining: tokens are distributed as a reward to those participants who solve certain verification operations most quickly (with consensus being established by proof of work). Bitcoin is one example of a DApp issuing its tokens through mining.
- Fundraising: tokens are distributed to those who funded the initial development of the DApp.
- Development: tokens are generated using a predefined mechanism and are available for the future development of the DApp (with consensus being established by proof of stake).

Execution of transactions

In blockchain transactions, cryptographic proof replaces the third-party intermediary. The chart below shows a peer-to-peer transaction conducted without the assistance of any third-party intermediary. In this context, it is important to distinguish between the two components of a blockchain address, namely the private key and the public key. The public key can be used to view the transaction history of a user but it cannot be used to make a transaction unless the private key is also known. The private key is what is needed to access an account and actively execute a transaction.

The chart illustrates how Owner 1 transfers a token to Owner 2 by digitally signing a hash of the previous transaction and the public key of the next recipient (digital signature). The transaction is then added to the blockchain. The party receiving the information/payment (Owner 2) can verify the "chain of ownership" by verifying the signatures using the public key of Owner 1 stored on the publicly accessible blockchain. What they cannot check is whether a previous owner had already used the same token prior to the current transaction ("double spending"). Double spending can be verified either by a central authority or, in the case of Bitcoin, through a verification process carried out by a decentralised authority.

5 Source: Satoshi Nakamoto

2. A look at other sectors:

blockchain experience in various areas of application, with a particular focus on improving the consumer perspective

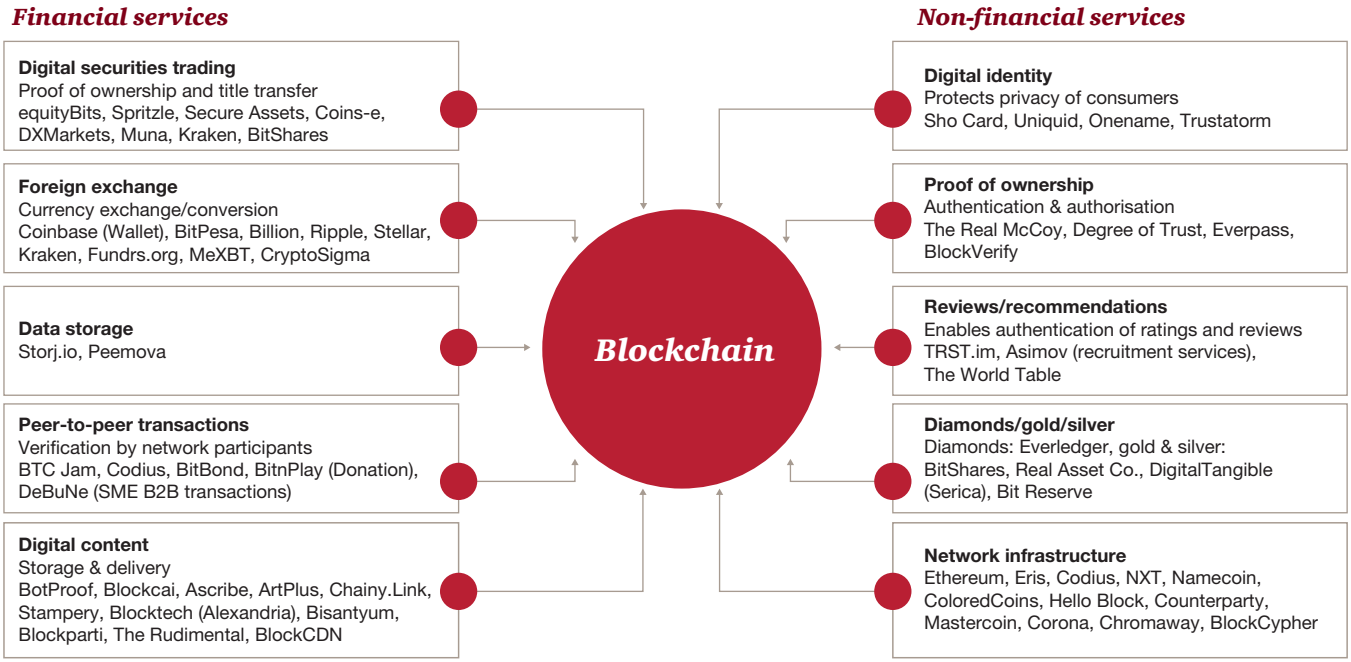
When it comes to the practical application of blockchain technology, by far the most progress has been achieved in the financial sector. In finance, unlike in other industries, blockchain solutions are not only used and developed by small communities but also by established players, e.g. international commercial banks.

For the most part this can be explained by the fact that in the area of financial services, the blockchain transaction model can deliver huge cost reductions and make processes more efficient, all within a short length of time. From a consumer perspective, the most interesting questions are which blockchain model – public or private – will win the day and how smart contracts will be used in the future.

2.1. Blockchain applications in different sectors

As is shown in the overview below, blockchain applications are being developed for a variety of industries and use cases.

Figure 5: New blockchain applications

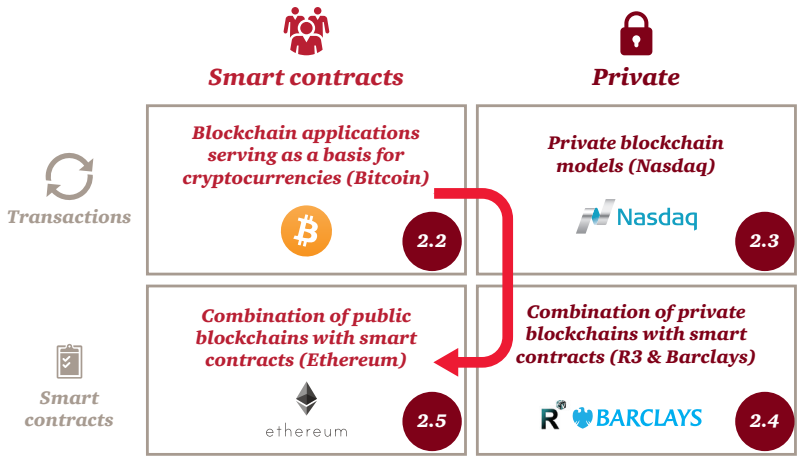


All these developments are still at a very early stage of development, with the primary focus of most projects being on refining their concepts or running first pilots. Yet initiatives such as **Onename** give us a glimpse of the potential impact blockchain technology may have in areas outside finance. Onename creates virtual IDs that uniquely identify users and allow them to log on to social networks using their own identities. Its IDs, which build on blockchain technology and are thus tamper-proof as well as unforgeable, are already being used on the Internet today, for example in blogs, forums or digital exchanges. From today's perspective, it may have quite a futuristic feel to think of digital driving licences or identity cards, which are potential future developments of this technology, given that such digital IDs are not currently a legally valid form of identification, and as such are not recognised by any government at present. But they do provide an outlook on what blockchain technology may make possible in the future.

Another example is the Swedish start-up company **Bitnation**. Its application stores public administrative acts on a blockchain, for example contracts, insurance policies or official certificates. In a few isolated cases this is already used in practice, for example in Estonia, which has recognised marriages via Bitnation since 2015. Bitnation has not yet succeeded in establishing other comparable use cases of its blockchain, though. Honduras, for instance, has abandoned the planned migration of its land registry onto the blockchain.

In the financial industry, in contrast, the number of functioning blockchain applications is growing by the day. The technology and its various use cases have made plenty of headway since the first blockchain application Bitcoin was launched in 2009. The two most important developments in finance that can currently be observed are the trend to build smart contract applications on blockchain technology and initiatives to create private blockchains.

Figure 6: Blockchain applications in the financial sector



These developments will broaden the range of possible blockchain applications. In the following parts of this chapter we describe the different types of blockchain models using examples from the financial sector.

The insight gained here will allow us to draw some conclusions as to what developments we may be about to see in the field of energy. In particular, the matter of which of the two blockchain models is likely to be used in the energy industry will have a significant impact on the potential advantages and disadvantages the technology may have for consumers.

"In the financial industry, in contrast, the number of functioning blockchain applications is growing by the day"

2.2. Blockchain applications serving as a basis for cryptocurrencies (Bitcoin)

Bitcoin was the first blockchain-based application and has become the most widely known cryptocurrency. The technology has been enabling users to transfer bitcoins between them without involving a third-party intermediary since 2009, with Bitcoin not only being the name of the system as such but also of its currency unit.

Users do not need profound technical understanding to install and operate the system; it can be accessed relatively easily even by inexperienced consumers. Moreover, access to the Bitcoin system is not restricted. Every user can log on to the system and even develop new applications building on the Bitcoin blockchain. When registering via the Bitcoin website, users choose a so-called "wallet" (which represents their electronic purse) and a Bitcoin address. Bitcoin addresses are similar to email accounts, via which users can send bitcoins to other users. Whenever a transaction is made, the corresponding information is broadcast to the entire Bitcoin blockchain via the associated peer-to-peer network. The wallets calculate the account balances based on the tamper-proof information stored on the blockchain, and can be configured so as to execute only certain transactions, for example only if the sender disposes of a sufficient fund of bitcoins. This provides receiving users with comprehensive protection against fraud or non-payment. Still, inexperienced users in particular are also exposed to some risk when using Bitcoin, for example if they forget their access details, which means that their stored assets will be irretrievably lost. It is also not possible to reverse transactions that were made erroneously.

Payments made using Bitcoin can be clearly and unambiguously verified, which makes system-related accounting errors impossible. Contrary to what is often assumed, this high level of transparency also results in a loss of anonymity. Each step of all money transfers made via Bitcoin is publicly accessible on the Internet. Though the accounts, and thus the users, participating in a transaction are anonymous, once the login name (alias) of a user is known, the user's entire transaction history can be found on the blockchain and traced back to the user.

In the seven years of the system's operation no one has ever succeeded in subsequently altering a Bitcoin transaction or attacking – or at least disturbing – the network. Nevertheless, there have been incidents in the past, among them cases where bitcoins have been stolen through manipulated exchanges.[6]

Outside the virtual environment, where bitcoins can be used to pay in online shops etc., there are growing numbers of restaurants, hotels or record stores that accept bitcoins as a means of payment. The Swiss municipality of Zug has even become the first public administration to accept Bitcoin payments. Exchanging bitcoins for real products, however, remains difficult. One former problem for consumers, which was posed by the strongly fluctuating exchange rates of the digital currency against "real" currencies, has in the meantime been largely eliminated, thanks to apps which offer to exchange bitcoins against euros at the time of making payment.

It remains to be seen whether and to what extent the average consumer will value the enhanced protection against tampering and the – theoretical – cost savings delivered by blockchain applications such as Bitcoin as a meaningful and notable improvement on the traditional payments system. The latter normally offers free money transfers, high security standards and a considerably higher processing rate of money transfers per second (50,000 under the Visa system vs. 7 in the case of Bitcoin) even today.

6 The Mycoin case, where the operators of a Hong Kong-based exchange were able to steal several million euros' worth of bitcoins using a Ponzi scheme.

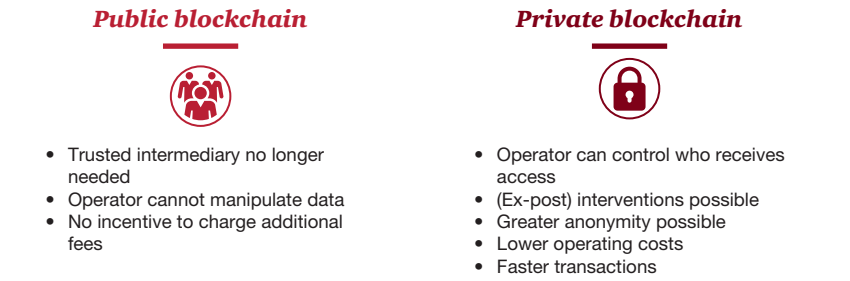
2.3. Private blockchain models (Nasdaq)

Private blockchains have been developed primarily on the initiative of financial services companies. Users can access a private blockchain only if the operator controlling the blockchain, for example a bank, uniquely identifies them and grants them access to the blockchain.

Private blockchains are therefore usually seen as an opportunity for banks and exchange operators to protect their business cases, as they would allow them to reroute their customers to a blockchain they control. In addition, they could continue to charge fees for services that can be provided automatically, and hence at almost no cost, by blockchain applications. At the same time, blockchain models provide banks with an opportunity to automate their processes, making them more efficient and cost-effective. Another advantage private blockchains offer from the perspective of the operator is that, technically, the rules governing the blockchain can be changed easily, which would make it possible for the operator to also reverse transactions on an ex-post basis. Also, the operator would be the central authority verifying all transactions. As no global peer-to-peer network would be required in this case, transactions could be processed at lower operating costs and at a faster rate. Furthermore, at least in theory, greater anonymity could be provided, as the transaction history would no longer have to be publicly accessible. Conversely, this would also mean that private blockchains no longer offer protection against tampering, or only to a certain extent, which was one of the key characteristics of blockchains in the first place.

On closer examination, it becomes clear that many private blockchain models no longer operate according to the principles originally described for blockchain systems, because - among other things -they offer at least a theoretical possibility of tampering or ex-post revisions by the operator. Private blockchains are quite similar to conventional client/server or cloud structures in this regard.

Figure 7: Comparison of public and private blockchains

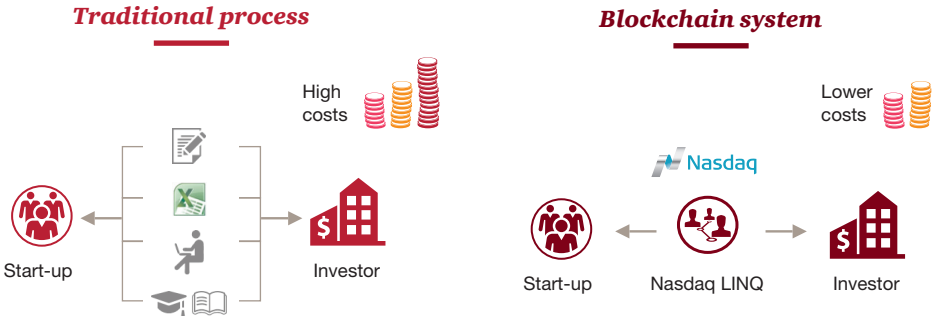


A typical example of a private blockchain system is the initiative of the US stock exchange operator **Nasdaq**. Nasdaq is currently trialling its first private blockchain application on its blockchain-based Private Market platform, which is used for pre-IPO trading activities (start-ups selling shares to investors prior to going public). In the past, lawyers, accountants and consultants have been required to execute and clear such transactions. In particular, the task of verifying the information exchanged between buyer and seller has been a time-consuming and costly exercise, since otherwise both parties run the risk of breaching procedural legal provisions in the run-up to a transaction. For this exact purpose, in 2015 Nasdaq developed a cloud-based platform called **LINQ,** built on a private blockchain, which stores information on current shareholdings and related changes, the prices of shares issued in each investment round and information on available stock options.

In addition, the platform records individual steps before and during transactions. Users can thus keep track of who purchased which shares of a company and how they were sold on. At the end of last year this system replaced the previous manual process operated on the basis of documents and records maintained by lawyers, accountants and consultants as well as on the basis of spreadsheet data provided by the start-ups themselves, which used to be prone to errors.

According to Nasdaq, the first transactions carried out for a total of 6 start-up companies and their investors have been successful, following which the application is to be migrated to other areas soon. Other than improving transparency and providing a record-keeping functionality, the platform delivers additional user benefits by reducing costs and accelerating the process. Nasdaq does not pass on its entire cost savings to customers, though, but continues to charge a fee in exchange for providing the service.

Figure 8: Nasdaq's LINQ platform



2.4. Smart contract applications based on private blockchains (R3 & Barclays)

The LINQ application described in the previous example has no smart contract functionality thus far, and so is primarily a tool to maintain a record of past transactions. In the medium term, though, companies are bound to start building smart contracts on private blockchains in order to achieve greater automation.

In this particular area all eyes are on the 45-strong consortium of major international banks funding the start-up company **R3**. Banks like Barclays, BBVA, Credit Suisse, JPMorgan, Royal Bank of Scotland, Deutsche Bank and UBS have been working with R3 since 2015 to apply blockchain technology to real currencies such as the euro or the dollar. The aim of this collaboration is to develop common industry standards permitting use of blockchain systems across multiple banks. On 3 March 2016, R3 successfully used its proprietary **Corda** blockchain for the first time to trade bonds as part of a pilot project involving a total of 40 banks.

The Corda blockchain, much like any other private blockchain, has some benefits for banks, e.g. it allows them to use the transaction platform whilst receiving exclusive access to the data. A particular focus of the project is on the integration of smart contracts. In April 2016, British banking giant Barclays demonstrated for the first time how the Corda blockchain can be combined with smart contracts in order to trade derivatives.

Derivatives are reciprocal contracts used in the financial sector. Similar to a bet, the value of a derivative is dependent on the future value of a certain underlying asset, e.g. the price of a share, an interest rate or the price of a commodity, at a specified future point in time. Derivatives trading today requires filling in a large number of paper or digital documents, similar to the situation in the bond market cited in the previous example.

Barclays has been developing a blockchain tool that besides recording all transaction data in a manner similar to Nasdaq's LINQ platform, implements a first version of a smart contract for the settlement of derivatives. The vision is for the smart contract to be capable of automatically transferring the value of a derivative to the account of the transaction's beneficiary from the account of its counterparty. The current legal framework still requires the counterparty owing the payment to authorise automated transfers, but technically it is already possible today to fully automate the process without leaving any possibility for intervention by the parties.

This is another case where the technology has the potential to cut costs and speed up processes by automating manual tasks. In addition, the parties involved are afforded greater certainty about the payments receivable or owed by them, as the smart contract can determine the derivative's status definitively and also settle it.

"The vision is for the smart contract to be capable of automatically transferring the value of a derivative to the account of the transaction's beneficiary from the account of its counterparty"

2.5. Smart contract applications based on public blockchains (Ethereum)

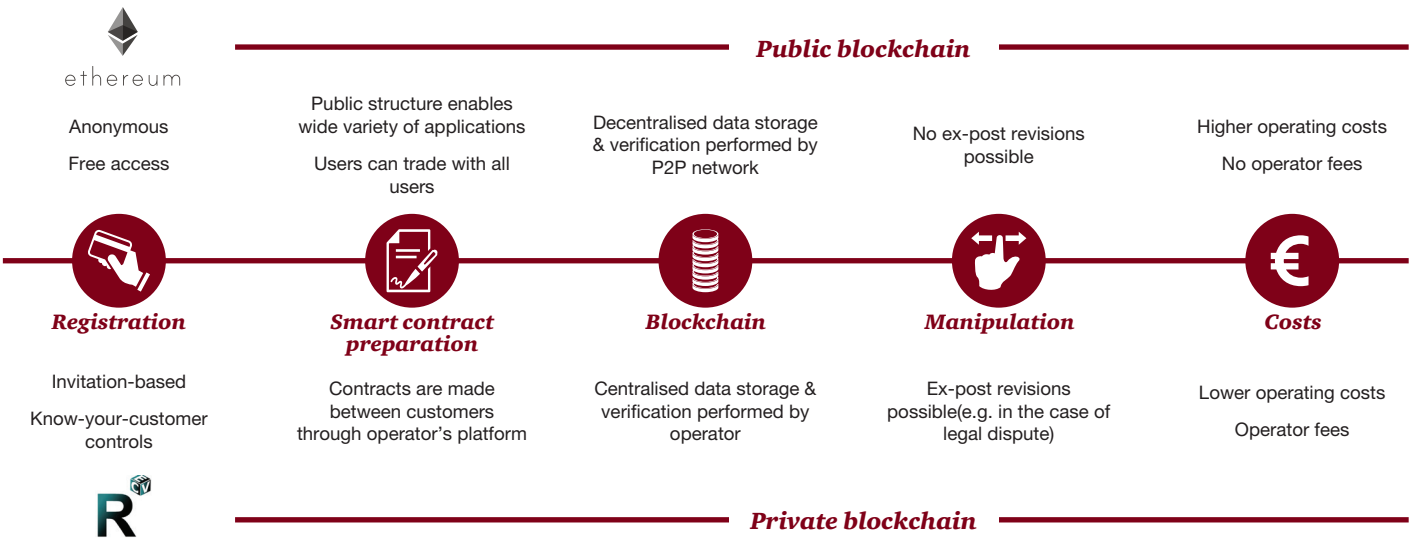
Outside the financial services industry and its participants' efforts to defend market shares by building private blockchain systems, efforts are underway to also develop public blockchains that could be used in combination with smart contract applications. The Ethereum project in particular is widely seen to be a strong contender in this field. The cryptocurrency project developed by the 22-year-old Russian developer Vitalik Buterin has been garnering lots of public interest since the start of this year.

Ethereum has caught the attention of established companies such as Microsoft, Samsung or RWE. RWE is planning to use the Ethereum blockchain in cooperation with the German start-up company Slock.it to operate charging stations for electric cars (see chapter 3). The main reason for this initiative is that Ethereum is considered to be capable of building a common and automated international payment system. This is a very positive development for consumers, as it could provide a nearly free alternative to the private blockchains currently being built in the financial sector. In addition, Ethereum provides an opportunity to implement smart contracts on a public blockchain.

However, not even Ethereum can entirely allay the security concerns of the general public when it comes to public blockchains. In June 2016 it was revealed that a user managed to siphon 3.6 million ethers (the original currency unit used on the Ethereum blockchain) worth 50 million from the investment fund "The DAO". The hack exploited an integrated smart contract, whereas the underlying blockchain has operated flawlessly to date (see chapter 6). Although the exact circumstances of the case have not been determined as yet, the incident can be considered a setback for the acceptance of public blockchain applications. At the time of writing of this study, "The DAO" was working to resolve the issue.

A comparison between Ethereum and R3 highlights the two fundamental and diverging trends that can be observed for blockchain solutions with integrated smart contract functionality. Which blockchain model will come to be applied in the energy sector is a decisive factor that will determine what advantages or disadvantages the technology will have for consumers. Also, the individual models actually implemented in practice would not necessarily have to conform fully to the underlying theoretical ideal: gradations are possible. For instance, it can be assumed that a future company operating a private blockchain in the energy sector will charge a fee for its use in order to increase its own profits. It could just as well be the case, though, that changes in the competitive environment will increase competition between different operators to such an extent that they will be forced to pass on at least part of their cost savings to consumers.

Figure 9: Comparison of public and private blockchains



3. A look around the world: international blockchain experience in the energy sector from a consumer perspective

Various companies are currently developing blockchain applications for the energy sector. None of these have moved beyond the concept or pilot stage yet. One trial run in New York in April 2016 saw decentrally generated energy being sold directly from one neighbour to another via a blockchain system for the first time.

International energy companies are also working on blockchain-based pilot projects. All these applications are designed to interconnect prosumers and/or provide a direct link between energy suppliers and energy consumers. Blockchain technology may thus pave the way for a further decentralisation of energy systems.

3.1. Possible use cases for blockchain technology in the energy sector

Some of the basic assumptions driving blockchain developments in the financial industry can also be applied to the energy sector:

- Decentralised storage of transaction data increases security and ensures greater independence from a central authority.
  >> in principle, this also applies in the energy sector

- Blockchain technology has a wide range of uses; blockchains can help to make payments via cryptocurrencies, to digitise contracts, to manage digital content, to verify transactions, to execute trades or be used in many other areas. The next big development step is expected to involve smart contracts.
  >> in principle, this also applies in the energy sector

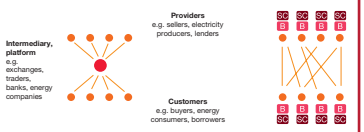
- New decentralised business models no longer require third-party intermediaries.
  >> in principle, this also applies in the energy sector

- Whether the technology will succeed will be determined not only by the technical capabilities of the system but will also be dependent on the applicable regulatory and legal framework, the technology's scalability and resilience as well as the economic viability of investments.
  >> in principle, this also applies in the energy sector

The energy sector differs from the financial industry in that the physical product itself (e.g. electricity) must also be taken into account. Transactions here not only involve values and information, but also the trading of energy which is delivered via network infrastructure.

The overview below shows possible use cases of blockchain technology in the energy industry.

Figure 10: Overview of possible blockchain use cases in the energy sector

Applications with a focus on transactions and smart contracts (automated execution of transactions)		*Applications with a focus on documentationof ownership*	*Applications with a focus on distributed transaction records*
Decentralised energy transaction and supply system  • *Decentralised buying/selling of energy (primarily electricity)* • *Special opportunities and use cases for prosumers* • *No supplier-switching process Cryptocurrency integration*	***Other smart contract applications,** e.g. in the fields of electric mobility, smart devices*	***Register recording ownership and current state of assets (asset mgmt.)***	***Metering and billing of electricity consumption***
		Guarantees of origin, certification of renewable energy	***Metering and billing ofheat use***
		Guarantees of origin, certification of emission allowances	***Billing ofelectric mobility (“roaming”)***

A key application –which we will return to throughout the course of this study as our basis for evaluating the potential of blockchain technology in the energy sector – is to develop a decentralised energy transaction and supply system.

Other use cases mostly leverage the blockchain’s functionality to provide a distributed and secure record of transaction data accessible to all participants (e.g. documentation of ownership, metering and billing of consumption).

Decentralised energy transaction and supply system

If the experience gained with blockchains in the financial sector are applied to the energy context, blockchain technology appears capable of enabling a decentralised energy supply system. It may be possible to radically simplify today’s multi-tiered system, in which power producers, transmission system operators, distribution system operators and suppliers transact on various levels, by directly linking producers with consumers, provided we manage to adjust the way the networks are controlled so as to reflect the new requirements.

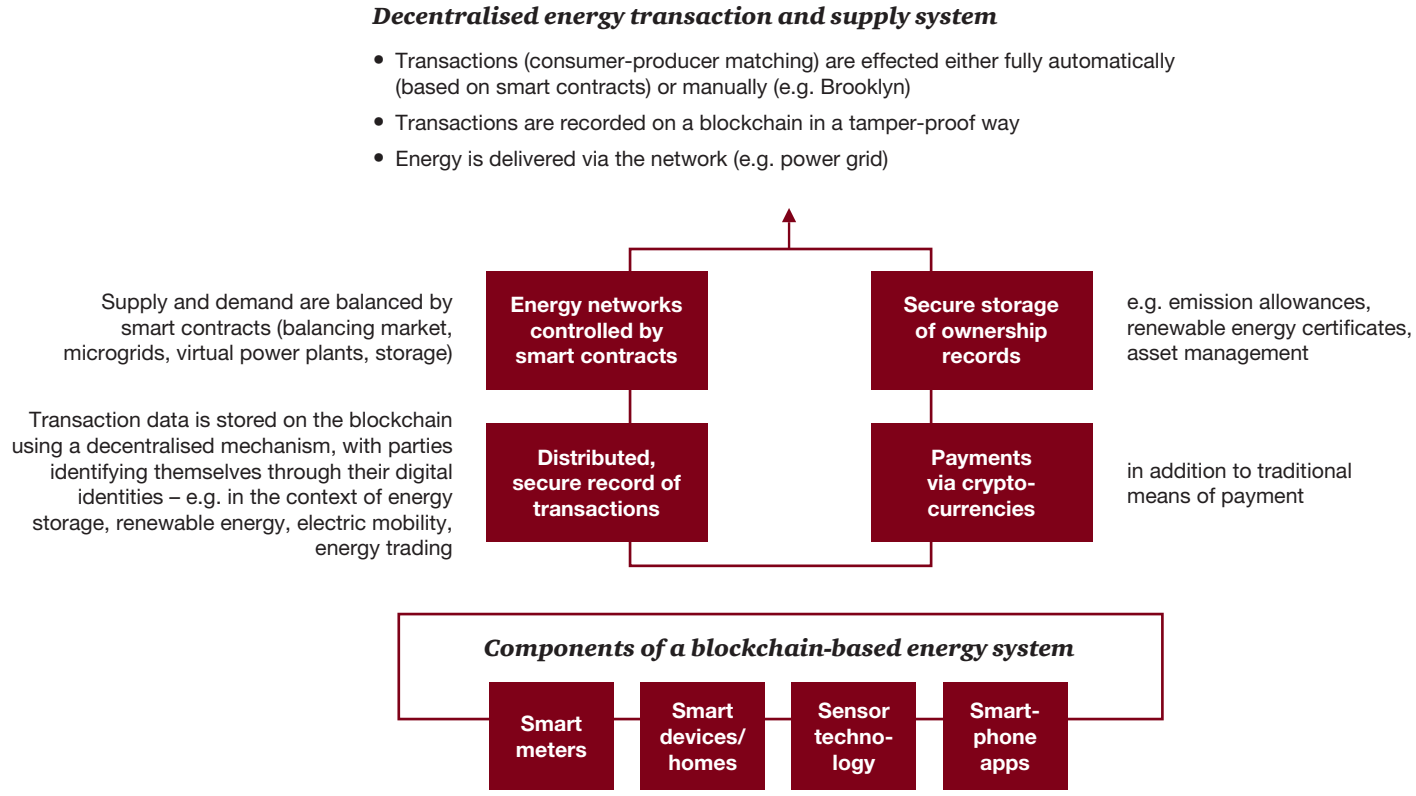
Some consumers are also producers: so-called “prosumers” not only consume energy but also dispose of generation capacity in the form of solar systems, small-scale wind turbines or CHP plants. Blockchain technology could enable them to sell the energy they generate directly to their neighbours.

Blockchain systems initiate and transmit transactions whilst recording them in a tamper-proof manner. All transactions made between individual parties are directly executed through a peer-to-peer network. A fully decentralised energy transaction and supply system as illustrated in Figure 11 can be considered to represent the ultimate level of energy-related blockchain applications from a theoretical perspective.

“Blockchain systems initiate and transmit transactions whilst recording them in a tamper-proof manner”

- Blockchain technology makes it possible for **energy networks to be controlled through smart contracts**. Smart contracts would signal to the system when to initiate what transactions. This would be based on predefined rules designed to ensure that all energy and storage flows are controlled automatically so as to balance supply and demand. For example, whenever more energy is generated than needed, smart contracts could be used to ensure that this excess energy is delivered into storage automatically. Conversely, the energy held in storage could be deployed for use whenever the generated energy output is insufficient. In this way, blockchain technology could directly control network flows and storage facilities. Smart contracts could also be used to manage balancing activities and virtual power plants.
- Decentralised storage of all transaction data on a blockchain would make it possible to keep a **distributed, secure record** of all energy flows and business activities. Both flows of energy and transactions, which would in part be initiated by smart contracts, could be documented in a tamper-proof way if recorded on a blockchain. The combination of smart contracts controlling the system and distributed ledgers securely documenting all activities would also have a direct impact on network and storage operations.
- Another potential future area of application is to use blockchains for the purpose of documenting ownership and related transactions, by providing **secure storage of ownership records**. The possibility of storing all transaction data in a tamper-proof and decentralised way opens up great opportunities in the field of energy certification. Two applications come foremost to mind: the first is in the verification of renewable electricity and of emission allowances (emissions trading). The ownership history of each certificate could be recorded exactly on the blockchain. This would provide a tamper-proof and transparent way of managing certificates for renewable power and emission allowances. Another use case, which is related to the Internet of Things, is to set up a blockchain-based register that records and regulates the ownership and current state (asset management) of assets such as smart meters, networks and generation facilities (e.g. solar systems).
- Customers could use **cryptocurrencies** to pay for the energy supplied.

Figure 11: Cornerstones of a decentralised energy- transaction and supply system

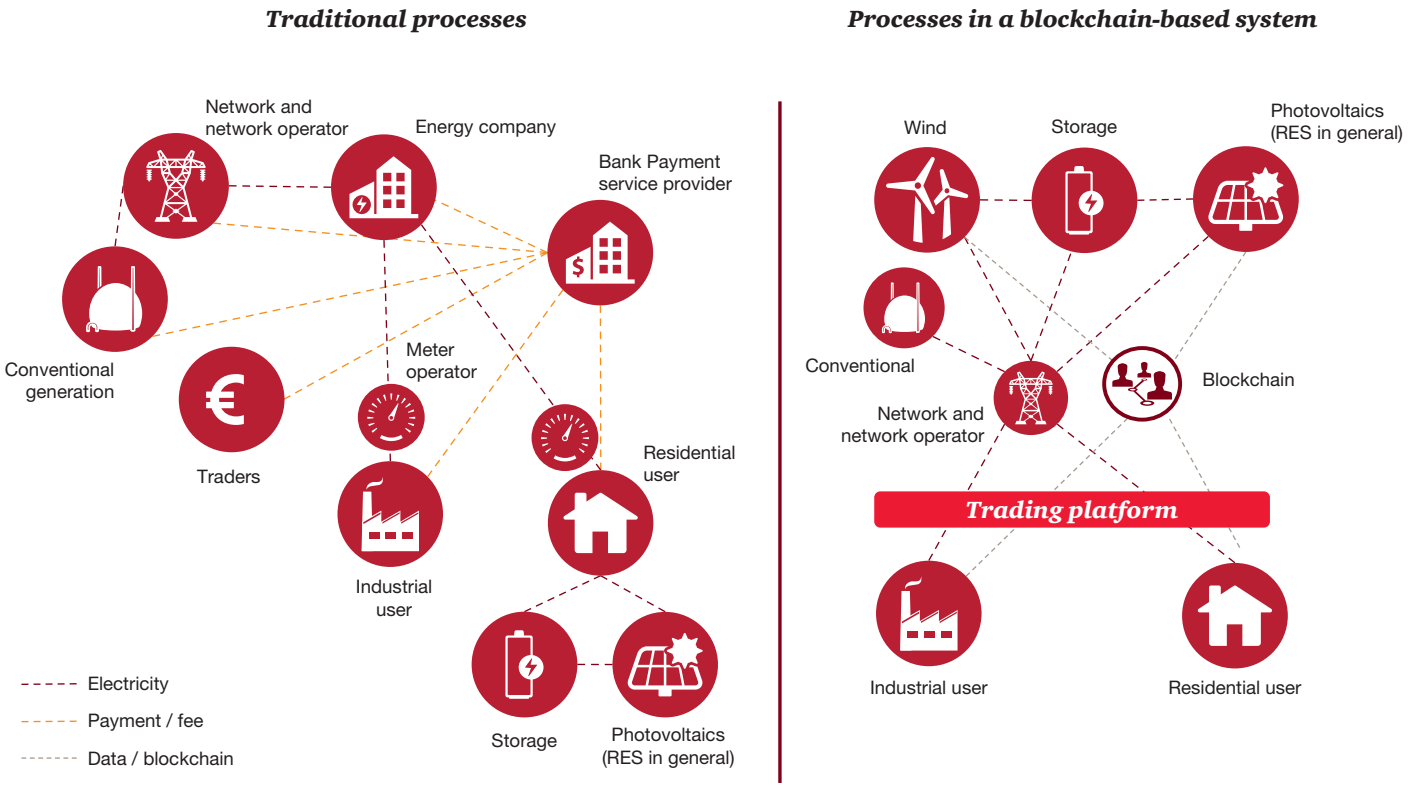


Where individual blockchain applications are combined, a **decentralised energy transaction and supply system** can become possible for the future. Energy that is generated in distributed generation facilities would be transported to end users via smaller networks. Smart meters would measure the amount of energy produced and consumed, while energy-trading activities and cryptocurrency payments would be controlled by smart contracts and executed through the blockchain.

Transposing these mechanisms to the German energy market shows that an energy supply without brokers or energy companies is possible. Under the current system, energy is produced in centralised generation facilities and delivered to industrial and domestic users via the distribution networks operated by energy companies.

Traders buy and sell energy on the exchanges and banks act as payment service providers, handling the transactions made by the parties involved. Blockchain-based energy processes would no longer require energy companies, traders or banks (for payments). Instead, a decentralised energy-transaction and supply system would emerge, under which blockchain-based smart contract applications empower consumers to manage their own electricity supply contracts and consumption data.

Figure 12: Transformation of market structures on introduction of decentralised transaction model



Other possible uses of blockchain technology in the energy sector

Besides being used to create a decentralised transaction model as outlined above, there are other areas in which blockchain technology could be applied in the energy sector.

Blockchain technology could be used to build a **simple, blockchain-based billing model** and thereby help remove one of the largest barriers currently preventing users from adopting **electric mobility** on a large scale. Widespread use of electric vehicles (EV) can only become a reality if EV drivers can access charging stations everywhere. One issue we face today is how to simplify billing at charging stations, which may be located in public spaces where they can be used by anyone. Blockchain technology could be one option (besides other advanced payment models) on which to base a model under which EV drivers could park their cars, for example to go shopping, whilst the car autonomously logs on to a charging station and is recharged automatically (in the long run maybe even through induction). Once the driver leaves the parking lot, the charging station would automatically bill them for the electricity received, using blockchain technology.

Another area of application that might become more important in the near future is the **integration of blockchain technology in the area of smart devices**. With smart devices communicating with each other as well as with other devices both inside and outside of homes and businesses in the future, a communications medium will be needed that is capable of transmitting and storing the related information and transactions. Using blockchains for this purpose could be a good option.

Moreover, the blockchain's functioning as a distributed record of transaction data can be used to create a **comprehensive archive of all electricity billing data**. Following a smart meter rollout (which would be a prerequisite for this), blockchain technology could become a tool consumers can use for meter reading and billing purposes in connection with their digital electricity meters. The key here is the added control consumers would gain over their electricity supply contracts and consumption data.

An important current development that will fundamentally shape the framework for the above applications is the German **Act on the Digitisation of the Energy Transition** (*Gesetz zur Digitalisierung der Energiewende*), which entered its final reading stage in the German federal parliament, the Bundestag, in June 2016 and is expected to enter into force in 2017. The primary focus of the act is to introduce an obligation to install intelligent measurement equipment for the purpose of metering and transmitting the energy demand of consumers and the energy output of producers. Aspects of electric mobility are also to be a part of the concept underlying the act. Both charging points for electric cars and their users are expressly defined as end users for the purposes of the act. Where charging points are to be fitted with intelligent measurement systems, the envisaged statutory provisions for their installation and operation thus apply.

In principle, other related applications outside the electricity sector are also possible, for example when it comes to **billing customers for the energy they use for heating space and water**, an activity which is now mostly carried out by professional providers of meter-reading services such as Brunata, ISTA or Techem. Suspected cases of overcharging and oligopolistic control are frequently reported for this market segment, where tenants in particular have few options at their disposal to challenge the fees they are charged. In a blockchain-based system, tenants could select their meter readers by picking a service provider that offers a good deal and using the blockchain to exchange their smart meter data with them in a transparent way.

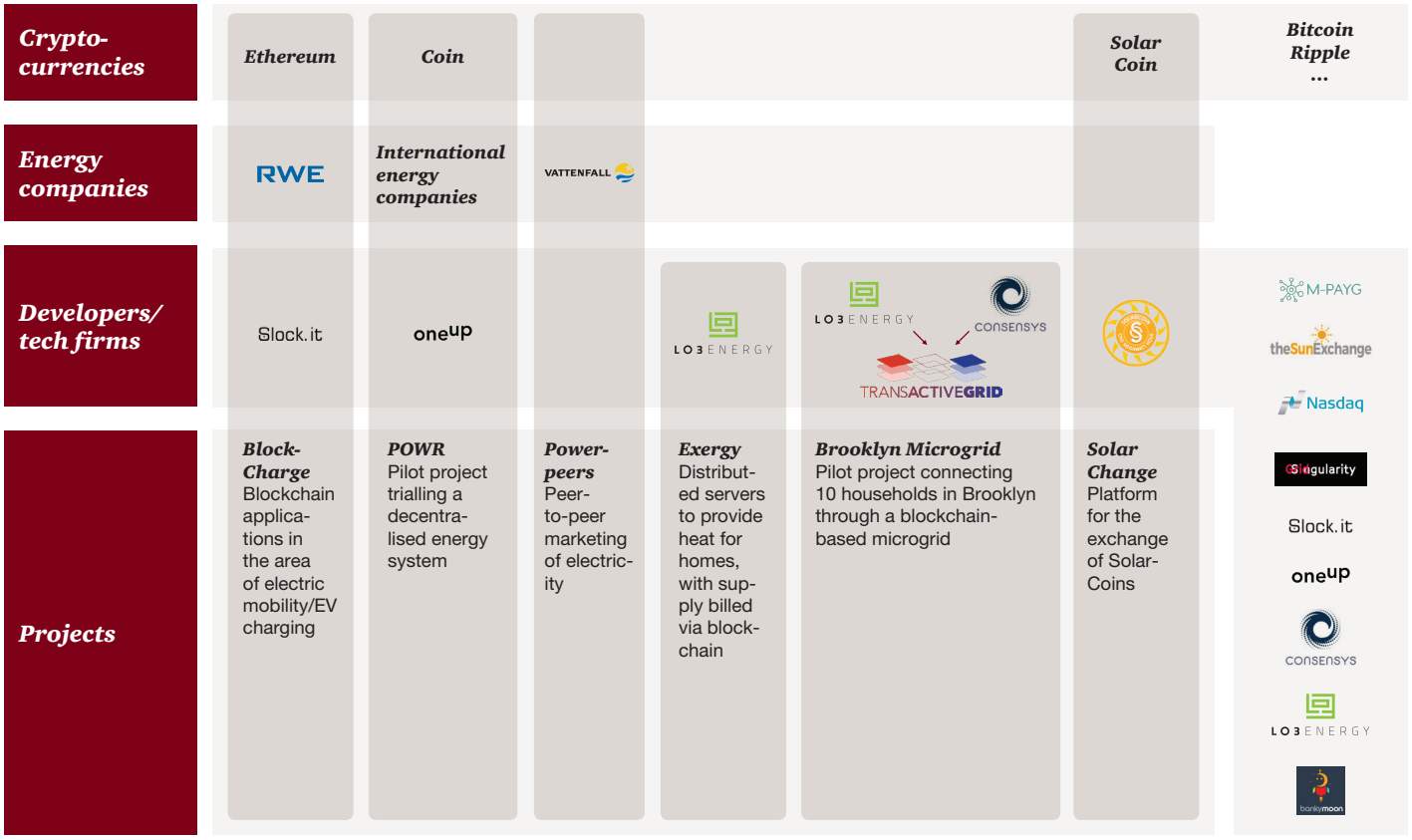
"Another area of application that might become more important in the near future is the integration of blockchain technology in the area of smart devices"

3.2. Selected current projects and market players

At present, RWE and Vattenfall are spearheading the development of energy-related blockchain applications in Germany. It can be assumed that other energy companies are also working to implement blockchain solutions, but are not yet visible on the market.

The chart below provides an overview of companies currently known to be working on blockchain projects for the energy sector.

Figure 13: Map of key blockchain players in the energy sector



Brooklyn Microgrid (TransactiveGrid)

www.brooklynmicrogrid.com

The "Brooklyn Microgrid" project is currently being developed in the USA by **TransactiveGrid**, a joint venture between **LO3 Energy** and **ConsenSys**. The aim of the project is to test how blockchain technology can be used to effect direct neighbour-to-neighbour sales of solar energy. The technology used in the project builds on the **Ethereum** blockchain.

Since April 2016, an initial pilot project run in Brooklyn has been exploring how to integrate buildings equipped with distributed energy resource systems (in this case: solar energy) in a decentralised peer-to-peer power grid. The rooftop photovoltaics systems installed on five of the buildings participating in the neighbourhood project generate solar energy. All energy not used by the buildings themselves is sold to five neighbouring households. All buildings are interconnected through the conventional power grid, with transactions being managed and stored using a central blockchain. This set-up demonstrates what a future distributed power grid managed autonomously by a local community might look like.

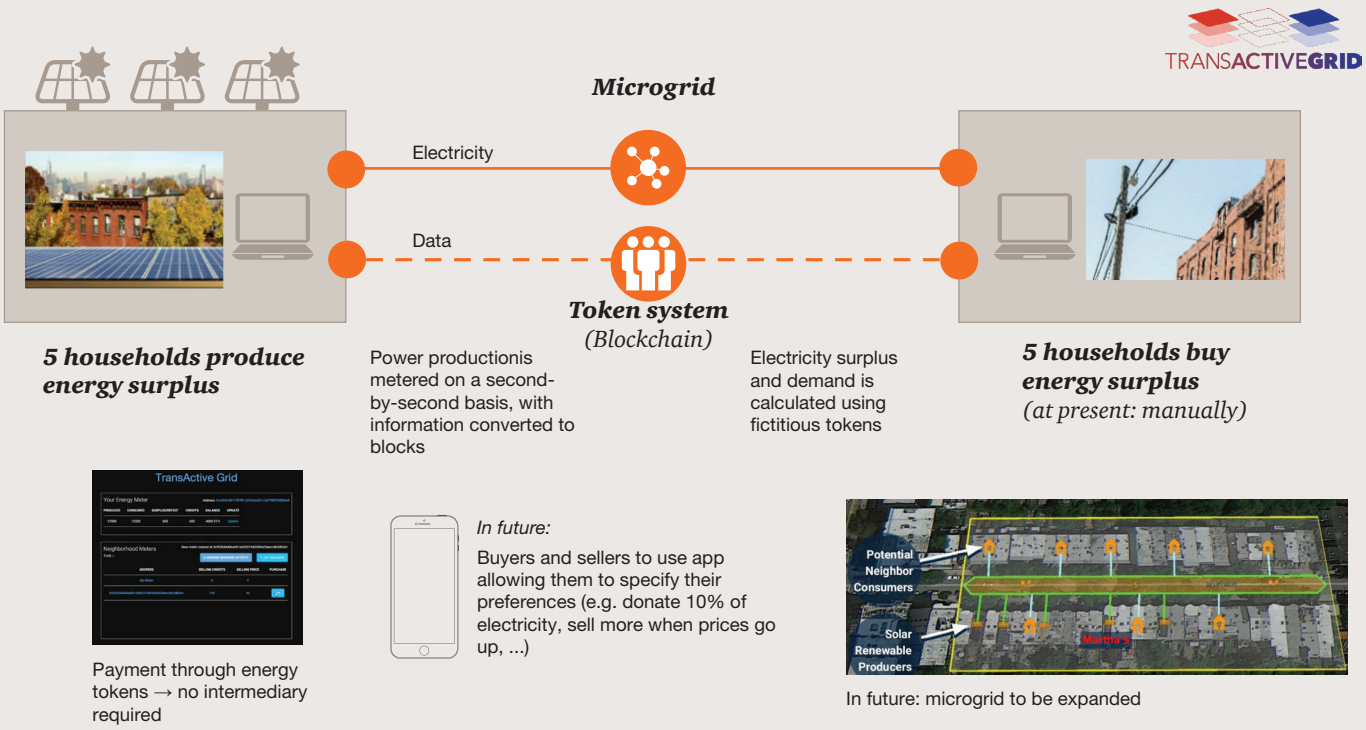
Implementation of the project requires both smart meter technology and blockchain software with integrated smart contract functionality: smart meters are needed to record the quantity of energy produced, blockchain software is needed to effect transactions between the neighbours, and smart contracts are needed to carry out and record these transactions automatically and securely.

The transactions made as part of the pilot project are executed manually. For the future, it is planned that the system can be controlled by means of an app that could be used to specify certain parameters, for example at what prices electricity is to be purchased from the neighbours. All transactions are then to be carried out fully automatically according to pre-agreed rules.

One of the project's goals is to create a local community market for renewable energy. In this way, it can be tested whether consumers actually make use of the option to trade energy with one another. With this new technology, the market can reach a point where a single person with a single solar panel can participate in the end user market. This is an opportunity for prosumers that allows them to no longer just feed their excess energy into the grid against payment of a fixed fee, but to market it individually.

In the future, the project is planned to be operated by a cooperative community organisation, with neighbourhood residents being the shareholders of the company. These plans envision that all renewable generation assets would be owned by the community itself, with members deciding collectively how to apply the revenue generated. This will allow people to own part of a solar panel, for example in urban areas where not everyone has access to a roof. To date, more than 130 homeowners and tenants have registered to participate in the project, either as a prosumer or as a consumer of electricity. It will still be some time, however, until this larger group can actually join the project, as the technology must first be developed further.

Figure 14: BrooklynGrid project



Parties can decide individually with whom to enter into a contract and transactions are executed immediately

Vattenfall: Powerpeers

www.powerpeers.nl

In June 2016, Vattenfall announced the launch of the start-up company "powerpeers" in the Netherlands. According to Vattenfall, many customers want to be more engaged in the energy-generation process and to have greater control over how the energy they consume is produced. As was also the case in the previous example, the mission of the start-up company hence builds on the idea of sharing energy through a peer-to-peer network. Powerpeers users can offer their self-generated energy and share it with other participants. Consumer participants can also choose from whom to purchase their electricity, e.g. family members, friends or neighbours, or also from certain wind, solar or hydropower suppliers. How much energy is provided by each chosen supplier can be viewed online.

The project does not require blockchain technology, but rather places its emphasis on the idea of sharing self-generated energy with others through a peer-to-peer network. Using a blockchain as the data medium was tested as part of the project, yet the current payment system is not based on this technology but is operated in a conventional manner, with payments being made in euros.

RWE and Slock.it: BlockCharge

www.slock.it

The Ethereum-based start-up company **Slock.it** from Germany and **RWE** have launched two projects in which they are working to simplify the charging of electric vehicles (see chapter 2.5). The first project explores how a blockchain-based system integrating smart contract functionality can be used to charge electric vehicles. Blockchain technology can provide a common, simple and secure payment system in this context. The project's vision is for electric vehicles to interact automatically with charging stations to manage the billing process for the electricity received during a charging session. Ultimately, the project partners envisage that every car will have a chip with a cryptocurrency installed, which will permit the vehicle to autonomously manage the payment process for electricity.[7] Slock.it and RWE are currently working on a prototype which is to undergo testing at a later stage.

The second project currently being developed by RWE and Slock.it, **Blockcharge**, focuses on enabling electric cars to be recharged using a smart plug – a plug that is operated by an app. Blockcharge smart plugs would not only be available at charging stations, but could also be installed in any location with power infrastructure. Consumers could control the smart plug using an app without this requiring the involvement of a third-party intermediary. Each charging session would be visualised in the app, allowing the consumer to monitor and manage the process. All transactions would be managed using a blockchain-based system, with all charging and transaction data to be stored on the blockchain. The aim is to develop a contract-less payment system not relying on third-party intermediaries.

Oneup: POWR

www.oneup.company

The Netherlands-based start-up company "**Oneup**" (formerly BigDataCompany) has developed a similar prototype for a decentralised energy-transaction and supply system and tested it using the energy data of ten households. As in the Brooklyn case, households located within the same neighbourhood generate solar energy in distributed generation facilities. Any energy that is not consumed by a household itself is delivered to its neighbours and billed using a blockchain system.

All transactions are made on the basis of smart contracts. Each building has a smart meter that is connected to a Raspberry Pi – a mini computer – which in turn is connected to a network. The Raspberry Pi is configured with a smart contract that checks in real time whether the conditions for a contract are met, and signals to the system whether a household is in a position to provide energy or whether it has a demand for energy. The software automatically initiates the energy transfer and corresponding payments using its own cryptocurrency.

LO3 Energy: Exergy

www.projectexergy.com

The **Exergy** project developed by the US-based company **LO3 Energy** is a research project aimed at heating homes using the heat generated in data centres. Heat generated from computing and the use of other electrical devices is to be captured and stored with the help of a technical module, in order to be re-used in other applications. The concept builds on a storage system for thermal energy operating in conjunction with an interface directly delivering the heat to existing heating systems in homes. The system is supported by a blockchain system which allows participants to purchase (stored) heat via a cryptographically secured system.[8]

7 https://Bitcoinblog.de/2016/02/26/rwe-und-slock-it-wollen-ethereum-fuer-elektroautos-nutzen/

8 http://lo3energy.com/projects/ http://lo3energy.com/projects/

Other blockchain applications developed by start-up companies	
Cryptocurrencies	The SolarChange project was created to financially reward producers of solar energy via a blockchain. For every megawatt of solar energy fed into the grid the producer is awarded one SolarCoin, which they can either store in their SolarCoin wallet or convert to bitcoins[9]. The project was launched by the company SolarCoin, which has developed its own cryptocurrency – similar to Bitcoin – for the purpose of selling solar energy. *www.solarchange.co/* *http://solarcoin.org*
Peer-to-peer lending	Sun Exchange offers investors an opportunity to fund small-scale solar projects and receive monthly returns measured in relation to the size of their investment. *www.thesunexchange.com/*
Decentralised energy-transaction and supply system	The Austrian company GridSingularity is developing a blockchain-based platform that is intended to connect energy producers, network operators, regulators and consumers. Specifically, the project's mission is to build a DApp platform for the energy industry that will cover all parts of the supply chain. *www.gridsingularity.com*
Decentralised energy-transaction and supply system, supply of solar energy to developing countries	**MPAYG** from Denmark is also working to leverage blockchain technology to enable consumers in developing countries to benefit from distributed generation. *www.mpayg.com* The **Bankymoon** initiative based in South Africa has developed a Bitcoin-based billing system for smart meters that operates in connection with the crowdfunding platform Usizo. Donors can use the crowdfunding platform to donate bitcoins to schools that have a smart meter in order to provide energy directly to the school of their choice. *www.bankymoon.co.za*
Smart devices	In the field of smart devices, Slock.it is not only working with RWE but also collaborating with **Samsung** and **Canonical**. As part of its ARTIK series, Samsung offers a range of intelligent applications in the fields of smart home, personal monitoring, smart cities and automotive. Canonical provides apps for these applications via its Ubuntu Core platform that can be used to control these smart devices. Slock.it's blockchain technology is intended to make the applications more secure. *www.artik.io* *www.insights.ubuntu.com* *www.slock.it*
Solar power certificates	Following the implementation of its **LINQ** platform, **Nasdaq** has presented a new authentication service offering to make solar energy certificates available via a blockchain. The new service works by connecting solar panels to an IoT-enabled device (IoT = Internet of Things) that measures the wattage of the power produced and fed into the grid. Certificates supporting PV growth can be bought and sold anonymously via Nasdaq's LINQ platform. In May 2016, solar energy produced in the Midwest was shown in New York as a data block. *www.ir.nasdaq.com/releasedetail.cfm?releaseid=948326*

9 http://www.fintechblue.com/2016/05/blockchain-electricity/

3.3. Assessment of the current state of the art and of the prospects for blockchain projects in the energy sector

As of now – at June 2016 – all energy-related blockchain applications are still in a concept or prototype stage, both in terms of their underlying technology as well as in terms of their possible use cases for consumers. Nevertheless, the technical potential of blockchain applications is clearly apparent *even today*: particularly decentralised energy supply relationships as well as the execution and recording of transactions are realistic prospects, so the potential for blockchain technology in the energy sector is promising.

Evaluation of the technology's maturity as compared to alternatives

Its decentralised structure for the execution of transactions and the storage of data is seen by experts to be the key benefit of blockchain technology. With data being stored in several locations at once the information becomes more difficult to tamper with, whilst being available everywhere.

However, the majority of experts also believe that there are alternative solutions capable of ensuring the functioning of a decentralised supply system. The trend to revert to more decentralised forms of supply, e.g. customer self-generation or distributed generation from renewable energy sources, is already being promoted in Germany as it is, with the country managing its transition towards a sustainable energy system (the so-called "energy transition"). Blockchain technology is not a necessary requirement for the operation of such a decentralised model and its associated data flows and transactions. Both transactions and data flows could just as well be recorded in conventional databases: this is a belief shared by most experts we have interviewed. At least judging from the current state of developments, these would be faster and less costly to operate, with the added benefit of being largely already available. While blockchain-based data transmission and data storage as such can currently be provided at minimal cost, the verification process leads to very high hardware and energy costs. The cumulative energy costs of some public blockchains have been driven to immense levels due to the many decentralised transaction verification processes that are carried out simultaneously. It must be mentioned, though, that new applications have been able to achieve great progress in this area.

The answer to the question of whether blockchain technology will be a more suitable tool for the energy sector than conventional databases and solutions will also depend on technological progress. The state of the technical infrastructure, data security and the scalability of the technology are key aspects here. Implementation of a decentralised energy-transaction and supply system will require technical infrastructure that includes for example smart meters for all consumers. Data security must be guaranteed by ensuring that the software is proof against tampering and attacks. Also, a framework for incidents like the case involving The DAO (chapter 2) must be created. The technology must be capable of being deployed on a large scale, with computing processes fast enough to ensure that energy can be supplied and transactions executed in real time and without any delay. In the following chapters we will discuss these prerequisites and the way in which they influence the development of blockchain applications in the energy sector.

Considering the present state of the technology and the progress that has been made since the first blockchain application was launched, it appears safe to assume that solutions will be found to resolve currently open issues. Experts believe that one particular requirement is that people's awareness of the opportunities provided by blockchain applications must grow in step with the technology's development. Critics assume that the technology is developing faster than the public's understanding of how to use it responsibly.

Applications and their use for customers

Whether users' awareness of the technology will grow will also be dependent on the availability of concrete suitable applications for consumers. At present, blockchain is a purely technology-driven development. There are no suitable applications available for customers who wish to actively control and manage their energy supply, nor are there automated software solutions for customers who do not want active control of their energy supply. The first group of end customers require suitable applications they can use without difficulty. These apps must be user-friendly, easy to use and effective. No such applications have emerged as yet, although individual companies and start-ups are working to develop solutions. Customers who do not wish to actively manage their energy supply, for example because they do not own a smartphone or do not want to spend any time on doing this, require automated software solutions. Blockchain technology will not succeed in the energy sector unless such applications are developed and used on a large scale. Or rather: only a small group of consumers will be using blockchain applications within small, decentralised networks without this affecting the majority of consumers.

4. A look at energy law:

current legal framework for the application of blockchain technology in dealings with consumers and prosumers and future legal challenges presented by blockchain

The German Energy Industry Act contains provisions on energy supply contracts which are aimed at balancing consumer protection interests with the interests of energy suppliers.

Some relevant legal principles have their basis in general civil law, most importantly in the provisions of the German Civil Code and the case law established in relation to this. This legal framework and a series of other acts and regulations must be taken into account when implementing blockchain projects. The law on consumer protection and data protection is comprehensive and must be taken into account for every blockchain project.

Except where noted otherwise, our following evaluation of blockchain models from a legal (chapter 4) and regulatory (chapter 5) perspective considers the technology in the context of its key application, the creation of a "decentralised energy-transaction and supply system" (chapter 3, pages 17 et seq.). The focus of our analysis is on the electricity market.

4.1. European energy law

Europe has been pursuing the goal of establishing a competitive internal market in electricity and gas since 1998. Several directives have been adopted to this effect, each of which has been transposed into domestic legislation. The latest legislative initiative is the so-called "Third Energy Package". One of the main objectives of the Third Energy Package is to separate the business of operating transmission networks from supply and generation activities, either through ownership unbundling or by establishing so-called "Independent System Operators" (ISOs) or "Independent Transmission Operators" (ITOs).

Another goal underlying the provisions of the Third Energy Package is to strengthen consumer rights, including the right of consumers to switch their gas or electricity supplier at no extra charge within a timeframe of no more than three weeks. In addition, the EU has set itself the target that at least 80% of consumers are to have smart electricity meters installed by 2020; EU law further provides that consumers are to have a general right to be supplied with electricity and that legal provisions must be in place to ensure the protection of "vulnerable customers".

One characteristic feature of all blockchain models is that they transfer control over data back to the consumer. Blockchains and the smart contracts implemented on the basis of them could empower consumers to manage their own electricity supply contracts and consumption data. Control over this data would therefore largely reside with the consumer. With network operator data (regulated business) and supplier data (competitive activity) being separated directly at customer level, blockchain technology has the potential to be an efficient measure for the implementation of unbundling requirements, which may result in increased competition and more efficient prices for end customers.

4.2. Applicable primary and secondary domestic legislation

Where contracts are made using blockchain applications, the **civil law principles** governing the conclusion of contracts as set out in **section 145** of the **German Civil Code** (*Bürgerliches Gesetzbuch, BGB*) and the rules governing contractual **liability** as set out in **sections 241 et seq. of the German Civil Code** apply.

Furthermore, there are additional legal requirements for energy-related contracts which must also be taken into account. A specific area of law dealing with energy supply contracts has emerged, which has its basis in general civil law principles and is today largely determined by EU legislation. These energy-specific provisions are set out in the **German Energy Industry Act** (*Energiewirtschaftsgesetz, EnWG*). The aims of the Energy Industry Act are to provide a secure, affordable, consumer-friendly, efficient and environmentally friendly supply of energy to customers. Ensuring functioning competition in the supply of energy (electricity and gas) and securing an effective, reliable and forward-looking energy supply system are important objectives underlying the current legal framework. In general, domestic energy law must promote implementation of EU legislative requirements (see section 1 of the Energy Industry Act).

The purpose of all these provisions is to strike a balance between consumer protection interests on the one hand and the interests of energy producers and energy suppliers on the other hand. The basic provisions in this area, which is mostly governed by statute law, can be found in sections 36 to 42 of the Energy Industry Act.

The provisions set out in **section 41 of the Energy Industry Act**, for example, can serve as a starting point for the drafting of future energy supply contracts to be made via blockchain applications. Section 41 sets out the minimum content and formal requirements for energy supply contracts entered into with special-rate customers (this also includes ordinary residential customers if they are supplied by any supplier other than the statutory default supplier or under any tariff not falling within the scope of the statutory rules on deemed basic supply or last-resort supply contracts):

"(1) Contracts for the supply of energy to residential customers other than for the supply of energy under a basic statutory supply must be drafted in a clear and comprehensible manner. All such contracts must at least include provisions on:

1. the contract's term, price variations, termination deadlines and notice periods as well as the customer's right to rescind the contract,
2. the supply and services to be provided, including information on any maintenance services offered,
3. the available methods of payment,
4. the liability of the parties and the damages or compensation payable on a breach of contract,
5. supplier switching, with the option to switch supplier to be provided at no extra charge and with all supplier switches to be effected in a timely manner,
6. how the customer can obtain up-to-date information about the applicable tariffs and maintenance fees,
7. information on residential customers' rights in relation to dispute resolution procedures available to the customer in the event of a legal dispute, including information on the conciliation service for consumer complaints to be established pursuant to section 111b including its address and website, information on the supplier's obligation to participate in any conciliation proceeding and the contact details of the consumer service established by the Federal Network Agency for matters pertaining to electricity and gas."

In addition, the specific rules for energy bills (whether for the supply of electricity or gas) issued to end users must be complied with. The basic principles are set out in sections 40 and 42 of the Energy Industry Act, with details provided in the Statutory Electricity Supply Regulations and the Statutory Gas Supply Regulations respectively. These are mandatory requirements that must be taken into account when developing blockchain projects, provided the existing statutory framework is to remain unchanged.

In addition to the Energy Industry Act, **various regulations** must be taken into account or adapted accordingly in the implementation of blockchain applications:

- The German Electricity Third-Party Access Regulations (*Stromnetzzugangsverordnung, StromNZV*) set out the general provisions governing access to the public power grid. All prosumer applications must comply with the general rules for use of the public networks.

- The German Electricity Network Tariff Regulations (*Stromnetzentgeltverordnung, StromNEV*) provide the rules for the tariffs network operators charge for granting access to their electricity networks to third parties, as well as for setting the tariffs charged for use of the electricity networks for the purpose of delivering electricity to consumers. These regulations also apply to all blockchain applications using public networks.

- In addition, there is a statutory obligation for certain suppliers to provide at least a so-called "basic" electricity or gas supply to residential customers, the details of which are set out in the Statutory Electricity Supply Regulations (*Stromgrundversorgungsverordnung, StromGVV*) and the Statutory Gas Supply Regulations (*Gasgrundversorgungsverordnung, GasGVV*). These regulations place an obligation on the largest energy supplier active in a supply area (the "statutory default supplier") to also supply energy to customers who do not have a supply contract with any other supplier. Where the statutory rules on basic supply contracts apply, the supplier must contract with the relevant customer, i.e. the supplier has an obligation to supply energy to the customer at defined prices.

- Where contracts are formed through blockchain applications, this will require high levels of standardisation. The rules controlling standard terms of business as set out in the German Civil Code (sections 305 et. seq.) can therefore be expected to become even more important than they are today.

- Data protection requirements (e.g. the provisions set out in the German Federal Data Protection Act (*Bundesdatenschutzgesetz, BDSG*)

Meter operators are especially affected by the introduction of blockchain technology. Germany, unlike other European countries, has also liberalised the meter operation business. The legal principles governing this type of activity are defined in the German **Meter Operation and Metering Regulations** (*Messzugangsverordnung, MessZV*).

The regulations set out the requirements and rules for the operation of meters and the metering of energy. Under the current framework, it is not the party that owns a connection (the "connection customer", i.e. the landlord) but the party that uses the connection (the "connection user", i.e. the tenant) who has the right to choose a third-party metering service provider. Where a third-party meter operator has been appointed, the meter operator is responsible for transmitting all data to the relevant network operator in compliance with the applicable deadlines, with the network operator then forwarding all data to the relevant market participants for billing purposes. Under the Meter Operation and Metering Regulations, meter operators are required to enter into a meter operator contract with the relevant network operator that describes the necessary process for replacing a meter (e.g. deadlines, commissioning etc.), the requirements the meter operator must meet (e.g. registration with the local calibration office) as well as the technical requirements for the measurement equipment used.

It is to be expected that blockchain applications will fundamentally transform the market role of meter operators, as they will no longer be required to perform the aforementioned tasks of collecting and transmitting data. All information will be shared directly between energy producers and energy consumers.

However, a key prerequisite for blockchain models that are used for more than just virtual transactions (as opposed to Bitcoin, for instance) is that the fundamental physical data (e.g. metered electricity consumption) can be provided in a tamper-proof way. Meter operators' tasks of certifying, approving and regularly inspecting the measurement equipment used would therefore be activities of utmost importance. It must be ensured that all metering data is recorded and collected in accordance with the provisions of the German **Measurement and Verification Act** (*Mess- und Eichgesetz*). The security requirements for meters and data transmissions are bound to increase even further where blockchain applications come into play.

In the context of blockchain applications relating to electric mobility, the German **Charging Station Regulations** (*Ladesäulenverordnung, LSV*) are also of relevance. These regulations were adopted under section 49(4) of the Energy Industry Act and set out the framework for the expansion of the public EV charging infrastructure in Germany. They provide technical specifications for the connection of electric vehicles to charging points, such as power output (kW) and permitted plugs. A definition of public vs. non-public charging points is also provided. The regulations do not contain any express provisions relating to the execution of transactions, so in principle they allow for all possible use cases to be implemented. In relation to blockchain technology, the Charging Station Regulations are relevant insofar as prosumers operating their own solar systems may produce and supply power for electric cars. Other business models envisage using blockchains for the purpose of billing charging sessions (e.g. Blockcharge).

4.3. Energy law and consumer protection

Under German law, there is no single consumer protection act governing all legal matters relating to consumers. Many individual acts contain legal provisions that serve to protect consumers, whether directly or indirectly. A multitude of measures are currently in place for the protection of consumers. Due to information asymmetry, consumers are generally in an inferior position when they deal with producers or sellers of goods and services. Statutory consumer protection provisions are adopted to redress this imbalance of power and protect consumers, but protection is also provided through the work of consumer organisations.

The aim of all consumer protection efforts is to protect consumers in economic, digital and health matters. Economic consumer protection measures in the energy sector involve ensuring that markets operate fairly, that suppliers provide non-harmful products and services, that consumer information is provided in a transparent manner and that consumer rights can be exercised effectively. Digital consumer protection involves the protection of consumer data.

Economic consumer protection through unbundling

In the field of energy law, unbundling is the primary tool used to increase competition and thereby prevent excessive prices for consumers. Unbundling provisions impose an obligation on energy companies to separate their network and sales activities in order to ensure the neutrality of the entity operating the network, which is also a requirement under the Energy Industry Act. The unbundling measures provided in the Energy Industry Act relate to the unbundling of accounts as well as to information unbundling, functional unbundling and legal unbundling. Unbundling was introduced as a regulatory tool in order to ensure that all market participants can operate under the same conditions. If energy companies not only sold energy but also operated the energy networks, it would be possible for them to transport their energy through the network at lower charges or even for free. This would place their competitors at a competitive disadvantage, in that the incumbent supplier would have superior knowledge about the capacity available or about customer switches. It is the objective of unbundling rules to prevent discrimination, cross-subsidies and other distortions of competition and thus ensure a level playing field for all market participants. This is to be achieved by weakening the monopoly position of vertically integrated enterprises – businesses operating across all parts of the supply chain, for example production, transmission, trade, sales – and thereby promoting competition. Please see chapter 5 for a discussion of the changes that could result from the use of blockchain technology and the regulatory challenges this would pose in the area of unbundling.

Digital consumer protection

The **Federal Data Protection Act** sets out provisions for the handling of personal data that is processed manually using information or communications systems. The provisions of the act define the rules for how to deal with individual personal data, i.e. pieces of information that relate to the personal or factual circumstances of a natural person, e.g. their telephone number, email address, IP address or employee number. A key principle underlying the act is that all data activities are prohibited unless authorised. According to this principle, the collection, processing and use of personal data is generally not permitted. It is permitted only where it has a clear basis in law, i.e. the processing of personal data in a specific context is permitted by law, or where the affected person has given their consent to their data being collected, processed and used.

Other important principles are the concepts of data avoidance and data minimisation. According to these principles, all data processing systems should be designed so as to ensure that no or as little personal data as possible is used and that data should be anonymised or pseudonymised to the extent possible.

From 2018, the **European General Data Protection Regulation** (Regulation (EU) 2016/679) will also apply. The aim of this regulation is to harmonise the rules for the processing of personal data by private-sector businesses and public-sector entities across the EU.

Overall it can be said that diverse provisions have been adopted for the protection of consumers and prosumers which are embedded in a European as well as domestic legal framework. As regards the energy-related blockchain use cases for which prototypes are currently being developed based on the current state of development of the technology, the protection of consumers and prosumers can be guaranteed under the existing legal framework. The way and extent to which blockchain technology has a legal impact on consumers and prosumers should continue to be reviewed and assessed as the technology progresses and new use cases emerge for consumers.

5. Regulatory challenges posed by blockchain applications in the energy sector

If a decentralised transaction model were to be implemented on the basis of blockchain technology, this would probably transform current market roles, with the changes to be reflected in the regulatory regime. All energy consumers would have to manage their own energy balances. Meter operators would no longer be required to collect data themselves, as all transaction data would be recorded automatically on the blockchain.

5.1. Current regulatory framework

The current regulatory unbundling provisions require energy companies to separate their network activities (regulated business) from the supply of energy to customers (competitive activity). Customers have the right to freely choose their **electricity supplier** (or gas supplier) in a liberalised electricity market. In order to ensure that customers can smoothly transfer between suppliers, so-called **balancing groups** were introduced. This made it possible for each customer to be assigned to a supplier in a simple way.

Another significant area of regulation is the so-called **clearing process**, which is run to reconcile planned consumption against customers' actual consumption as recorded by their meters. The difference between these is referred to as balancing energy and the costs incurred in relation to this are charged to each electricity supplier according to causation.

A key prerequisite for the regulatory regime to function properly is that each customer is accounted for as part of a balancing group – by clearly assigning customers to balancing groups and their suppliers to the responsible balancing group managers (which may or may not be the same entity).

The meter operators obtain readings of the verified meter data relevant for billing and transportation charging purposes and pass them on to the other players involved:

- to the relevant electricity supplier for billing purposes
- to the relevant transmission system operator (TSO) for clearing and settlement purposes. The TSO collects all data for each balancing group and aggregates it in order to determine the balancing energy costs to be allocated to the balancing group.
- to the relevant distribution system operator (DSO)
- to the relevant balancing group manager, who in turn charges the balancing energy (cost-generating) it has been allocated to the suppliers using its balancing group.

The above shows clearly that a simple delivery of electricity entails complex settlement processes across the entire electricity market and that the corresponding meter readings are required for various purposes.

In order for the market model to function properly, each customer must be clearly assigned to a balancing group. Balancing group managers are required to provide security in order to ensure that the costs incurred in relation to balancing energy can be recovered.

5.2. Changed market roles under a blockchain-based market model

One major benefit of a blockchain-based transaction model is that all electricity delivered to the networks can be clearly attributed to individual customers in small time units (down to time windows of only a few minutes). This means that all electricity produced and consumed can be settled very precisely at variable prices. The physical electricity as such would continue to flow to the end user directly from the closest generator. A significantly improved database would allow for network operations to be fine-tuned better at both distribution and transmission levels. A simplified clearing process would lead to less balancing energy being charged to market participants.

The chart below shows the current market roles and what would change if the system were based on blockchain technology.

Blockchain technology allows for direct contractual relationships to be established between energy consumers and energy producers. Both energy consumers and energy producers could act as prosumers.

This would result in the following changes:

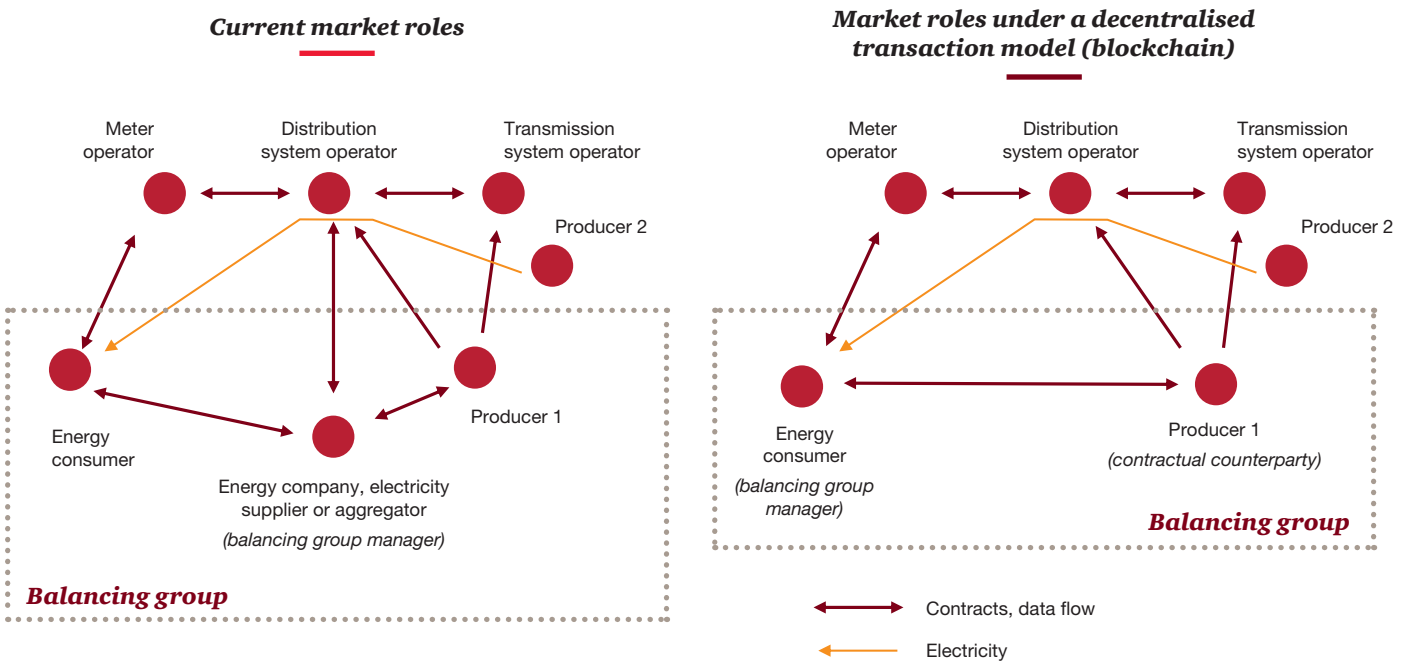
- All **energy consumers would have to become balancing group managers** and to comply with the requirements of this market role (provision of security, risk management etc.). Most notably, energy consumers would have to submit their own demand forecasts to the relevant network operator. In the electricity sector, the provisions set out in the "Market Rules for Balancing Group Invoicing and Settlement" (*Marktregeln für die Durchführung der Bilanzkreisabrechnung*, referred to as "MaBiS") must be complied with; in gas, it is the administrative ruling on gas balancing handed down by the Federal Network Agency in December 2014 (the so-called "GaBi Gas 2.0" decision).

- The **role performed by meter operators** would change: they would no longer have to collect and record data themselves, as all consumption and transaction data would be exchanged automatically and accurately through blockchain technology (smart contracts). The transaction data necessary to determine network tariffs would be provided to meter operators (and thus also to network operators) by the blockchain. So the responsibility of meter operators could be limited to providing reliable and tamper-proof meters.

- **Distribution system operators** would also receive the information on transactions they require to charge their network costs to customers from the blockchain.

- Provided the decentralised transaction model is fully implemented, **transmission system operators** would no longer require data for clearing purposes, as all transactions would be executed in real time and settled only on the basis of actual consumption.

Figure 15: Current market roles vs. market roles in a blockchain-based system



The following regulatory areas must also be reviewed:

Financial market regulation

With financial transactions being shifted from energy companies or banks to a peer-to-peer system, the question arises of who will be responsible for ensuring that financial transactions (especially payments for obligations arising under supply contracts) are properly settled. It would probably not be possible to impose such an obligation on energy consumers themselves, maybe not even on their energy suppliers. Instead, an actual responsible entity, e.g. a platform operator, would be needed that would meet the requirements to be satisfied by a financial service provider, namely compliance with the German Banking Act (*Kreditwesengesetz*), application for a licence from the German Federal Financial Supervisory Authority (BAFIN) and compliance with the requirements of the REMIT and MIFID regulations.

Regulation of commercial activities

It must be clarified whether a blockchain model would mean that all parties supplying energy (and thus possibly also energy consumers) have to meet the requirements set out in the German Trade, Commerce and Industry Regulation Code (*Gewerbeordnung*).

Liability

It is conceivable that the idealistic blockchain model envisaging a system entirely without a responsible central authority cannot be realised in the foreseeable future, as this would require clear and transparent liability rules to ensure that such a platform can be operated securely. Rules would be needed to govern the liability of the parties involved in the case of payment defaults, technical failures or intentional tampering, to mention a few examples.

As the energy supply business usually involves use of critical infrastructure, a clear emergency plan is required to define the procedures to be followed in the event of a complete or partial failure of the system.

"One major benefit of a blockchain-based transaction model is that all electricity delivered to the networks can be clearly attributed to individual customers in small time units"

5.3. Obstacles hindering the implementation of blockchain applications and issues to be addressed

If energy is to be supplied directly from an energy producer to an energy consumer, followed by a financial transaction between the parties, and all of this is to be effected on the basis of blockchain technology, this raises the following questions:

- ***Who performs the meter operator role?*** As the energy consumer (see Figure 16) would be the party taking the electricity from the network, the energy consumer would have to provide its meter readings to its distribution system operator. The customer would therefore have to register as a meter operator. An alternative solution would be to retain the meter operator role as it is currently defined in section 21b of the Energy Industry Act.

- ***Who is responsible for submitting schedules and forecasts to the transmission system operator?*** The transmission system operators need to produce forecasts for the entire market for each day, which they prepare on the preceding day at the latest, on the basis of so-called schedules (which are submitted to them by the balancing group managers). So the issue also arises of who is to submit these schedules to the TSOs.

- ***Who is the registered electricity supplier?*** The party supplying the energy to the energy consumer will, through this act, become an electricity supplier. For this role, they require a licence as well as IT interfaces so as to be able to provide the necessary data. Blockchains are not yet reflected in the current market rules and market communication processes and should explicitly be taken into account. But in any case, the energy supplier would have to apply for a licence, which generates significant costs (if they have not already obtained one; this will not be the case for most prosumers).

- ***Who performs the balancing group manager role?*** Given that all energy consumers must be assigned to a balancing group, a blockchain model would require the setting up of an individual balancing group for each energy consumer. Balancing groups can generally be implemented down to customer level, but managing a balancing group can present a significant financial and organisational challenge.

So one major obstacle hindering the adoption of blockchain-based transaction models is that they would have to meet the current regulatory requirements. Some of the benefits that can be delivered by a decentralised system of peer-to-peer relationships would thus be lost.

A rollout of blockchain technology would have a huge impact on competition in the German energy market. There is a chance that small or local businesses would encounter **fewer or reduced barriers to market entry**, which would make it harder for other market players to prevent them from participating in the market.

Yet, conversely, a blockchain rollout might also reinforce anticompetitive trends in the energy market. For example, as was shown in chapter 2, one possible development is that established energy companies develop **private blockchains**, which would permit them to lock small suppliers out by not allowing them into the transaction model and thus the market.

Another obstacle to the implementation of blockchain applications is the current **uncertainty regarding their legal recognition**, owing to the fact that blockchain systems no longer require a central authority, at least when they operate strictly in accordance with blockchain principles. The corrective element in such systems is provided by “swarm intelligence”. Today’s legal systems, in contrast, are based on a clear allocation of organisational and legal responsibility.

5.4. Blockchain potential from a regulatory perspective

Our initial analysis of the regulatory issues to be addressed in connection with blockchain applications has also revealed the areas where the technology can potentially deliver its benefits:

- ***Direct customer-to-customer transactions & financial settlement:*** Customers could take over the supply business themselves. This would facilitate community funding of energy assets, regional energy pools and regional energy self-sufficiency. The new technology could help implement this in a more efficient way whilst providing a verifiable record. It is already possible for citizens to participate in energy projects today, but this still requires the involvement of many other actors, such as banks and energy companies. Blockchain technology would allow them to realise concepts such as "From your region - for your region" on their own initiative and on their own terms.
- ***Verification & certification:*** Figure 15 illustrates another strength of blockchain technology – the option to clearly verify the source of electricity. Thanks to its synchronicity (generation and consumption) and capability to provide clear and verifiable records, blockchain would be the first technology to make it possible for the source of electricity to be determined. Guarantees of origin could be issued with greater certainty. This would also make it easier to issue certificates for emission allowances and energy-efficiency improvements, which would in turn simplify the complex systems currently used.
- ***Clearing & settlement:*** It is not only prosumers who may stand to benefit, but also transmission system operators, as using blockchains would allow them to clearly attribute clearing data to individual market participants. The planned introduction of smart meters will only help to allocate consumption quantities to a balancing group and to the electricity suppliers using that balancing group. A blockchain-based system would make it possible for the energy consumed to be clearly traced back to the point where it was generated. Overall, this would lead to significant cost reductions, with end users directly benefiting from a more efficient system.

"So one major obstacle hindering the adoption of blockchain-based transaction models is that they would have to meet the current regulatory requirements"

6. Blockchain risks and opportunities from a consumer perspective

If the decentralised transaction model outlined for the energy industry in chapter 3 were to be adopted, this would fundamentally transform the relationships between energy producers, energy suppliers, network operators and consumers.

Consumers would probably benefit from greater transparency and flexibility. Lower transaction costs due to the elimination of intermediaries and a larger number of market participants would mean falling energy prices. As with any new technology, unresolved technical issues and a lack of long-term experience also mean an uncertain future, which poses some risks. Time will tell whether other technologies or intelligent databases and protocols can provide more appropriate solutions from a consumer perspective.

As has been described in the previous chapters, blockchain technology is currently still in its infancy, and the energy sector is no exception. However, the experience gained in the financial industry and with initial projects in the energy sector allow us to guess at the positive and negative consequences this technology is likely to have for consumers. We have evaluated the opportunities and risks for consumers based on the following assumptions:

- If applied in the energy market, blockchain technology will replace (some of) the intermediaries currently operating there and lead to a fall in transaction costs
- The possibility to fine-tune network operations and the deployment of smart meters, smart contracts and other new technologies will enhance flexibility and promote customisation across all segments of energy consumption and sales (e.g. customers configuring their individual power mix, taking advantage of lower electricity prices in the evening etc.)
- Prosumers will enter the fray and become more active participants in a decentralised market
- Blockchain applications will first be used in the electricity sector, with other sectors and use cases to follow later

Even though we cannot reliably predict the exact developments to come, it does seem safe to assume that blockchain technology has the potential to bring about substantial structural changes, at least in the energy industry. These will deliver opportunities but also entail risks for consumers, which we have summarised below.

Figure 16: Opportunities and risks from a consumer perspective

Opportunities +

- ***Lower transaction costs*** due to the cutting out of intermediaries
- ***Falling prices*** as a result of greater ***market transparency***
- Simple ***option for customers to become a service/electricity provider***
- ***Transactions are generally made more simple*** (documentation, contracts, payment)
- ***Greater transparency*** thanks to decentralised data storage
- ***Flexible*** products (tariffs) and supplier switching
- ***Strengthening of prosumers*** thanks to independence from central authority (direct purchases/sales of energy

Risks –

- ***Complete loss of data*** on loss of ID
- Currently ***high transaction costs for public blockchain systems***
- Possibly ***lack of acceptance*** on the part of consumers
- No ***authority in the case of disputes***, no direct possibility of escalating conflicts
- Risk of ***fraudulent activities*** at the interface between the real world and the digital blockchain world (e.g. the smart meter/ blockchain interface)
- ***Lack of long-term experience***
- ***Technical problems with initial applications*** possible to start with
- Insufficient or inadequate functionality and security risks due to ***lack of standardisation***
- Networks must cope with ***greater flexibility***

"The experience gained in the financial industry and with initial projects in the energy sector allow us to guess at the positive and negative consequences this technology is likely to have for consumers"

6.1. Blockchain opportunities in the energy sector

Lower energy bills for consumers

Blockchain models operate on the assumption that all providers transact directly with their customers. One consequence of this would be that the intermediaries previously operating in the market, among them trading platforms, traders, banks or energy companies, might no longer be needed at all but in any case they would be reduced to a considerably smaller role. This could lead to a significant decrease in system costs. The types of system costs that could be reduced or even completely eliminated include the following:

- no or lower costs to account for the costs (including personnel and other operating costs, infrastructure etc.) and profit margins of the above companies that are currently active in the market but will have no or only a reduced role in the future system
- no or lower operating costs for meter reading, billing etc.
- no expenditure required for payment reminder and debt collection processes
- no costs for bank payments (especially direct debits for payments by customers)
- possibly lower transportation charges
- no certification costs for renewable electricity

The above cost reductions would lower the energy bills of consumers, whether directly or indirectly.

On the other hand, there are the operating costs of blockchain systems, which include transaction fees for blockchain transactions. The required computing power and related energy use might also have to be factored in. The actual costs of blockchain applications cannot be projected today. It is becoming clear, though, that there will be differences in terms of cost between private and public blockchains. Private blockchains usually involve lower transaction costs and operate on the basis of simplified verification processes (for instance, proof-of-work verification uses up more energy than the proof-of-stake process), which decreases costs.

All cost considerations must also factor in the investment required to make the electricity networks more flexible: blockchains can only be used effectively if the power grid is capable of coping with a larger number of individual energy producers and of managing greater flexibility, all of which is also essential to ensure supply security. The smart meter rollout planned to be launched in 2017 will provide favourable conditions for more flexible power markets. Another point to be considered is that maximum cost benefits can only be achieved if as many providers and customers as possible agree to use blockchain applications that are based on common standards and rules. This would prevent the parallel emergence of incompatible applications.

Another factor enabling savings on energy bills is that energy consumers would also have considerably greater flexibility in choosing their supplier. In blockchain-based transaction systems customers almost constantly switch supplier, as they can find new transaction partners and contract with them within extremely short timescales (down to a few minutes).

Transparency

Use of blockchain technology would ensure greater transparency for consumers. It would allow consumers to track exactly where the electricity they purchase was produced. Direct transactions between energy providers and energy consumers would enable the parties to specify exactly the "contractual counterparty", i.e. the wind or solar farm delivering the energy. This would make it possible to determine precisely the source of the electricity supplied, for example in terms of the percentage share of renewable energy. Every energy consumer would specify these aspects individually and to an unprecedented level of granularity.

Accordingly, the entire transaction history stored on the blockchain (energy consumed and payments made) would also become transparent. The availability of a full transaction history and the possibility of running analyses on this basis would afford customers an as yet unrivalled level of clarity. Commercial and large customers who already have such data at their disposal today would be charged less for them, whilst probably having more details available on which they could base their analyses.

A point to be critically reviewed in this context is what drawbacks this level of transparency would entail, as under the basic blockchain model all transactions are publicly accessible. The individual users would use aliases, but it is theoretically possible to "decrypt" a certain number of aliases without authorisation, which might pose a risk.

Local value creation and prosumers

Blockchain technology could give a boost to a currently emerging trend: the rise of the role of the prosumer. Lower transaction costs and simpler billing processes would enable small providers or energy consumers to participate in the market not only as consumers but also as providers. Consumers who operate their own solar systems, for instance, could more easily sell on the electricity they produce to their neighbours or feed it into the network. This would improve the economic viability of solar systems, small-scale wind turbines or customer-owned CHP plants, which in turn would increase the number of prosumers. Consumers also stand to benefit from a more diverse product offering and lower prices. In addition, blockchain models could facilitate the realisation of community-funded energy projects.

Simplified routes to market for distributed energy generators would further boost the growth of renewables. Indirectly this might also have a positive effect on the economic structures in their region. Distributed generation can provide economic stimulus through services, for example in the fields of maintenance or operations. Increased deployment of windpower could be a particular benefit in areas with little infrastructure and slow economic growth.

6.2. Blockchain risks in the energy sector

Blockchain technology is still in its infancy at present, which means that it comes with a range of uncertainties and risks. Outside the Bitcoin context – the most established blockchain application to date – no long-term experience is available. After a somewhat rocky start, Bitcoin itself has proven to be a reliable and robust system.

Many experts also suspect that blockchain technology might not be as scalable as needed. Given the extremely fast rate of data growth, the sheer data volumes accumulating after several years of operating a blockchain place high demands in terms of security, speed and costs.

As a new technology operating on the basis of a completely new transaction model, it is to be expected that blockchain technology will at least to some extent be rejected by some energy players, among energy consumers and in part by the general public.

The anonymity underlying the blockchain concept also entails the risk of the system being used for the purpose of illegal activities (e.g. organised crime). In particular, cryptocurrencies such as Bitcoin have repeatedly made the headlines on account of insolvent exchanges set up by dodgy founders or blackmailing services using Bitcoin.

A decentralised blockchain system without any superior authority might also turn out to entail drawbacks for consumers, as at least under the models discussed today there is no responsible entity that could intervene in a regulatory capacity, provide simple services or revise previously executed transactions. One recurring issue raised in connection with blockchain technology is what happens when a user has forgotten their personal access details needed to access their own account. In this case, users are irrevocably locked out of their accounts and lose their settings, information and assets stored in them.

Security risks

Non-cryptocurrency use cases of blockchain technology are far more complex and require the direct participation of end users. These applications must therefore be particularly secure but user-friendly at the same time. Still, there will always be a risk of tampering (e.g. attacks by hackers) and technical faults (e.g. system failures).

Just how realistic the hacking scenario is was proven by the attack on the application “DAO” (Decentralized Autonomous Organization), which came to light as we were still working on this study. The DAO, an application built on the Ethereum platform, is described below.

DAO (Decentralized Autonomous Organization)

The DAO is a complex type of DApp. It can best be understood as a new kind of organisation that is similar to a digital company or investment fund but not a legal entity. The DAO was created as a self-governing body operating on democratic principles that is not influenced by outside forces. This principle can currently be observed in practice in connection with the recent hack into the system. The DAO token holders are currently discussing different approaches for responding to this incident, which will subsequently be translated into code and implemented on the basis of a democratic process. At the time of writing of this study, the introduction of an externally-led management and governance scheme was ruled out.

The DAO’s by-laws are embedded in the Ethereum blockchain. The DAO concept builds on smart contracts which are:

- immutable (from the perspective of individual participants): only a majority of DAO token holders can decide by vote to adapt the code (and thus the DAO itself)
- unstoppable: the program runs on the Ethereum blockchain, which consists of thousands of independent nodes. In order to stop the program, you would require a majority of these nodes, which is all but impossible in actual practice
- irrefutable: all actions executed by the program are transparent and recorded on the Ethereum blockchain for eternity

The DAO protocol has no artificial intelligence, which means that certain activities – for example manufacturing products, writing code, developing hardware – cannot be performed by the DAO itself. The DAO therefore relies on so-called "contractors" who participate on its behalf in the physical world. These contractors are connected with one another and carry out so-called "proposals" – provided these have been accepted by the DAO.

Proposals are submitted by DAO token holders, who can then profit from the sale or use of the products created. In addition, so-called "curators" are elected in order to prevent attacks. The curators maintain a whitelist on which all contractors (i.e. the entities authorised to receive ethers from the DAO) are listed. The curators make sure that each proposal – which is submitted in the form of a smart contract – actually contains what the relevant DAO token holder and contractor allege it contains. They further verify whether a proposal was made by a real person or organisation.

DAO token holders have the right to collectively decide on proposals (with their right to vote being proportionate to the number of tokens they hold) and participate in the profits based on their share of funds held in the DAO if the proposals executed are successful.

As is the case with Bitcoin, owing to the international nature of the network it is unclear which country or courts would have jurisdiction to certify any identity information, or in what way legal jurisdiction could be established.

Whether the overall impact of blockchain applications on energy consumers will be positive or negative will also depend on how they are implemented. It is to be expected that applications with a primary focus on creating distributed records of transactions will deliver positive results sooner than comprehensive applications which enable decentralised transactions to be carried out on the basis of smart contracts. Private blockchain models are likely to generate lower costs but this would come at the price of throwing out the principle of a decentralised organisation. And they would also raise the question of what advantage such solutions would have over traditional database-based processes, as the key aspect of decentralised and tamper-proof data storage would then become of secondary importance.

"The anonymity underlying the blockchain concept also entails the risk of the system being used for the purpose of illegal activities (e.g. organised crime)"

6.3. Outlook on possible long-term social consequences

A rollout of blockchain technology in its purest form would fundamentally transform the way in which our economy operates and the way in which we transact. The aim behind blockchain is to create a decentralised model for the exchange and storage of data that is controlled by a decentralised operating system. Decentralised systems cannot be controlled by a minority or central authority and they are transparent for all participants as well as self-governing.

Creation of an Internet of Value

In blockchain systems, data storage no longer requires central locations. Blockchain technology is the next step away from a universal space of information (which was created by the World Wide Web) towards a universal space where values and value-related interactions can be represented in a structured way. It leads to the emergence of a so-called "Internet of Value", a kind of trusted protocol that could, amongst other things, provide a notarial function for all transactions carried out on the web, automated and transparent for all. Other than efficiency improvements and cost savings, blockchain technology thus primarily promises to ensure independence from human authority, with decisions being taken on the basis of solid proof and intermediaries being cut out of the process in order to gain efficiency. Incorruptible transparency and automation of all transactions executed on the blockchain are to take security on the Internet of Value to a whole new level.

Decentralising society, creation of decentralised organisations

A blockchain represents a transparent digital ledger of transactions that is hardened against tampering and revision. All information is stored in a decentralised network and not controlled by a central authority. The blockchain itself does not set the rules, but rather describes a predefined procedure which is translated into digital code based on a decentralised democratic process. The rules are digitally implemented by means of smart contracts, with the rights of all contracting parties being enforced automatically. Blockchain technology allows for a self-regulating, self-governing economic and social system to be created which is managed by computer programs and in which transactions are executed by self-executing digital contracts. This kind of decentralisation promises to reduce inefficiencies and mitigate corruption. As every individual element of the network processes every transaction, no single element can control the database as a whole. In this regard, decentralisation also contributes to improving system security and stability.

One challenge presented by blockchain technology is how to integrate a social concept with no control mechanism into a socio-technical system. In social concepts, such control mechanisms are the result of an evolutionary cultural development and have brought about a series of interconnected systems, each with a certain degree of elasticity when it comes to dealing with inappropriate or malicious behaviour shown by individual participants. These interconnected systems can exclude participants temporarily and reintegrate them once their behaviour has improved, for example through the social concept of forgiveness. Social systems based on such collective interactions are relatively stable, fair and just. Technical systems, in contrast, are based on deterministic, isolated concepts that ensure fast decisions, which may have severe consequences for individual participants.

Given that self-adapting and self-governing systems can change any way they like, and given that some behaviours run counter to a system's goals or can mean a disturbance to other systems or people, the system's behaviour must be subject to boundaries and regulated. How to set these norms, laws and rules, enforce them and regulate the system through computer code is one of the most challenging tasks in this context. A learning process and continuous adjustment will be necessary in order to ensure a well-engineered concept and to make sure that the potential benefits delivered by a decentralised structure can be fully exploited.

Blockchain applications operate on the principle that decisions are taken autonomously by technology or by the entire system itself. Clear rules must be defined for smart contracts, but also at a higher level, so as to rule out the system being misused or taking unwanted decisions (e.g. by excluding certain constellations that may provide a theoretical optimum but do not have the support of society).

Blockchain: the end or the beginning of privacy?

Blockchain technology has the capability to map the digital daily life of each individual on a blockchain. This could result in the creation of biographical blockchains that fully document all stages of a person's life. People are already storing data recorded by health apps in the cloud, including information on their heart rates, the quality of their sleep and their calorie intake. In the future, it may be possible that blockchains are used to provide a decentralised record of health data. Data privacy concerns could be alleviated by allowing users to use various unrelated identities or aliases in areas where their exact identity does not necessarily need to be known.

Blockchain technology is freeing people to transact on their own terms. Each user can send and receive payments in a similar way to cash, but they can also take part in more complex contracts. Multiple signatures allow a transaction to be accepted by the network only if a certain number of a defined group of persons agree to sign or verify the transaction. This allows innovative mediation services to be developed in the future. Such services could allow a third party to approve or reject a transaction in the case of disagreement between the other parties, without having control of their money. As opposed to cash and other payment methods, each use of blockchain technology always leaves public proof that a transaction did take place, which can potentially be used in recourse against businesses engaged in fraudulent practices.[10]

10 https://bitcoin.org/en/faq#what-about-bitcoin-and-consumer-protection

7. Summary and outlook

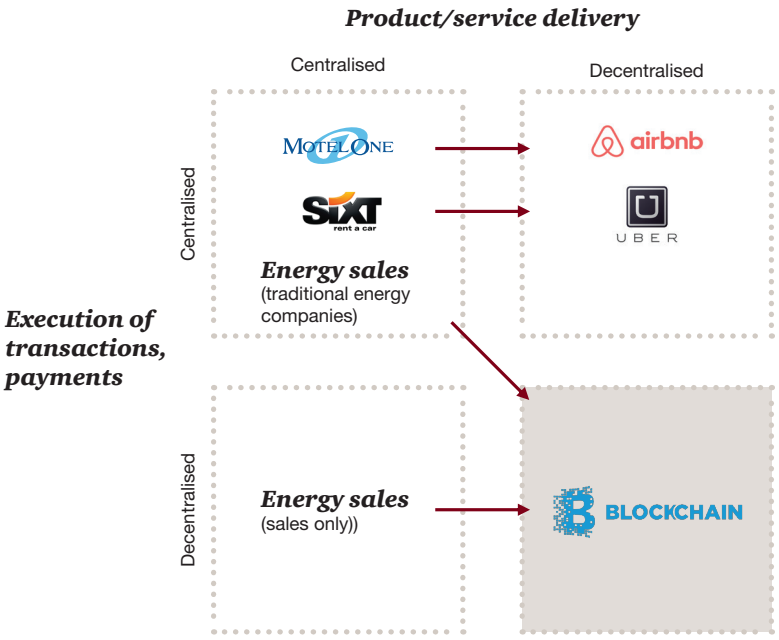
Financial blockchain applications have already reached an astounding level of maturity; whether the technology will succeed in revolutionising the sector remains to be seen. Initial pilot projects have provided a glimpse of the enormous benefits blockchain applications could deliver in terms of cost savings, speed and flexibility.

When it comes to blockchain applications for the energy sector, it's early days yet. In theory, the technology has the potential to shape our future energy supply too. The further course of its development will be determined by technological progress and competing technologies as much as by legislation and regulatory practices in individual countries. However, it appears safe to assume that blockchain technology will promote the emergence of new innovative business models in various industries.

Blockchain technology is a further driver pushing the trend towards a "sharing economy" based on joint use of assets. Joint in this context mostly means that transactions are made directly between providers and their customers. Platforms support the matching of transactions between many individual providers and their prospective customers (peer-to-peer).

The chart below shows the different forms such a sharing economy can take.

Figure 17: Risks and opportunities from a consumer perspective



Traditional centralised business models, for example hotel chains, car hire, taxi companies, are increasingly coming under pressure from providers like Airbnb and Uber, who operate platforms through which distributed (private) individual providers can offer their capacities. While product and service delivery is decentralised, the arrangement and execution of the underlying transactions as well as the corresponding payments are effected through the aforementioned central platforms.

Blockchain systems are fully decentralised, with all transactions being arranged, executed and performed on a peer-to-peer basis. This is what makes blockchain technology potentially disruptive.

The potential energy use cases of blockchain technology show a lot of promise. In addition to reducing transaction costs across the system, increasing the efficiency of processes and thus delivering cost benefits for customers, the technology can enable direct interactions between all parties involved. This ensures that existing generation capacity is utilised optimally, whilst energy is made available at the best price. The role of prosumers is strengthened considerably under such a model.

Whether the technology will succeed in the energy sector will ultimately depend on the following aspects:

- ***What applications are available to customers?*** At present, blockchain initiatives are a purely technology-driven development, with no applications or alternative offers available that customers can use conveniently and easily. Such applications would have to be designed just like apps: user-friendly, easy to use, effective.

- ***Can the overall system work efficiently?*** The costs and benefits of blockchain models cannot be fully assessed as yet. Data transmission and storage costs will probably play a minor role. But the costs for the verification process (mining), which is central to all blockchain applications, can be high.

- ***What added value can blockchains deliver to use cases with a primary focus on recording transactions?*** Blockchain applications without smart contract functionality (e.g. applications documenting ownership) have yet to show in actual practice what advantages they have over tried-and-tested client-server solutions (controlled by a central authority). It is quite likely that mixed forms – e.g. blockchain models controlled by a central, responsible authority – will also succeed in the market.

Overall, it can be said at the present point in time that blockchain technology certainly shows a lot of potential – from a customer perspective too – and should be further developed by market participants. The approaches seen thus far may have a disruptive effect in the future and might require additional regulatory intervention in an already tightly regulated energy market. If blockchains are to deliver benefits for consumers (whether as consumers or prosumers of energy), a strong focus on consumer issues will be needed.

Appendix 1:
List of experts interviewed

In addition to evaluating all documents available to us on blockchain models and how they could be applied in the energy sector (studies, presentations, articles, videos), we conducted telephone interviews with experts from the related fields while working on this study (in June 2016). The interviews have allowed us to discuss our findings and views with these experts and to bring their perspectives to bear on this study.

We thank the experts listed below for their willingness to let us draw on their expertise in producing this study.

Company	Website	Interview partner or contact
Energy-related blockchain applications		
OneUp *(NL)*	www.oneup.company www.bigdata.company	Mark Dijkman
Gridsingularity *(international)*	www.gridsingularity.com	Ewald Hesse
consenSys *(USA)*	www.consensys.net	John Lilic
Winwest *(Austria)*	www.winwest.at	Hein Popovic
Vattenfall *(Germany)*	https://www.vattenfall.de/	Claus Wattendrup
Energie Steiermark *(Austria)*	https://www.e-steiermark.com/	Martin Graf
SolarCoin *(Israel)*	solarcoin.org/	Yau Ben-Or
Next Virtuelle Kraftwerke *(Germany)*	www.next-kraftwerke.de/	Henrik Sämisch
Carinthia University of Applied Sciences *(Austria)*	www.fh-kaernten.at	Thomas Klinger, Christian Madritsch
Blockchain applications with a focus on financial services		
Coinimal *(Austria)*	www.coinimal.com	Eric Demuth, Paul Klanschek
Other blockchain applications		
lab10 *(Austria)*	www.lab10.at	Thomas Zeinzinger

Appendix 2:
Sources and relevant links

Below we provide a list of example links and references to companies and websites other than those cited in this study which we consider to be of particular relevance in relation to the subject of this study.

- bankymoon.co.za
- brooklynmicrogrid.com
- gridsingularity.com
- insights.ubuntu.com
- ir.nasdaq.com/releasedetail.cfm?releaseid=948326
- projectexergy.com
- slock.it
- solarchange.co/
- solarcoin.org
- Solarpraxis Neue Energiewelt AG and Kirsten Hasberg, webinar on blockchain technology in the energy sector ("Blockchain für die Energiewelt 2016")
- www.artik.io
- www.mpayg.com
- www.oneup.company
- www.powerpeers.nl
- www.thesunexchange.com/

Authors of this study

Felix Hasse

Axel von Perfall (project lead)

Thomas Hillebrand

Erwin Smole

Lena Lay

Maximilian Charlet

Contacts

Key contacts

Norbert Schwieters
Global Power & Utilities Leader
Telephone: +49 211 981 2153
Email: norbert.schwieters@de.pwc.com

Jeroen van Hoof
Global Power & Utilities Assurance Leader
Telephone: +31 88 792 14 07
Email: Jeroen.van.Hoof@nl.pwc.com

David Etheridge
Global Power & Utilities Advisory Leader
Telephone: +1 925 519 2605
Email: david.etheridge@pwc.com

Axel von Perfall
Blockchain expert
Telephone: +49 30 2636 3958
Email: axel.von.perfall@de.pwc.com

Territory contacts

Asia-Pacific

Australia
Mark Coughlin
Telephone: +61 3 8603 0009
Email: mark.coughlin@au.pwc.com

China
Lisa B Wang
Telephone: +86 10 6533 2729
Email: binhong.wang@cn.pwc.com

India
Kameswara Rao
Telephone: +91 40 6624 6688
Email: kameswara.rao@in.pwc.com

Indonesia
Sacha Winzenried
Telephone: +62 21 52890968
Email: sacha.winzenried@id.pwc.com

Japan
Yoichi Y Hazama
Telephone: +81 90 5428 7743
Email: yoichi.y.hazama@jp.pwc.com

Korea
Lee-Hoi Doh
Telephone: + 82 2 709 0246
Email: lee-hoi.doh@kr.pwc.com

Europe

Austria
Michael Sponring
Telephone: +43 1 501 88 2935
Email: michael.sponring@at.pwc.com

Belgium
Koen Hens
Telephone: +32 2 710 7228
Email: koen.hens@be.pwc.com

Central and eastern Europe
Adam Osztovits
Telephone: +36 14619585
Email: adam.osztovits@hu.pwc.com

Denmark
Per Timmermann
Telephone: + 45 39 45 91 45
Email: per.timmermann@dk.pwc.com

Finland
Mauri Hätönen
Telephone: + 358 9 2280 1946
Email: mauri.hatonen@fi.pwc.com

France
Pascale Jean
Tel: +33 1 56 57 11 59
Email: pascale.jean@fr.pwc.com

Germany
Norbert Schwieters
Telephone: +49 211 981 2153
Email: norbert.schwieters@de.pwc.com

Greece
Vangellis Markopoulos
Telephone: +30 210 6874035
Email: vangellis.markopoulos@gr.pwc.com

Ireland
Ann O'Connell
Telephone: +353 1 792 8512
Email: ann.oconnell@ir.pwc.com

Israel
Eitan Glazer
Telephone: +972 3 7954 830
Email: eitan.glazer@il.pwc.com

Italy
Giovanni Poggio
Telephone: +39 06 570252588
Email: giovanni.poggio@it.pwc.com

Netherlands
Jeroen van Hoof
Telephone: +31 88 792 1328
Email: jeroen.van.hoof@nl.pwc.com

Norway
Hildegunn Naas-Bibow
Telephone: +47 9526 0118
Email: hildegunn.naas-bibow@no.pwc.com

Poland
Piotr Luba
Telephone: +48227464679
Email: Piotr.luba@pl.pwc.com

Portugal
Joao Ramos
Telephone: +351 213 599 296
Email: joao.ramos@pt.pwc.com

Russia
Tatiana Sirotinskaya
Telephone: +7 495 967 6318
Email: tatiana.sirotinskaya@ru.pwc.com

Spain
Manuel Martin Espada
Telephone: +34 686 491 120
Email: manuel.martin.espada@es.pwc.com

Sweden
Anna Elmfeldt
Telephone: +46 10 2124136
Email: anna.elmfeldt@se.pwc.com

Switzerland
Marc Schmidli
Telephone: +41 58 792 15 64
Email: marc.schmidli@ch.pwc.com

Turkey
Murat Colakoglu
Telephone: +90 212 326 64 34
Email: murat.colakoglu@tr.pwc.com

United Kingdom
Steven Jennings
Telephone: +44 20 7212 1449
Email: steven.m.jennings@uk.pwc.com

Middle East and Africa

Middle East
Jonty Palmer
Telephone: +971 56 683 8192
Email: jonty.palmer@ae.pwc.com

Anglophone & Lusophone Africa
John Gibbs
Telephone: +27 11 797 4461
Email: john.gibbs@pwc.com

Francophone Africa
Noel Albertus
Telephone: +33 1 5657 8507
Email: noel.albertus@fr.pwc.com

The Americas

Argentina/Latin America
Jorge Bacher
Telephone: +54 11 5811 6952
Email: jorge.c.bacher@ar.pwc.com

Brazil
Roberto Correa
Telephone: +55 31 3269 1525
Email: roberto.correa@br.pwc.com

Canada
Brian R. Poth
Telephone: +1 416 687 8522
Email: brian.r.poth@ca.pwc.com

Mexico
Guillermo Pineda
Tel: +525514736289
Email: guillermo.pineda@mx.pwc.com

United States
Michael A. Herman
Telephone: +1 312.298.4462
Email: michael.a.herman@us.pwc.com

PwC helps organisations and individuals create the value they're looking for. We're a network of firms in 157 countries with more than 208,000 people who are committed to delivering quality in assurance, tax and advisory services.

The Global Energy, Utilities and Mining group is the professional services leader in the international energy, utilities and mining community, advising clients through a global network of fully dedicated specialists.

For further information, please visit:
www.pwc.com/utilities