THINK TANK & RESEARCH

BACKGROUND PAPER

Blockchain – Opportunities and threats for the energy transition

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GERMANWATCH

Executive summary

Blockchain is a type of collectively written digital ledger, a transaction technology that could bring about fundamental changes in many sectors of the economy over the coming years. It has even been attributed the potential to effect change on a scale comparable to that made by the Internet in the years after 1990. Based on decentralised peer-to-peer networks, cryptography and game theory, blockchain applications promise transparency and tamper-proofness but also significant cost-cutting potential as intermediaries are replaced with software solutions. According to enthusiasts, these programs could render established services providers such as banks, law firms and stock exchanges obsolete and alter the way groups of two or more people interact globally.

The energy sector is one of many areas experiencing the force of these changes as pioneering start-ups show that it is both conceivable and feasible for private individuals to trade electricity independently of energy companies. Blockchain can also be used to integrate storage technologies more efficiently into decentralised energy systems, to simplify the balancing of supply and demand, to perform automated battery charging and billing functions in the electric mobility sector and to guarantee the authenticity of green energy certificates.

As well as explaining how it works, the fields in which it might be applied and the opportunities it can provide, this background paper highlights the threats posed by blockchain and the areas in which the technology requires further development. Operating a blockchain network, for example, requires a huge amount of computing power which, in turn, results in high energy consumption and the accompanying environmental backpack, which is completely incompatible with sustainable energy transition. Blockchain technology is also inappropriate for storing large amounts of data and too slow for many potential applications. Similarly, the legal framework remains unclear and issues of data protection and transparency need to be considered against this backdrop.

In theory, blockchain technologies could give the energy transition new impetus. Blockchain has the potential to transform power structures and players' roles in the energy landscape. Here, too, though, lie both opportunities and threats. Anyone wishing to make a significant political, economic or technological contribution to this question in the future should start addressing blockchain now.

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Glossary

Altcoins: Altcoins or 'alternative coins' are means of payment that have emerged as copies of or variations on the freely available Bitcoin code.

Block rewards: Block rewards are the incentive for miners to solve a mathematical problem in order to create a new block in the blockchain. A block reward is given to the miner who solves a problem the fastest. Block rewards vary from blockchain to blockchain, but generally consist of at least the block transaction costs. In addition, the successful miner is allowed to create coins, e.g. in the Bitcoin blockchain by means of a coinbase transaction, and transfer them to his/her account.

Blockchain: A blockchain is a collectively written digital ledger or account that records and checks transactions (Wiedmaier 2017: 14). It is based on a decentralised data storage process in which transaction data is distributed over the thousands or millions of computers that make up a network rather than stored on one specific server.

CHP plant: In combined heat and power (CHP), generation input energy is converted into mechanical or electrical energy and the heat created is simultaneously used in a thermodynamic process (German Environmental Agency (Umweltbundesamt) 2017b). This heat can be used for heating or in manufacturing processes. This simultaneous generation of electricity and heat generally takes place in a thermal power station, where it helps reduce harmful emissions.

Coinbase transaction: A coinbase transaction is the transaction which, together with block transaction fees, constitutes the 'payment' of a block reward. A successful miner transfers a set number of coins out of nowhere to his/her account, so increasing the total number of coins available. In the case of Bitcoin, this set number halves every four years, thereby limiting the possible number of bitcoins in the system.

Cryptocurrency: A cryptocurrency is a virtual means of payment created by private actors using a validation process based on computing power (Wilson 2017). It uses the principles of cryptography, i.e. data encryption and protection.

DAO: DAO stands for Decentralised Autonomous Organisation. DAOs are organisations whose articles of association take the form of smart contracts.

DApps: DApps are decentralised applications in which all actions from the substructure of the app through to the user interface run on a blockchain.

Demand-side management: Demand-side management refers to the process of adapting electricity demand to supply. Today power-plant output (supply) is frequently adapted to demand. As renewable energies develop, however, it will be increasingly necessary to adapt demand to supply in order to better compensate for fluctuations in power supply.

Difficulty: Difficulty refers to the sum of the conditions that a hash value generated for a block has to meet in order to be integrated into a blockchain using a consensus method and accepted by all nodes. Difficulty artificially prolongs the time required for technical reasons to create a block and so determines how many transactions can be collected together in one block.

Forger: Forgers are miners who work in a blockchain system that uses a proof-of-stake consensus method.

Hash function: A hash function is a computer program that transforms any data of any length into a fixed-length number or 'hash value' (Kaulartz 2016: 2).

Hashing: Hashing refers to the process by which a hash function transforms any data of any length into a fixed-length number or 'hash value' (Kaulartz 2016: 2).

Hash reference: A hash reference is created by combining the hash value of a dataset with the storage location of that same dataset. If an item of data in a transaction is altered, the hash-value reference no longer refers to the correct data location. A hash reference that no longer functions is a clear indicator that data has been subsequently altered.

Hash value: A hash value is the result of hashing. It is a number, which – in the most frequent hash function – comprises the digits 0 to 9 and the letters A to F (16 different characters), is 64 characters long, allows no conclusions to be drawn as to the original message and which changes completely and in an unpredictable manner in case of even minor alterations to the original text.

Initial Coin Offering (ICO): An initial coin offering is a decentralised form of crowd-funding in which DAOs sell tokens to interested parties to raise finance to operate a business, for example. Once acquired, the tokens are used according to the 'one token/one vote' principle to exercise voting rights in the DAO.

Intermediaries: Intermediaries are middlemen or -women or brokers (individuals or organisations) who organise, control or facilitate interaction between two or more parties. The best known examples are banks, stock exchanges and platform companies and distributors. Intermediaries often assemble products or compile information and generally charge a fee for their services.

Inventory data: Inventory data refers to the amount of inventory items stored at any given time. It is similar to an account statement that simply reflects an account balance at a given point in time.

Ledger: "A distributed ledger is a public, decentrally organised book of accounts. It forms the technological basis of virtual currencies and is used in digital payment and trading systems to record transactions between users without the need for a central point that legitimises each individual transaction. For example, blockchain is the distributed ledger underlying the virtual currency bitcoin." (BaFin 2016)

Market clearing price: The market clearing price reflects the marginal costs of the most expensive power station whose power is still in demand. All power stations are then paid this price even if they are able to produce energy at lower marginal costs (Next Kraftwerke 2017).

Microgrids: Microgrids are regional networks of energy suppliers, consumers and prosumers. Microgrids are generally connected to a higher-level network. If the higher-level network fails, the microgrid operates for a limited period as an island network and can thus continue to supply consumers with locally generated electricity.

Miner: A miner checks transactions, collects them together into a blockchain candidate, performs hashing and verifies whether the hash value meets the requirements. The miner's incentive to perform these actions lies in the fact that the successful miner receives a block reward. This benefits the blockchain system because the block created is valid for all nodes, is added to the blockchain and accepted by all nodes, thereby preventing conflicting transactions being sent simultaneously.

Mining: Adding information or a new block to a blockchain requires a problem to be solved. The process of solving this problem is called mining. The problem can only be solved by trial and error, by trying out various possible solutions.

Nodes: Nodes are computers that belong to network members, are connected to one another and, in principle, have access to the same information at any given point in time. Rather than being connected to every other node in the network, each node has at least eight and on average 32 links to other nodes, which are spread around the world. Nodes generally have no personal contact outside of the network (Berentsen und Schär 2017: 88 et seq.).

Nonce: A nonce is a number which, together with the unalterable components of an identification number, makes up the hash value of a block. Since it is generally a serial number, a small number will be tried first, then increased until the hash value meets the block generation requirements (Berentsen and Schär 2017: 208 et seq.).

Power-to-X measures: Power-to-X measures are measures by which electricity is converted into another form of energy (heat, gas, liquid fuel). The X stands for the form of energy or intended use (e.g. chemical raw materials). In power-to-gas measures, for example, electricity is used to split water into hydrogen and oxygen and produce a fuel gas, which can subsequently be converted back into electricity.

Private key: A private key can be used for several transactions and remains in the possession of the recipient. A private key is used to produce a corresponding public key or keys, which in turn generate one or more addresses to which messages can be sent. Each address can receive several payments.

Proof-of-stake consensus method: The proof-of-stake consensus method requires less computer power than the proof-of-work consensus method since network members are not in constant competition to find correct hash values. There is no need for large numbers of miners to solve complex cryptographic problems and so miners do not need the latest hardware. The mining process simply involves determining which miner has the biggest stake and awarding the block to him/her.

Proof-of-work consensus method: In this method, each miner collects transactions into a block candidate, performs hashing and checks whether the hash value meets the requirements. This means that there are numerous competing blocks with different transactions. If a block meets the requirements, the successful miner has provided 'proof of work' and his/her block is accepted by all the other nodes (i.e. a consensus emerges). If the requirements are not met, the miner changes the nonce and checks the requirements again. The problem can only be solved by changing the nonce and checking again. The fastest miner earns the block.

Prosumer: Prosumers are commonly defined as people who are both consumers – in that they use or store electricity – and producers – in that they feed electrical energy, e.g. from their own photovoltaic systems – back into the grid. However, they can also be defined to include both consumers and flexibility providers, who can influence production by providing flexible consumer behaviour.

Public key: A public key is a key that can be assigned specifically to a single user. It is known to the receiving nodes and is used to encrypt messages or to check that senders have genuinely commissioned the message in the form in which it appears.

Relay chain: Relay chains link different blockchains with the aim of making it possible to use a means of payment from one blockchain in the DApp of another blockchain. The process works with individual data from one block rather than with whole blocks and can therefore help to reduce volume and so energy consumption.

Side chain: A side chain refers to a network comprising a reduced number of computers that are linked to a main blockchain and so meet the necessary security requirements.

Smart contract: Smart contracts are computer protocols or programs used to conclude digital 'contracts' using blockchain technology. The parties first agree on the details of the contract, e.g. the parties, volumes and prices involved. Actions are then performed automatically as soon as a given condition is met or a given event occurs (when-then function).

Smart grid: Smart grids are energy networks in which energy flows and grid status data are captured automatically so that energy supply, storage and demand can be adapted accordingly. The integration of smart meters makes it possible to inform producers, consumers and prosumers about energy supply and demand – and therefore prices – in real time and to reward them for adapting their consumption to fluctuations in supply and demand. These adjustments can also be made by the grid operator or by an algorithm in order, for example, to avoid the peaks in demand that are so costly for grids.

Smart home: The term 'smart home' refers to the networking of electronic domestic appliances, small electricity generating systems and in some cases electric vehicles, and the efficient use of these devices according to time of day and weather thanks to smart meters. It allows appliances to be switched on and off by means of a central control device. The variable use of appliances can be rewarded by means of variable electricity pricing.

Smart meter: Smart meters are 'intelligent' electricity meters designed to allow secure, standardised communication between grid actors. They can offer private households greater transparency in terms of electricity consumption and so potential savings. When integrated into smart homes, smart meters form the basis for flexible electricity pricing based on spot electricity prices and so provide consumers with an incentive to use energy-hungry appliances during periods of electricity surplus.

Token: The term 'token' is commonly used in the sense of a share in a product or service. It is different to a coin, which has a monetary function.

Transaction data: Transaction data describes transfer of ownership. It is similar to an account statement that lists all withdrawals, deposits and transfers and discloses a full transaction history. Inventory data asserts ownership claims; transaction data describes and evidences these ownership claims.

1 Digitalisation in the energy sector

With its Act on the Digitalisation of the Energy Transition (Gesetz zur Digitalisierung der Energiewende vom 1. September 2016) the Federal German government hoped to send out a “starting signal for smart grids, smart meters and smart homes” and, in so doing, to create “the digital infrastructure that would successfully link over 1.5 million energy producers and large-scale consumers” (BMWi 2017a). The law was to bring together these two central issues for the future and to pave the way for a networked, low-emission society. Nowhere, however – despite the fact that it had been hyped as “the new Internet” (Tapscott 2016) and hailed as triggering a “grass-roots revolution across entire sectors” (Stiftung Neue Verantwortung 2017) as early as 2015 – did this 31-page document mention the word ‘blockchain’. Does the new legislation’s omission of blockchain technology, which boasted USD 1.2 billion of risk capital investment[1] prior to September 2016, mean that the new law was “out of date even before it took effect” (Reetz o.J., cited in Amelang 2017)?

Digitisation, i.e. the transformation of analogue information into digital form, is particularly attractive to the energy sector because it involves a wide range of data (e.g. power station performance data, consumption data, temperature and weather data, etc.), which, if managed cleverly, offers enormous potential for increasing efficiency and reducing costs (Peters and Mohr 2015: 9). Above all, however, digitisation can be a key enabler for flexibilisation, which can in turn help improve the market integration of volatile renewable energy sources (Mielke/Zimmermann 2016). Flexibilisation measures such as **demand-side management**, energy storage, **power-to-X measures** and cross-border trade (Next Kraftwerke 2016) can be used to integrate more renewables, thereby paving the way for Germany’s target of obtaining 65 % of the electricity it uses from renewable energy sources by 2030 (German Coalition Agreement, Koalitionsvertrag 2018).

1.1 Smart meters and smart homes

The installation of smart meters (intelligent electricity meters) is now compulsory for consumers with an annual electricity consumption of over 10,000 kWh and for producers such as solar energy system owners with an installed capacity of between 7 and 100 kW. Their installation in households with smaller systems will start in 2020. Smart meters can, in principle, also be installed voluntarily at any time (see the Smart Meters Operations Act, Messstellenbetriebsgesetz 2016). The fitting of smart meters is designed to allow secure and standardised communication between different grid players. They enable consumers to see their electricity/heat usage levels past and present displayed on devices installed in their homes, helping them to identify potential savings and energy-guzzling appliances. They also allow electricity customers to check their bills more easily and to negotiate variable supply tariffs with their energy suppliers that are better able to suit to their individual consumption patterns and the weather-dependent supply of volatile renewable energies. In the past it has been impossible to reach such agreements because variable tariffs have been too complex – both economically and technically – and unviable (Mielke, Zimmermann et al. 2016b: 22 et seq.). In the medium term, the introduction of smart meters should also facilitate the cross-sector bundling of electricity, gas and district and other sources of heating energy (Bundesnetzagentur (Federal Grid Agency) 2017).

The term ‘**smart homes**’ refers to the networking of electronic domestic appliances and their efficient use depending on time of day and weather. This technology makes it possible to chill

[1] Cf. Statista (2017a): https://de.statista.com/statistik/daten/studie/654326/umfrage/venture-capital-investitionen-in-blockchain-technologien-weltweit (last downloaded on 24 October 2017).

freezers to a lower temperature during periods of sunny or windy weather when the electricity supply is higher, for instance, and to maintain them at a higher temperature when less renewable energy is being generated. It also means that appliances can be turned off automatically when the occupants leave a house, for example. For this to be possible, the domestic appliances need to be controlled by a central system such as a smartphone in conjunction with an app that provides information on electricity consumption, temperature and brightness levels in individual rooms (Ropenus 2017b: 108). Smart home systems can even include charging stations for electric vehicles. The integration of smart meters lays the foundations for the introduction of financial incentives to encourage users of electric vehicles to charge them when the supply of flexible renewable energies is at its highest and demand for electricity is at its lowest. This has the potential to reduce emissions, economise on grid capacity and save costs.

1.2 Smart grids and decentralised energy systems

The homes of the future, along with electricity producers of all sizes, the electro-mobility sector and manufacturing industry, will be part of smart or 'intelligent' electricity grids. As electricity production becomes more decentralised, it will be necessary to integrate more and more **prosumers** into the overall system. These prosumers are both consumers – in that they use electricity for their homes and cars – and producers – in that they feed electricity from their solar energy systems back into the grid or have an indirect impact on generation as a result of flexible consumer behaviour. In the future, information and communications technologies (ICT) will make it possible to match supply more effectively to demand and the flexibilisation measures set out above will help counter fluctuations in the supply of renewable energies (Mielke, Zimmermann et al. 2016: 15).

The energy transition is significantly increasing the number of electricity generation plants and it is now necessary to reorganise the distribution and control of this electricity (BDEW 2017). In an ever more decentralised electricity generation landscape, digital technologies can make balancing electricity generation and consumption easier and prevent the electricity grid from becoming overloaded. The collection and digitisation of data can support demand-side management by improving load forecasting and controlling and by setting a framework of incentives for electricity demand. In addition, digitalisation can assist in linking together the electricity, gas, heating, industrial and mobility sectors so that by the use of storage technologies energy can be directed automatically and efficiently where it is needed or can be used in the most efficient manner at any given time (Mielke, Zimmermann et al. 2016a: 17). As a result, it is possible to use surplus electricity in the manner most efficient for the economy as a whole.

Some observers emphasise the opportunities offered by digitalisation to make social improvements. Some highlight the fact that simplified participation in the energy market may have a democratising effect and reduce consumer dependence on the market (Rifkin 2015: 7). They point out that 'intelligent' technologies will enable all grid participants –producers, suppliers, grid operators and consumers – to talk to one another and could facilitate closer cooperation between them (enviaM 2017). They see the potential for achieving technical, ecological and social improvements at one and the same time.

1.3 The risks of digitalisation and the relevance of blockchain

On the subject of **smart grids**, however, the trade unions, for example, have warned of the erosion of solidarity from the wealthy who, as a result of self-generation combined with storage and digital technologies, are becoming largely energy self-sufficient in their neighbourhoods and so ceasing to contribute to the costs of developing and maintaining the electricity grid and public energy provision (Mielke, Zimmermann et al.: 16). With this type of system it is possible that the costs might end up being split between all those who are unable to join forces and supply themselves. It would be even more problematic if, during periods when renewable electricity was in short supply (in dark and windless conditions, for example), the wealthy wanted to be able to fall back on the capacity of the electricity grid after all without having paid for it.

There are also concerns that increasing dependence on technology will have an ever greater impact on personal privacy, creating a feeling of being 'remote controlled' (ibid.: 15). In addition, the energy sector might be vulnerable to hacking attacks, which in the case of a critical infrastructure such as the power supply could potentially be highly problematic. Similarly, the issue of the economic and political use of data has yet to be sufficiently elucidated. Current trends towards population control in China, for example, as a result of the development of digitalisation serve to strengthen these fears[2]. Similarly, when newly acquired data is concentrated in the hands of a small number of businesses, there is the risk that their market power will increase. There are also a number of ecological questions waiting to be answered. Is it possible that digitalisation – whether as a result of digital technologies or rebound effects – might actually lead to greater electricity consumption? And, of course, the vast majority of raw materials such as lithium and rare-earth elements are obtained with little regard for human rights or environmental concerns.

Many express the view that **blockchain** promises innovative solutions in this area (in terms of security and data protections, for example). Its capacity to replace **intermediaries** with programmed codes and so to reduce transaction costs could prove significant. In a study carried out by the German Energy Agency (Deutsche Energie-Agentur, dena), 70 decision-makers from the German energy sector were asked to assess the potential of blockchain. Approximately 60% of respondents assumed that blockchain applications would proliferate, while 21% saw blockchain as a 'game changer' for the energy sector and 14% expected the technology to be limited to niche applications. Only 5% assessed its potential as very low to inexistent. Of those questioned, 50% indicated that they were already experimenting or planning to experiment with blockchain applications (dena 2016: 18 et seq.).

On 29 June 2017, the German Blockchain Association (Blockchain Bundesverband) emerged from the heart of the German blockchain community with the aim of promoting the networking of private and public organisations using blockchain within a social framework and on solid legal foundations (Blockchain Bundesverband 2017a). The core demands of this Berlin-based group are to "deploy at least one public register with blockchain technology" by 2020, to "promote education and science on the topic of blockchain" and to "create innovation-friendly legal certainty in civil law, taxation and regulation in order to establish Germany as an attractive business location for the blockchain ecosystem" (ibid. 2017b: 1). As far as the energy sector is concerned, the Blockchain Bundesverband

[2] Under China's 2015 National Security Law, "the government can forbid almost any public activity – in the fields of IT, finance and the environment, for example – in the name of national security. The central government is working on a comprehensive system for monitoring and classifying its population. The aim: to use data on social media friends, browsing patterns and money transfers to make its citizens and their behaviour more predictable – both economically and politically." (Die Zeit 2017)

sees many possible applications for blockchain technologies that could help "guarantee security of supply and grid stability during the energy transition" (ibid. 2017c: 12). This background paper is intended to help better classify these demands.

2 What is blockchain?

2.1 An overview

Even specialists are unsure how significant the potential benefits of blockchain may be. A PwC study published in March 2016 concluded that 57% of decision-makers in the financial services sector were not yet in a position to assess the potential of blockchain and remained unaware of how they should react to this new development (PwC 2016: 3). This is despite the fact that it is the financial sector that has made the greatest advances in both applying the technology and researching possible areas of application.

This and the following chapter set out to provide a simplified explanation of the theories and complex mechanisms underlying blockchain technology.

Blockchain can be seen as a collectively written digital book or '**ledger**' that records and checks transactions (Wiedmaier 2017: 14). It is based on a decentralised data storage process in which **transaction data** is stored not on a specific server but on thousands or millions of computers joined together in a network. The members of this network neither necessarily know nor trust one another but are able to check one another, which – in theory – could assist in building up a relationship of trust as the process develops, in the same way as if it were being monitored by a central authority (Wilson 2017). The technology was developed as a response to the global financial crisis of 2008, which did untold damage to trust in the financial sector (Tapscott and Tapscott 2016: 5) and, in particular, undermined the reputation of the banks as trustworthy institutions[3].

In the past, database systems have invariably been provided by institutions that had overall control over them and financed resources such as the server and variable costs (e.g. electricity for operating and cooling electronic components) themselves. Most social media, email programs and websites are operated in this way[4] with changes being made at the discretion of the operators alone (Wilson 2017).

The underlying principle behind blockchain applications is that they have dispensed with the need for mediating authorities because their data is stored thousands of times and so never lost, their transactions are processed decentrally and their members collectively provide the necessary (though unfortunately still inordinate) computer resources. Each network member has a complete copy of the entire database and none of the members needs permission to consult the data. All **nodes**, that is the computers operated by the network members, are connected together and, in principle, have access to the same information at any given time. Messages containing information about the value of a transaction or the parties involved are regularly stored on the network and can be read by everyone.

[3] NB. The authors of this have not assumed that the advent of blockchain technology makes the need for reasonable bank regulation any less urgent.
[4] This is not the case, however, with open-source programs such as Wikipedia, for example.

No one definition of blockchain has yet to gain acceptance; a multitude of views on its attributes is currently in circulation. Daniel Drescher gives a solid working definition, which provides an initial and understandable overview, in his book "Blockchain Basics: A Non-Technical Introduction in 25 Steps" (2017: 35):

> *"The blockchain is a purely distributed peer-to-peer system that utilizes a software unit that consists of an algorithm, which negotiates the informational content of ordered and connected blocks of data together with cryptographic and security technologies in order to achieve and maintain its integrity."*

2.2 Processing transactions

Users can see no differences from other technologies at the application level as the software architecture is a matter for the developer and there are no restrictions on user interface design. However, different technologies have different system security requirements and use different means to guarantee it (Drescher 2017: 16). Theoretically, decentralisation is one of the key features of blockchain. At first glance, other systems and platforms such as Airbnb, the community platform for renting private accommodation, look decentralised because private users appear to network independently with one another. Behind this decentralised network, however, lies a central platform without which users would be completely unable to interact. At the same time, Airbnb has access to all data and the capacity to cripple the network at any moment (Voshmgir 2016: 10). Theoretically, this is where the innovations made possible by blockchain come into play.

However, blockchain is not the only technology to offer an underlying decentralised system. There are several alternatives in the broader field of 'distributed ledger technologies', though so far they have failed to attract much attention. These other alternative technologies offer different features and so different advantages and disadvantages. When they are compared directly, blockchain proves to be several years ahead in terms of development. Some experts argue that this increases the likelihood of its establishing itself in the market (Interview 2). There are various methods by means of which a decentralised blockchain system can supposedly be maintained. One of these – the most widespread, in fact – is the **proof-of-work consensus method** explained below (PwC 2016: 6). It is, however, likely that "the phase of variation will continue" – though opinions differ as to how significant these variations will be – and that we are still a long way from one dominant design (dena 2016: 30 et seq.).

2.2.1 The proof-of-work consensus method

2.2.1.1 Setting up and forwarding transactions

With the proof-of-work consensus method all the members of a network are connected together via the Internet and are able to leave and re-join the system at any time. Rather than being connected to every other node, each node has at least eight and on average 32 contacts to other nodes, which are spread around the world and to which the member generally has no personal contact outside the network (Berentsen and Schär 2017: 88 et seq.). Each computer has an independently managed list of computers with which it communicates. Each node that receives a message, forwards it to all its contact nodes. These receiving nodes in turn forward the message to all the nodes on their contact lists. This means that all the nodes in the network eventually receive the message, and multiple sendings are simply ignored. A time stamp in the message allows incoming information to be sorted chronologically. A new computer can join the network at any time by sending a type of contact request to other nodes in the network. When these nodes confirm the contact, the network grows by one node (Drescher 2017: 149 et seq.). One advantage of blockchain over other networks is that the joining computer is able to consult all the information on past transactions and so receives a complete update.

Ownership can be described in various ways, including by means of transaction data or **inventory data**. Inventory data describes the ownership position at any given time. It is similar to an account statement that simply shows a current balance. Transaction data describes transfers of ownership. It is similar to an account statement that lists all withdrawals, deposits and transfers, and discloses a full transaction history. These two forms differ in that inventory data asserts ownership claims, while transaction data describes and evidences these claims (Drescher 2017: 64 et seq.). Blockchain works with transaction data, which appears not only on the account statements of the parties involved in a transaction but also on the digital ledgers of all network members.

It represents a new type of proof in that each network member has access to the entire transaction history. Based on the principle that 'one witness is good, lots are better', it is impossible for transactions to be carried out in secret or be disputed as invalid. Each transfer must be recorded in the register (ibid. 41). If person A wishes to transfer money to person B, he/she inputs a message (e.g. 'person A sends 100 units of X to person B') into the network. This takes place via a series of technical detours, which protect both the anonymity of the parties and the integrity of the system. The aim is to identify transaction data quickly and unmistakeably by means of a 'digital fingerprint' (Drescher 2017: 71).

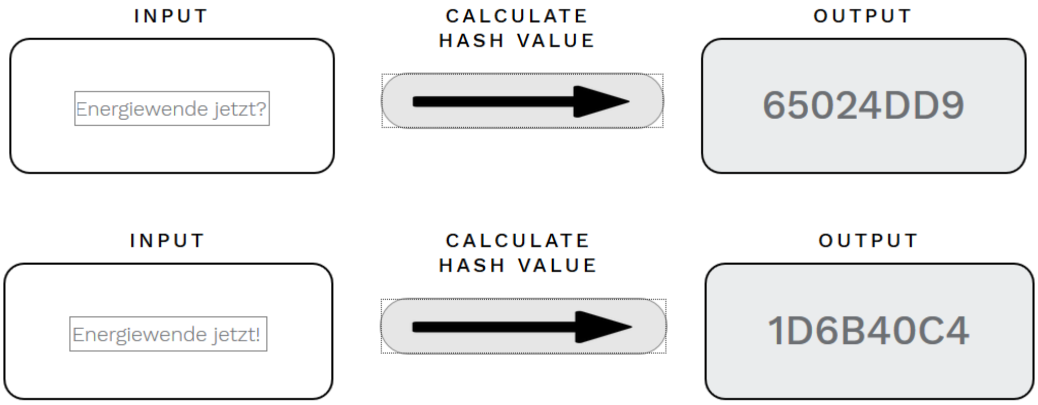
2.2.1.2 Hash functions and hash values

This is where **hash functions** come in. Hash functions are computer programs that transform any data of any length into a fixed-length number or '**hash value'** (Kaulartz 2016: 2). In the most frequently used hash functions, this number is always 64 characters long and comprises the digits 0 to 9 and the letters A to F, so that it amounts to 16 different characters. Identical inputs produce identical hash values. The smallest change in the original text changes the resulting hash value completely in an unpredictable manner. The 64-character alphanumeric combination provides no information as to the content of the original message (Drescher 2017: 73). Different hash functions produce numeric combinations of different lengths. They cannot be compared with one another and the same hash function is therefore always used within a blockchain system.

Hash functions are used in the comparison of datasets. They obviate the need to compare word-for-word and page-for-page, for example, two texts that look similar. It is sufficient simply to compare the two hash values to ascertain immediately whether the two underlying datasets are identical. There are a possible 2256 hash values, which means that it is as good as impossible for two different texts to have the same hash value (Kaulartz 2016: 2). The process of '**hashing'** makes transactions particularly safe. The slightest change in transaction details – the addition of another zero to a figure, for example – is identified immediately and makes fraudulent behaviour considerably more difficult.

At *www.blockchain-basics.com/Hashing.html* it is possible to enter various texts into a text field (input) with the help of an abbreviated version of the SHA256 hash function and to determine the corresponding hash value (output). It is immediately clear that the output provides no information as to the original text and that a slight change in the original message results in a completely different output.

Fig. 1: Calculating hash values for short texts using a simplified version of the SHA256 hash function[5]



However, hashing is used not only to compare information but also to store it so that it is easy to find and tamper-proof. To do this, the hash value of a dataset is combined with its storage location to generate a **hash reference**. Drescher (2017: 83 et seq.) compares this to the use of cloakroom tickets. If you leave your jacket in a cloakroom, you are given a ticket providing information about the place where the jacket has been left. The ticket need not provide all the information about the jacket or the storage location: a simple system indicating a specific, unique hook is sufficient. Here, too, the process ensures that data cannot be altered subsequently. If an item of information within a transaction is altered, the hash-value reference ceases to refer to the correct storage location. A hash reference that no longer works is a clear sign that data has been altered subsequently.

2.2.1.3 From individual transactions to the chain

Finally, all the transaction data is joined together in a chain or blockchain. The individual blocks are linked together in the same way as the pages of a book. Reading a book, you notice immediately if a page is missing, firstly because sentences that run on from one page to the next no longer make sense and, secondly, because two page numbers are missing. A blockchain operates in a similar manner (Drescher 2017: 34). A specific number of transactions is collected together into a block. This block of new transactions is added to a chain of past blocks comprising individual transactions. Each block refers to its immediate predecessor because it contains the hash value of the preceding block. The first block in a chain has no such reference; it is the only block that does not refer back to all previous transactions. The second block refers to the first, the third to the second, etc.

There are other security mechanisms used in the creation of blocks. Before a transaction can be performed, a hash value must first be created for it. Next, two transactions are combined. These two transactions are linked together and another hash value is created. This process of combining two hash values is carried out with a number of transactions until only one hash value is left. This value then becomes the root of a 'Merkle tree' (Drescher 2017: 88).

[5] Source: Authors' own graphic

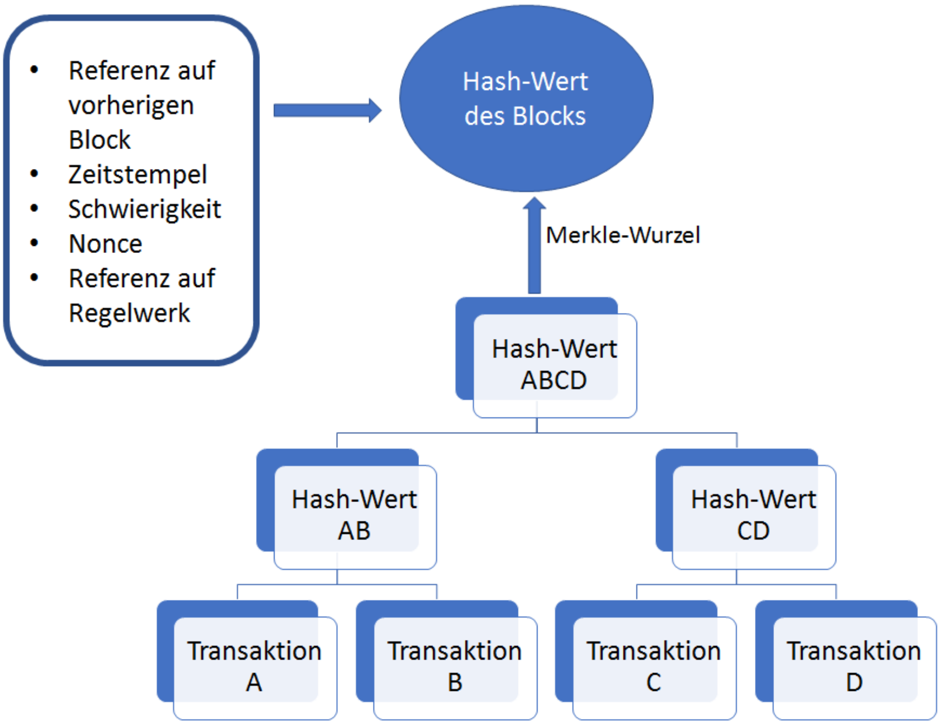


Fig. 2: Structure of a Merkle tree and creation of a block[6]

A new block is created by combining the root of a Merkle tree with the hash reference to the previous block and a time stamp (Berentsen and Schär 2017: 202). This information can only be added by a **miner** in the blockchain structure. First, each miner creates block candidates, that is blocks which he/she would like to add to the blockchain. He/she then takes part in a problem-solving competition. The problem in question cannot be solved by using data, knowledge or IQ; it is based on the principle of trial and error (Chuen and Deng 2018: 150) in which various possible solutions are tested. This is comparable to opening a combination lock. If you do not know the unique code, there is no point in thinking about how to determine the right combination of numbers. It is just a matter of trying a series of number combinations one after the other. Though this method may be slow, it is always successful (Drescher 2017: 89). It is a processor-intensive task and the likelihood of finding a solution increases according to the amount of computing power available. As a result computer clusters, for example, have a critical advantage over standard laptops.

The problem to be solved comprises various elements. First, there is a piece of data that must remain unaltered at all costs and contains information about transactions. As illustrated in Fig. 2, this information comprises the time stamp, the reference to the last block, the Merkle root and the reference to the rulebook. Then there is the hash function, which is used to obtain the right solution. Finally, certain conditions must be fulfilled and the whole thing solved using alterable data. This alterable data is referred to as a **nonce** and may contain anything so long as it is in the form of a hash value. The aim is to combine various nonce-number combinations with the hash value of the non-alterable data and to calculate a hash value that meets certain additional conditions. These additional conditions are also referred to as the '**difficulty**'. It is very easy to calculate the combined hash value of two previously single hash values – a simple smartphone would be able to do it (Berentsen and Schär 2017: 203 et seq.). To artificially extend a transaction's processing time, conditions are set to ensure that (in the case of the Bitcoin blockchain[7]) no more than seven or so

[6] Source: Eigene Darstellung
[7] Bitcoin, the very first blockchain technology, is also the best known virtual currency, cf. 2.3.1.

transactions can be performed per second (PwC 2016: 11). This prevents data from passing through the network too quickly, because the nodes only spend time solving problems for which financial incentives are offered.

Difficulty is expressed as a natural number and means the number of zeros the hash value to be calculated should start with. If the difficulty is one, the hash value must be preceded by at least one zero. As there are 16 different digits, the probability of calculating this hash value is 1/16 (Berentsen and Schär 2017: 143 et seq.). If the difficulty is 10, the hash value must be preceded by at least 10 zeros. The greater the difficulty, the more processing power is required to solve the problem. Difficult problems therefore require more time, creating competition between the nodes (Vranken 2017: 2).

In practice, the process operates as follows. Starting with the various components illustrated in Fig. 2, a miner creates a hash value for a new block with any serial number as the nonce (Berentsen and Schär 2017: 209). This hash value is then compared with a threshold value, which is based on the difficulty (ibid. 208 et seq.). If the hash value meets the requirements, it is added to the chain and accepted by all the other nodes. If the hash value does not meet the requirements, the miner creates a new hash value and so a new block candidate in which all the components except the nonce remain the same. This process is repeated until the hash value generated meets the requirements.

In this method all miners compete with one another and the blocks generated are accepted only when the difficulty is met. As candidates for addition to the chain and acceptance by all nodes, the individual blocks are referred to as block candidates. Rather than the unalterable units illustrated in Fig. 2 simply being hashed once and the number combinations being tested, as when breaking a safe code, a new hash value and so a new block candidate has to be generated for each attempt (ibid. 208). This process results in the extremely high energy consumption levels required by blockchain technology: energy consumptions levels that are incompatible with the objectives of energy transition.

The first person to create a block candidate that meets the difficulty gets a **block reward**. The node operator may add a so-called **coinbase transaction** to the block candidate. This transaction is the last transaction to be integrated into the newly created block and indicates that the winner is sending X units created out of nowhere to his/her own account. In the Bitcoin system the reward currently stands at 12.5 bitcoin units, which on 14 March 2018 equated to approximately to EUR 84,900[8]. The amount of coins, i.e. of monetary units inherent in the system, halves every four years. Different blockchains all have their own method of rewarding miners.

As a general rule, however, successful block miners always receive the transaction fees for the transactions contained in a given block. The one who transfers ownership pays the transaction fee, a sort of residual amount resulting from the sum of all transaction inputs less the sum of all transaction outputs (Berentsen and Schär 2017: 215 et seq.). Anyone initiating a transaction generally announces these transaction fees as an added incentive to process his/her transaction. While it is relatively difficult and time consuming to calculate a hash for an existing block, checking whether a hash value is correct is comparatively easy. This facilitates its passage through the network. Miners have an incentive to check hash values for new blocks calculated by others because if they identify an error they then have the opportunity to start from the beginning, calculate a correct hash themselves and so claim the block reward. This is where game theory comes into play. It explains how the creation of incentives results in miners stabilising the system and 'joining in'.

Lastly, the blockchain system contains one other mechanism that authorises transactions and is used to ensure that a transaction initiator really wants to make a transaction. Each person has a

[8] Cf. current bitcoin-euro exchange rate at Finanzen.net, www.finanzen.net/devisen/bitcoin-euro/chart (last downloaded on 9 December 2017)

public and a **private key**. Interestingly, these keys are not used to conceal data but to verify its origin (Berentsen and Schär 2017: 55). Once a message has been encrypted using the **public key**, it can only be decrypted with the private key. A person in possession of only one key can either only encrypt or only decrypt messages. It is for this reason that this mechanism is referred to as asymmetric cryptography. Ultimately, both keys operate in the same manner; they become private or public keys by dint of the way they are used. While a public key can be passed on to others and equated to a sort of account number, the private key stays in the owner's possession and remains secret (Voshmgir 2016: 13).

A person wanting to transfer his/her property to another party first creates a message and a corresponding digital signature. The message is then converted into a hash value and encrypted using a private key. This digital signature is unique and can only be traced back to one sender because a unique private key was used. The message and the digital signature are placed in a folder, which is then sent to the neighbouring nodes and distributed through the network. Anyone who knows this person's public key can use it to decrypt the text. Receiving nodes can check that this message was authorised by the sending node by calculating the message's hash value themselves and then decrypting the sender's digital signature using his/her private key. The two hash values are then compared. If they are identical, the recipient knows that the message was signed by the sender and that the message sent by the sender really is the message he/she wanted to send (Drescher 2017: 105 et seq.). If the two hash values are different, it is established that there has been a hack and the sender did not authorise the message. As a result, the message is not attributed to him/her.

A key feature of blockchain is that it does not differentiate between users. It is concerned only with the accuracy and consistency of all its hash values. If a transaction is subsequently manipulated, its hash value changes, as does that of the combined transaction pair and that of the hash value pair in turn. Finally, the hash value of the entire Merkle tree changes, along with the header of each block, its reference and each individual reference relating to this block. Any change is therefore associated with prohibitively high costs and complexity.

If the difficulty is reduced, however – e.g. if the only condition of the problem to be solved is that the hash value must be preceded by one zero – then manipulation no longer requires so much computing power (or electricity consumption) or so much time. If, conversely, the difficulty is too high, then the costs of the necessary computing power are so great that there is no incentive to add a new block (Drescher 2017: 142). When designing new blockchains it is important to take both of these factors into account and to find a suitable balance. This is made more difficult by the fact that technical innovations and improved hardware are more powerful and capable of calculating hash values more quickly. As a result, some blockchains contain mechanisms that automatically adjust the degree of difficulty to ensure that creating a new block takes a certain length of time (e.g. an average of 10 minutes).

2.2.2 The proof-of-stake consensus method

The best known alternative to the proof-of-work validation mechanism is the **proof-of-stake method**, which proves not work but stake. With the proof-of-stake consensus method, computing power (and so electricity consumption) is reduced because network members are not in constant competition to find correct hash values. Miners do not need to solve complicated cryptographic problems and as a result they do not necessarily need the latest hardware. Difficulty is set individually for each user: it is inversely proportional to the age of the coins or alternatively to the number of coins in a user's possession. Initially, one single miner is designated to mine a new block. This drastically reduces the amount of processing power required and avoids the use of unnecessary computing resources by thousands of miners.

The stake held by the miner (who is more correctly referred to in this system as a '**forger**', though we will continue to use the term miner for the sake of simplicity) is determined either by the 'coin age' or the number of coins held. This coin age is calculated by multiplying the amount of coins by the length of time since the user last used them (King and Nadal 2012: 1 et seq.). The older the coins, the greater the chance of earning a block. Once a block has been earned, however, the age of the winner's coins is reset. This regularly creates new opportunities for all participants (Vranken 2017: 7). It is generally at least 30 days before one of these coins can take part in a transaction again. If a block is created, the miner does not receive a block reward, he/she simply receives the fees for the transactions contained in the block. A built-in protection mechanism against hacker attacks is provided by making all nodes pay a refundable fee for each transaction. As a result, there is no economic incentive to manipulate the system (Wiedmaier 2017: 51 et seq.).

This method, too, is the subject of numerous criticisms and the community as a whole is undecided as to which of the two consensus methods offers the best resistance against attacks[9]. To manipulate the proof-of-work system, a person or an institution needs enough money to be able to buy the **mining** hardware required to mine over 50% of coins. This level of capital accumulation would appear possible. With the proof-of-stake method, on the other hand, it would be necessary to buy over half of the coins in circulation.

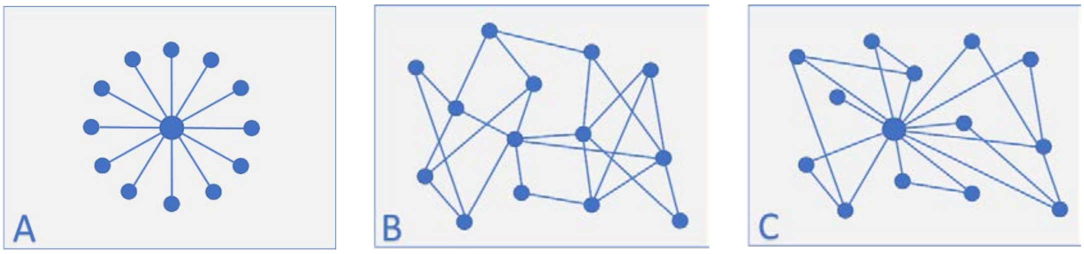
Alongside the two most widely used consensus methods – proof-of-work and proof-of-stake – there are also combinations of the two and entirely new concepts including proof-of-space, proof-of-space-time, proof-of-burn and proof-of-identity methods (Vranken 2017: 7; Mengelkamp et al. 2017a: 4). In this fast-moving environment, it is quite possible that neither of the current leading consensus methods will eventually prevail.

2.3 Examples of blockchains

2.3.1 Bitcoin

Bitcoin is not simply the most popular **cryptocurrency** or the most prominent example of a blockchain-based system, it represents the birth of the technology itself. In 2008 a person or group of people operating under the name 'Satoshi Nakamoto' published a white paper entitled "Bitcoin: A Peer-to-Peer Electronic Cash System" and sent it to a cryptography mailing list before the first version of Bitcoin went online in January of the following year (Wilson 2017). Nakamoto did not build in any particular role for himself and his draft was therefore amended and developed by third parties (Berentsen and Schär 2017: 67). Bitcoin emerged at the same time as various disruptive digital business models that presented new challenges to established businesses. 'Airbnb' (2008) turned tenants into landlords, 'Uber' (2009) transformed car owners into taxi drivers and 'ebay classified ads' (2009) turned buyers into sellers. This new type of trade was based on direct contact between users and earned the start-ups mentioned above substantial profits.

[9] Such criticisms can be found expressed in various places, including blogs such as:
https://sjkelleyjrblog.wordpress.com/2017/09/16/criticisms-of-proof-of-stake/
https://medium.com/@tuurdemeester/re-buterins-criticism-of-my-pos-piece-4ee70d6fd289
https://cointelegraph.com/news/the-inevitable-failure-of-proof-of-stake-blockchains-and-why-a-new-algorithm-is-needed
www.coindesk.com/short-guide-blockchain-consensus-protocols/



A)	Centralised network
B)	Decentralised network
C)	Decentralised network with a central element

Fig. 3: Network structures[10]

However, Bitcoin differs from these models in so far as there is no central control over the system. Although the Bitcoin Foundation does have a governance structure whose role is to standardise Bitcoin, it neither issues a means of payment nor operates as a central bank (Vranken 2017: 1). Network members have to use their own resources to trade. They are rewarded for mining with the block rewards already mentioned in section 2.1.2, which they can then convert into 'real' currencies. With a converted volume of some EUR 215 billion (at 9 December 2017)[11], though a significant currency, the bitcoin comes nowhere near the cumulated total value of the euro (EUR 10.9 trillion) (Trentmann et al. cited in dena 2016: 28). Today a substantial number of hotels, shops and restaurants accept bitcoins as a means of payment. The Swiss municipality of Zug was the first local authority to accept bitcoins as a means of payment (PwC 2016: 11).

Anyone wanting to do business in bitcoins receives an electronic 'wallet' (ibid.: 11). The Bitcoin address is the public key to which two hash functions are then applied one after the other. The double hash ensures that it is impossible to trace the public key from the Bitcoin address (one-way function). Thanks to the Bitcoin address, the public key is not made known until a transaction is made (Berentsen and Schär 2017: 126). To prevent usage patterns being employed to trace the identity of a node, a new pair of keys is created for each transaction (ibid.: 129).

The Bitcoin protocol contains an algorithm that adjusts the difficulty of calculating a valid hash value to ensure that a new block is created every 10 minutes. The more powerful the hardware, the more complex the mathematical problems that have to be solved and the greater the level of energy intensity. The block reward was originally BTC 50 (bitcoins). It halves every 210,000 blocks (approx. every four years) and will fall to under BTC 1 to 8 by 2140. This is the smallest bitcoin unit and is called the 'satoshi' (Vranken 2017: 2). This is the date on which the highest possible number of bitcoins – 21 million – that can ever circulate in the system will be reached as new bitcoins can only be generated by block rewards. After 2140, the transaction fee will be the only financial incentive for miners to contribute to system stability.

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[10] Source: Authors' own graphic

[11] This figure is based on a cumulative total of BTC 16.71 million on 9 December 2017 (see Statista 2017b: https://de.statista.com/statistik/daten/studie/283301/umfrage/gesamtzahl-der-bitcoins-in-umlauf/, last downloaded on 9 December 2017) and an exchange rate of EUR 12,922/BTC (see Finanzen.net. www.finanzen.net/devisen/bitcoin-euro/chart, last downloaded on 9 December 2017).

As with all cryptocurrencies, the exchange rate is subject to strong fluctuations. On 14 March 2018 the bitcoin stood at just under EUR 6,800[12]. A general upward trend is nevertheless discernible. Thanks to network growth the exchange rate has risen by 4,000% in eight years (Wilson 2017). One advantage of bitcoin over 'real' currencies may be that there is a fixed number of bitcoins, effectively protecting it from inflation. Some see bitcoin as a world reserve currency (Interview 2). This view is supported by the observation that the exchange rate rose rapidly when negotiations around a possible Brexit started and market uncertainty started to emerge (Berentsen and Schär 2017: 90).

Fig. 4: Bitcoin-euro exchange rate from March 2017 to February 2018[13]

Many bitcoin miners, i.e. those who solve the mathematical problems using powerful computer resources, are located in areas directly adjacent to favourable energy sources, e.g. in the vicinity of China's large dams, coal-fired power stations or Iceland's geothermal energy sources. Block mining (creation) is not very lucrative in Germany, where the price of electricity is three times higher than in Iceland (Pannewick and Herbst 2017). The market has high entry barriers because the capital expenditure required to purchase hardware is rising steadily. This has led to the creation of an oligopolistic market fuelled by hardware upgrades and mergers (Vranken 2017: 4). According to information provided by Bitcoinchain.com, in 2016 the five biggest miners generated over 85% of blocks. This figure stands in fundamental contradiction to the underlying principle of decentralised value creation. The system has proved incapable of maintaining decentralisation, something which should give pause for thought in relation to other blockchain applications.

Similarly, the original form of solo mining is only practised by computers with appropriately high processing power. This development means that individuals are increasingly banding together in networks, e.g. the BitClub Network, to mine bitcoins by pooling their resources and then apportioning the bitcoins to members on a pro rata basis. This increases planning security for participants; mining ceases to be a lottery in which miners have to go long periods without

[12] For the current exchange rate see: www.finanzen.net/devisen/bitcoin-euro/chart.
[13] Source: Finanzen.net 2018a

remuneration (Berentsen and Schär 2017: 222). However, it also contributes to the Bitcoin system's trend towards centralisation.

In all the history of Bitcoin, there has never been a single instance of a transaction being subsequently manipulated or of the system as a whole being shut down. There has, however, been a series of hacker attacks on stock exchanges in which bitcoins to the value of several millions of US dollars have been stolen (Berentsen and Schär 2017: 87 et seq.). As subsequently altering the code poses significant difficulties, actors whose bitcoins are stolen during hacks are left with nothing. In such cases, responsibility for security technically shifts to the individuals involved. Nevertheless, it would take something of the order of a global power blackout to cripple the system (BlockchainHub 2017).

Bitcoin is not without its critics. Firstly, the network's huge electricity consumption is the subject of increasing criticism (cf. Pannewick and Herbst 2017, Vranken 2017:1). Secondly, it has been alleged that its extreme price volatility is connected to speculative gambling by private individuals unable to properly assess the risks inherent in what is a highly complex system (cf. e.g. Spiegel Online 2017b). Thirdly, some critics suggest that Bitcoin's rapid growth has been assisted, in particular, by the darknet platform Silk Road and that Bitcoin has made it possible to deal in illegal goods and services with complete anonymity (Berentsen and Schär 2017: 83). There are, however, also counter examples of Bitcoin promoting transparency in the face of anomalous behaviour rather than concealing illegal activities. For example, Bitcoin has contributed significantly to the support for WikiLeaks, whose fundraising campaigns are no longer operated using PayPal (ibid. 83 et seq.). Fourthly, Bitcoin remains unsuited to real-time transactions because there is a delay of several minutes between the time a transaction is input into the network and the time it is confirmed. It does, however, allow money to be sent around the world in just a few minutes. In this Bitcoin is far in advance of conventional bank transfers. These are just a few of the pros and cons of blockchain applications specific to Bitcoin. Some are dealt with in greater detail in Chapter 4 (Strengths and opportunities) and Chapter 5 (Weaknesses and threats) with a specific focus on energy issues.

It is easy for anyone to copy the Bitcoin system. Since these copies do not result in the creation of new Bitcoin units, however, new networks pose no threat to Bitcoin's stability and Bitcoin's market dominance is not at risk from competitors. The Bitcoin code can be adopted and modified at will and this has already happened over 600 times (Statista 2017c). These copies are called **altcoins** or alternative coins. While these new systems have for the most part yet to achieve a critical mass, Bitcoin continues to take advantage of existing network effects (Berentsen and Schär 2017: 71).

2.3.2 Ethereum

Ultimately, Bitcoin is 'merely' a cryptocurrency; its transactions are restricted to transferring money from a sending to a receiving node. This became apparent to the 18-year-old Vitalik Buterin, who in 2013 published a white paper proposing Ethereum, a system which permits any type of peer-to-peer value exchange and represents the first real alternative technology to the Bitcoin blockchain (Voshmgir 2016: 15). Ethereum received USD 18 million of funding in less than 18 weeks – at the time the third largest sum ever raised in the history of crowdfunding (Bitcoin Generator 2017). In addition to offering new fields of application, Ethereum also represents an improvement on the Bitcoin blockchain in that it creates a new block every 10 seconds and can accept up to 1,000 transactions a second (Ewald Hesse 2017b).

Ethereum has turned the spotlight onto other possible functions and uses of blockchain. For example, the Ethereum computer network allows the setting up and use of the smart contracts, Dapps and DAOs discussed below.

Smart contracts are computer protocols or programs by means of which digital 'contracts' can be concluded and performed using blockchain technology. First, the parties agree on the details of the contract, e.g. the parties, volumes and prices involved. Actions are carried out automatically as soon as a given condition is met or event occurs (when-then function). Where, for instance, a contract has been made between an energy supply company and a consumer and the consumer fails to make a payment, the supplier will stop supplying electricity. This can prove extremely problematic in terms of social and human rights as no further electricity will be supplied until the missed payment is made (Sieverding and Schneidewindt 2016: 2). This principle can be applied to a wide range of possible agreements between individuals. If A and B agree that B will perform a specific task for A and receive in return a predetermined sum of money, A first puts this sum of money aside so that B does not have access to it. If B performs the task, A can release the money. If after seven days the parties are not agreed that the task has been performed in full, an independent judge can be called in to give his/her ruling (Buterin 2014). This attempts to address the inability of blockchain-based systems to make valid statements about the real world. However, it does nothing to solve the problem of whether the data is correct as, ultimately, the independent judge is just another intermediary.

Smart contracts need not always be concluded between parties who already know one another. A situation in which person A wants to sell 100 units of a commodity X to someone who is offering him/her 50 units of a commodity Y also represents a smart contract (ibid.), even though all those who will ultimately be involved in the contract are not named in it.

The performance of smart contracts follows the same logic as other transactions that use blockchain technology. When contract conditions are fulfilled, the ledger is updated and visible to all the nodes in the network (Wiedmaier 2017: 18). In theory, the people who previously dealt with 'contracts' of this kind, including lawyers and bank staff, need no longer be consulted. According to BlockchainHub (2017), the advantage of smart contracts is that they can reduce the transaction costs for coordination and enforcement and create transaction security. Stipulating in advance that a buyer can conclude a contract only if he/she is in possession of sufficient funds to cover the price would reduce or even eliminate the risk of non-payment (Scholtka and Martin 2017: 117). However, it might also considerably reinforce trends towards social exclusion.

In theory, therefore, smart contracts can simplify automation and streamline and speed up processes. However, a smart contract is only as smart as the people who code it (BlockchainHub 2017). Moreover, smart contracts should not be confused with legal contracts until such time as the technology has reached maturity and the legal framework has been adjusted to include them.

DApps are decentralised applications in which all actions from the app's substructure to the user interface run on a blockchain. They operate in a similar manner to smart contracts (Voshmgir 2016: 14), but differ from them in two ways. While smart contracts are made between a specific number of people, DApps have an unlimited number of participants. In addition, whereas smart contracts have so far generally related to finance, the scope of DApps is considerably broader. Smart contracts allow DApps to connect to a blockchain; they are components of DApps.

DApps are open-source applications; no single organisation is able to assert legal claims to the 'contracts' or control them (PwC 2016: 6). Similarly, DApps are subject to a decentralised validation mechanism and their data is stored decentrally and cryptographically. To date there are no decentralised user interfaces for DApps so only the technical background is based on smart contracts. BlockchainHub's goal is to become independent of third-party user interfaces in order to create a completely decentralised and autonomous application. A DApp uses cryptographic **tokens**, i.e. cryptocurrencies (coins) such as Bitcoin, Ether or other altcoins, for example, to reward supporters of the system (e.g. miners) for their contributions.

The acronym **DAO** stands for 'Decentralised Autonomous Organisation'. DAOs are a new form of organisation whose articles of association take the form of a smart contract. They are therefore the most complex form of smart contract (Voshmgir 2016: 14). The legal status of DAOs remains unclear. Changes can be made to the organisation by voting in which all token owners can participate (PwC 2016: 36). Their voting rights are based on the amount of tokens they hold. This can be viewed as problematic, 'one person, one vote' being more or less replaced by 'one token, one vote'. Though DAOs represent an entirely new form of organisation, they themselves – at least in their current form – have no artificial intelligence and cannot therefore write code or develop products (ibid. 36). In contrast to conventional organisations, they involve an undefined number of people interacting with one another according to a protocol specified by a code (BlockchainHub 2017). The advantage lies in the fact that there are no 'principal-agent dilemmas'[14] caused by information symmetries. Specific tasks that require specialist knowledge are performed by selected participants or external specialists (Voshmgir 2016: 14). DAOs are financed by **initial coin offerings or ICOs**, a sort of decentralised crowdfunding. Once a DAO has been set up, it is independent of its developers and cannot be influenced by external forces, making it incorruptible (BlockchainHub 2017). There is no hierarchical management and the rules that generally apply in a business are applied quasi digitally.

The most famous project based on the Ethereum blockchain was an organisation by the name of 'The Dao'. Formed in 2016, it found itself embroiled in a scandal after only a few months. The idea underlying The DAO was that anyone with internet access could buy DAO tokens and so vote on which projects should be financed. All stakeholders could also vote on the introduction of new rules and the removal of certain individuals from office (Finley 2016). After only a few weeks, it became apparent that there was an undetected error in the code. A hacker eventually spotted this security loophole and managed to extract USD 60 million from the system. This demonstrated a number of problems. Firstly, the incident made it clear that even excellent programmers can overlook serious errors in their code. Secondly, it confronted programmers with a dilemma: either they accepted the incident and the loss of the USD 60 million or they intervened in the network and altered the protocol. The majority of the community voted to change the transaction protocol and the money was returned to its legal owners. However, this break in the code triggered outrage among those who had voted against the intervention (Hertig 2017). Who is permitted to make changes in code is a key factor in assessing whether blockchain systems are centralised or decentralised.

Faith in the stability of Ethereum's cryptocurrency ether was also affected by a hoax message on the network. In June 2016, fake news spread online that Buterin had died in a car accident (Quartz 2016). Though he is neither the owner of Ethereum nor holds any office within it, he is seen as the mastermind behind it. Ethereum lost USD 4 billion in market value in a few hours, showing the potential instability of a decentralised system that claims to be independent of central authorities and figures. Though it is not strictly necessary to establish functions such as smart contracts or DApps for a system's cryptocurrency to be stable or for its price to increase constantly, a certain number of miners is required to maintain the system and guarantee security. Without the corresponding financial compensation there would be no incentive to stabilise the network. On the other hand, Buterin was able to demonstrate that he was safe by his cryptographic Ethereum signature, something he would not have been able to do so easily and without risk of forgery by posting on social media or in a video. The price recovered significantly, but remained volatile.

[14] Principal-agent theory: In a relationship between two parties, one party has an information advantage over the other. This lack of symmetry leads to inefficiencies in contract performance. If the principal is unable to monitor the agent's actions, the agent can act in secret (hidden actions). Both can consciously withhold information (hidden information) and the abilities and skills of the agent are not common knowledge (hidden characteristics) (Original German definition from Gabler Wirtschaftslexikon 2017).

Fig. 5: The ether-euro exchange rate from March 2017 to February 2018[15]

2.4 Private vs. public blockchains

Bitcoin and Ethereum are public blockchains. Public means that anyone with access to the Internet can access their data and services, that there is no central organisation and that the identities of the participants are anonymous. Validation is (currently still) either by the proof-of-stake or the proof-of-work consensus method (cf. Sections 2.1 and 2.2). In contrast to these are private blockchains, to which access must be bought by paying a fee or purchasing hardware or software, for example (Sieverding and Schneidewindt 2016: 2). Validation is generally effected by predetermined users and the identities of the participants are therefore generally known. The question of whether or not private blockchains relinquish some of the features claimed to represent essential advantages of blockchain technologies is more than legitimate.

Private blockchains were first developed at the initiative of businesses in the financial services sector. There are banks, for example, that provide a person with access to the blockchain once he/she has been clearly identified. The fact that there is no need to apply a complex, entirely decentralised validation scheme means transactions can be made even more quickly and at lower cost (PwC 2016: 9). Using private blockchains it is possible for established businesses such as banks and stock exchanges to defend their market power by routing customers to their own private blockchain for which they can charge fees. It is, however, also conceivable for new businesses to ‘capture’ market power with innovative applications using blockchains that they control.

Moreover, the tamper-proofness and immutability of the blockchain protocol are brought into question by the fact that it is, in principle, generally possible for the rules to be changed at any time by the higher-level authority. Whether the transaction history can be consulted and a certain system transparency is maintained is decided at the discretion of the controlling business. Private blockchains have more in common with conventional cloud structures (Sieverding and Schneidewindt 2016: 2). Cloud applications are based on central data storage with data being

[15] Source: Finanzen.net 2018b

stored via the internet on servers whose location is irrelevant (Voshmgir 2016: 9). Behind cloud providers such as Google Drive, Dropbox or iCloud are profit-seeking business, which have been shown to cooperate with intelligence services and offer no personal privacy.

As the primary role of applications used in the energy sector is to benefit consumers, ideally they would promote the setting up of public blockchains and limit the scope of action of private blockchain providers. Private blockchains may, but are by no means required, to guarantee transparency; public blockchains are completely transparent, open-source applications. Having said that, we can expect successful applications and results more quickly if blockchains are initially developed as private or syndicated blockchains (Interview 2).

A syndicated blockchain, generally comprising the leading businesses in a sector, lies somewhere between a private and a public blockchain in terms of its features, leaning further towards one or the other depending on its individual design. Blockchain technology offers enormous potential for large commercial applications, particularly in terms of standardisation, automation, process rationalisation and cost reduction (Drescher 2017: 247). There is still some doubt, however, as to whether public blockchains will be able to establish themselves once a few businesses have secured their market positions by means of private or syndicated blockchains.

2.5 Research and application

A literature review carried out by Cao et al. (2017) examined publications pertaining to blockchain technology in relation to origin, type of analysis and thematic focus. In the literature from China, 125 of a total of 188 articles fell under the ‘financial services’ heading. The fields of digital currencies and banking and Internet finance were central along with other themes including payment, billing and supply chain finance. 99% of the articles studied were qualitative in nature, a phenomenon explained according to the authors by the fact that blockchain research in China is still in its infancy. In their analysis of the English-language literature, they identify over 41% of articles as offering quantitative research results (Cao et al. 2017: 115). Here, too, at 70%, the majority of articles on the subject of blockchain technology related to the financial services sector.

Another relevant finding was that interest in blockchain technology did not really start to pick up speed until 2016. 2014 and 2015 saw the publication of fewer than five articles in China, a number which rose to 180 in 2016 (ibid.: 110). The same emerges from the research, based primarily on European publications and – with a few exceptions – written by pioneers in the field, on which this work is based.

On the ground, too, applications in the financial services sector dominate. While many other fields are still at the pilot project phase, businesses in the financial sector have already recorded their first successes in implementation and operation (PwC 2016: 9 et seq.). They come in a range of different areas of application.

The start-up Onename, for example, creates virtual, tamper-proof ID cards by means of which users can provide proof of identity. Possible developments include digital driving licences and ID cards (PwC 2016: 9). Bitnation, a Swedish company, stores public-domain administrative procedures such as insurance policies and certificates on a blockchain. Bitnation marriages have been officially recognised since 2015. Since blockchain technology is regarded as tamper-proof, electronic elections are another possible application, though significant reticence continues to prevail in Germany with regard to digital elections for very good reason (Simmchen 2017). A pilot project which uses blockchain to administer social welfare benefits and allow the government to consult them has been launched in Great Britain. There are also numerous projects dealing with the authentication of artworks and diamonds and the protection of intellectual property. In an attempt to prevent their work being pirated, some musicians still only make their music available via blockchain-based platforms (cf. Ujo Music 2017). Even the United Nations uses blockchain technology, e.g. in projects organising the provision of food in Jordanian refugee camps (FAZ 2017). Different observers will undoubtedly reach different conclusions as to the utility and desirability of the blockchain applications described above.

3 Relevance for energy transition

3.1 The German energy landscape

The energy transition poses new challenges for society, politics and the economy. While it continues to enjoy a high level of acceptance in Germany, as opinion polls have repeatedly shown, and is often celebrated as a success story on the international stage, it also attracts criticism from various quarters. Although few now question the principle of energy transition, some find progress too slow while others consider it too fast. On one side are the very many energy transition advocates for whom the pace of development of renewable energies in Germany is too slow. They argue that emissions in Germany are not dropping sufficiently quickly to achieve German climate protection targets, let alone the even more ambitious goals set out in the Paris Agreement, which is binding under international law. Between 2015 and 2016, for example, the percentage of renewable energies in gross electricity consumption rose by only 0.2 percentage points – albeit due in part to a year of relatively low wind and sunshine – to reach 31.7% in 2016, a level of progress described by the German Environment Agency (*Umweltbundesamt*) as “only moderate” (Umweltbundesamt 2017a). On the other side stand those energy groups whose core business still lies in the production of ‘brown energy’ and declining parts of the industry. The general public – increasingly though still insufficiently involved in the debate – is also starting to find its voice. Many are calling for all coal-fired power stations to be shut down as quickly as possible, while others seek to forestall the development of wind farms or slow down the phasing out of coal.

Though expansion of the transmission grid is now progressing more quickly, it remains sluggish and new forms of management are required to deal with the fluctuating supply of electricity from renewable sources. One of the major tasks will be to design grids capable of incorporating an increasing number of private households with lower installed generating capacities. Germany now has more than 1.5 million solar energy systems, some 27,000 wind farms and approx. 9,000 biogas plants that feed into the public grid (Agora Energiewende 2017: 19). Electricity grids therefore need to be remodelled to take into account the trend towards decentralised and regional electricity generation.

The selection of sites for renewable energy plants is influenced by both socio-political and physical considerations. The availability of sunshine and wind along with a raft of other factors such as population density, local economic development, legal requirements and, last but not least, the Renewable Energy Sources Act (*Erneuerbare-Energien-Gesetz, EEG*) all play a role (Ropenus 2017a: 59f.). Though there is a correlation between optimum location and installed capacity from renewables, they are by no means identical.

The connection of some 89% of renewable energy plants to the distribution grid means that the power flow changes with greater frequency, with “bidirectional load flows [causing] a “two-way flow” (ibid.: 64). Similarly, the simultaneous input of large volumes of power from both renewable energy and conventional power plants creates an increased risk of grid congestion. This can be dealt with using a range of different tools including short-term redispatching measures and feed-in management, both particularly relevant today. Redispatching is a technique by which transmission grid operators adjust the supply from conventional power stations by modifying local distribution patterns rather than the total amount of energy supplied. Redispatching measures increased almost tenfold between 2010 and 2015, generating costs of over EUR 400 million in 2015 (Bundesnetzagentur 2016: 8), only to drop again in 2016/17. Under feed-in management measures the output of both **CHP** stations and renewable energy plants is limited, though in principle feed-in priority is given to renewable energies. This can prove costly, for electricity must be paid for whether it is supplied or not. On the other hand – and in contrast to China where the amount of renewable electricity output curtailed is of a quite different order – it is precisely this cost which provides grid operators with a strong incentive to feed in as much renewable electricity as possible and to invest in facilitating measures and promote long-term options such as power-to-X.

A large number of these output limiting measures are implemented in the extra-high voltage grid. It would, in principle, be possible to establish several different price zones, thereby creating an incentive for controlling both future production and future consumption. Germany currently consists of one uniform price zone in which the costs – of grid expansion, for example – are socialised and the actual physical grid situation is not pictured (Ropenus 2017a: 64; Mengelkamp et al. 2017a: 1). The establishment of a regional energy market structure, which might create additional incentives for the development of renewables, is a question of federal German policy (Graichen and Zuber 2017: 88 et seq.), though the coalition agreement negotiated by the CDU, SPD and CSU parties opposes it. One argument claims that highly fragmented energy systems are economically less efficient and that the result of small markets with dwindling competition can be to strengthen the individual market power of a few energy companies. It must also be considered that differentiated pricing could result in socially undesirable effects as wealthy private households and manufacturing businesses opt to set up in regions with low electricity costs. Last but not least, regions such as Bavaria with little potential for particularly advantageous renewable energies – in particular wind power – could become the losers in the energy transition.

Consumers are increasingly critical of high electricity prices caused in part by the manufacturing exemptions in the German Renewable Energy Sources Act. While in China, for example, businesses subsidise electricity costs for the consumer, in Germany individual consumers subsidise the electricity costs of the energy-intensive manufacturing sector. If renewable electricity is marketed under EEG terms, it loses its green electricity status, a measure intended to prevent double marketing. By contrast, there are regional certificates that identify electricity as being from a particular region and can help improve acceptance of the energy transition in that region (Graichen and Zuber 2017: 89).

Finally, despite the fact that it has always attracted the lion's shares of media attention, the electricity sector is just one element of energy transition. If the energy transition is to be successful, it will need to create intelligent connections across sectors, forging close links between electricity, heat, gas, manufacturing and mobility. This means the electrification of the heat, manufacturing and mobility sectors with power from renewable energies. Tools frequently discussed with a view to achieving this goal and avoiding grid congestion include smart grids (cf. section 1.2 and Ropenus 2017b: 101).

3.2 Opportunities for using blockchain technology in the energy sector

In contrast to the financial services sector, many players in the energy sector are tied to physical infrastructures such as electricity grids. The issues at stake here are more complex than storing data and transferring money.

Areas of the energy sector in which blockchain technologies could, in principle, play a role:

- Trading in renewable energies
- Trading in renewable gas and district heat
- Metering services
- Meter-reading and billing processes
- Grid-related transactions
- System status logging
- Trading in CO_2 and green electricity certificates
- Electromobility charging and billing processes
- Smart home applications
- Cryptocurrency-based payment systems

Fig. 6: Areas of the energy sector in which blockchain technologies could, in principle, play a role[16]

As new technologies need to meet the highest security and performance requirements to avoid possible power failures, the smaller energy companies in particular have in the past been somewhat reticent in their response to new technological trends involving blockchain projects (Krauskopf 2017: 20). The larger, old-established companies, on the other hand, have been running their own blockchain projects for some time and the "technology's promising potential is therefore threatening to founder in these old structures" (Hesse 2017a). CEO of Grid Singularity and developer of a platform for exchanging decentralised energy data Ewald Hesse nevertheless expects to see 200 to 400 new start-ups interested in a blockchain application emerge in the energy sector in 2018.

3.2.1 Pilot project: the Brooklyn Microgrid

Microgrids, which generally comprise a small group of energy suppliers and consumers, some of which may be prosumers, could play an important role in a more decentralised energy supply system. Microgrids can increase the reliability of the electricity supply by continuing to supply

[16] Source: cf. Sieverding und Schneidewindt 2016: 2 et seq. and PwC 2016: 16 et seq.

consumers with locally generated electricity when the higher-level grid fails (Mengelkamp et al. 2017a: 2). They can operate both in connection with the higher-level grid and – for a limited time at least – in 'island mode' as a self-contained and independent solution. Microgrids are also characterised by a high number of small energy producers with an installed capacity of below 200 kW, generally owners of solar energy systems. The electricity they produce is generally consumed by the producers themselves or bought by consumers located in their immediate geographical vicinity. According to Graichen and Zuber (2017), electricity can be termed regional when "final consumers are supplied from power stations located within a radius of 50 kilometres around their post code areas" (p. 89).

The integration of blockchain technologies can facilitate the trading of electricity for very small grids with two or more players and cost-efficient sales processing. The first and best known project in the world to use a blockchain application in an electricity grid was the Brooklyn Microgrid project (BMG), which processes peer-to-peer (P2P) energy transactions. Located in New York, it is run by the start-up technology consultancy LO3 Energy.

Brooklyn has a physical microgrid, via which electricity is distributed, and a virtual microgrid, which connects the various members of the network through an information system. The physical grid is linked to the higher-level grid by a small number of connection points and so can be disconnected from it in an emergency such as a power failure in the higher-level grid. This connection also offers security of supply for the microgrid in case of problems in the grid itself. Both electricity generation and electricity demand are measured automatically by smart meters. Based on this information, individual member forecasts are created and surplus supply or demand is calculated and sent to all blockchain actors (Mengelkamp et al. 2017b: 3). Each household has a personal account containing information on energy consumption and generation (and in the future possibly storage) and on their (financial) account balance. Bank money can be transferred and withdrawn from the personal account at any time provided that the account balance permits the signalled transaction.

Electricity is traded via an auction system to which buy and sell orders are submitted. Consumers indicate their upper price limit for their preferred energy source and prosumers specify the minimum price at which they are willing to sell their electricity in the microgrid. Distribution then takes place on the merit-order principle: the highest bidder is supplied first, followed by the second-highest bidder, etc. The last bid is the **market clearing price** for the time slot in question. In the BMG, anyone not supplied with electricity by this distribution mechanism receives electricity from other energy sources, e.g. fossil fuels (Mengelkamp et al. 2017a: 7). In a system with sufficient renewables, grid and storage capacity, this minimises the demand for fossil fuels.

Initially, all local trade is purely virtual. The sums of money bid in the auction leave the buyer's account and are initially held as security with the blockchain acting as a sort of custodian to guarantee future transactions. After clearing, information on the matched electricity supply and demand volumes and the market price is sent via the blockchain to all the actors involved. Payments are made automatically via smart contracts and the security money is released.

The goal of this EMTS or Energy Management Trading System is, on one hand, to automatically guarantee the supply of energy whilst, on the other, implementing a special bidding strategy. An individual forecast is created based on real-time demand, production (and in the future possibly storage) data and a corresponding bidding strategy is developed. A simple EMTS, for example, would sell electricity whenever the price fell beneath the set limit. A more sophisticated EMTS also allows socio-economic factors such as a preference for electricity from renewables to be taken into account. To automate trading in electricity the EMTS must have access to the participants' accounts so that it can issue bids on the basis of individual utility functions (Mengelkamp et al. 2017a: 5), though this is not essential for the market to operate.

Using blockchains in the microgrid, neighbourhoods themselves are able to decide on and influence the composition of their electricity. In this particular case, a free user-friendly app that models various scenarios was developed and initially offered on a trial basis without obligation. Its functions have now been extended so that residents can determine collectively, for example, where the next solar power system should be installed. The BMG app also serves as an information tool providing details of current projects and updating production profiles (Brooklyn Microgrid 2017).

In the case of the Brooklyn Microgrid, the market mechanism was hardly used during the three-month test phase, with only one consumer and one prosumer trading electricity. In addition, the electricity price was fixed from the outset at the traditional renewable energy price in Brooklyn. The technology has since been developed further and, according to developer Scott Kessler from LO3 Energy, is now fully engineered. All that is missing in his view are new business models and a supportive regulatory framework (Kessler 2017).

In an example such as this, blockchain can both reduce the consumer's electricity consumption and costs and create incentives to invest in the renewable energies on which the system relies. Local price signals are combined with willingness-to-pay data for individual electricity customers and smart domestic appliances can be switched on or off – taking into account the needs of consumers – when predefined upper and lower price limits are reached. While it provides greater transparency than conventional electricity supply models, the system nevertheless protects personal privacy by restricting access to transaction data to those involved in the transaction – at least until the data is passed on. LO3 claims that it can integrate any type of smart device into the virtual network and it would therefore be possible to bill the electricity consumption of electric vehicles or manufacturing plant using the blockchain (ibid.).

Crucial in terms of its benefit for the energy transition is the fact that the application promises to send renewably generated electricity where it is most needed or can be used most efficiently automatically, quickly and – thanks to the blockchain – at very low transaction costs. In the event of an overload risk on the electricity grid, for example, price incentives could be used to encourage customers to use electric charging stations or heat pumps, thereby obviating the need to restrict renewable electricity generation. In general, however, electricity would be used primarily at times when demand was low but the availability of renewable electricity was high. This system allows surplus renewable electricity to be used in a manner that is efficient for the economy as a whole. The bottom line is that it permits the use of more renewably generated electricity so that less electricity needs to be produced by conventional means.

3.2.2 Other projects in the energy sector

The Brooklyn Microgrid became an inspiration for innovative energy start-ups and blockchain enthusiasts and was followed by a number of similar projects around the world that were often microgrid- and blockchain-based.

In Germany, for example, TenneT, one of the four transmission grid operators supplying an area stretching from north-western to south-eastern Germany, has worked with Sonnen, a home storage device manufacturer from Oberallgäu in Bavaria, to integrate decentralised battery storage devices into the grid. This pair are the first to use a home energy storage system for redispatching measures based on blockchain technology. The pilot phase started in November 2017 and is due to run for six months (TenneT 2017). A group of networked storage devices is managed according to grid status, avoiding transport congestion by instructing battery storage devices to release electricity to the grid. Inversely, the storage network can also take in surplus electricity in a matter of seconds (ibid.). Redispatching measures are costly, and limiting the output of wind farms in particular costs grid operators several million euros a year (Enkhardt 2017). Storage devices can compensate for short-term fluctuations in the electricity grid and absorb the kind of production peaks generated in strong winds. These storage devices also provide a buffer, in turn reducing the need for transmission grid expansion and so achieving further cost savings in certain circumstances.

On this model, blockchain could be used to control power stations decentrally or supra-regionally. Storage device owners benefit from making their devices available because they are rewarded with electricity at marginal costs close to zero. In the future, other consumers will pay lower grid charges because redispatching measures will be less frequent. Conventional power stations will continue to be solicited by transmission grid operators if they need to increase their output to balance supply and demand. If large power stations are shut down as a result of climate policy, one possible strategy is to integrate capacities from smaller plants. Given the high number of renewable energy plants, blockchain offers a quick and easy way of providing this flexibility through automation. The pilot phase of the TenneT/Sonnen project will examine whether blockchain technology can help it achieve its stated aims and find a scalable solution.

At the end of 2017, Wuppertaler Stadtwerke and energy trading company Axpo launched a blockchain trading platform for renewable electricity on which consumers can choose their energy producers themselves. These producers in turn benefit from increased willingness to pay, a factor which will become increasingly relevant when, from 2020, EEG funding runs out for many wind turbines and commercial revenues cease to cover operating costs in all scenarios (Wuppertaler Stadtwerke 2017). Blockchain technology also prevents a kilowatt hour of electricity being sold twice, thereby creating transparency in accounting data. All that remains for Stadtwerke to do now is take care of formalities such as billing (Flauger 2017).

Grid Singularity, an Austrian company, offers a platform for DApps which seeks to serve all levels of the value creation chain by linking up grid operators, energy producers, regulators and consumers (Grid Singularity 2017).

A PwC study (2017) provides a diagram showing what the integration of blockchain technologies into electricity grids and a decentralised energy supply might look like. The left-hand side of the figure illustrates a centralised system of the type in operation today, while the right-hand side shows the reduction in the number of actors achieved by the integration of blockchain technology.

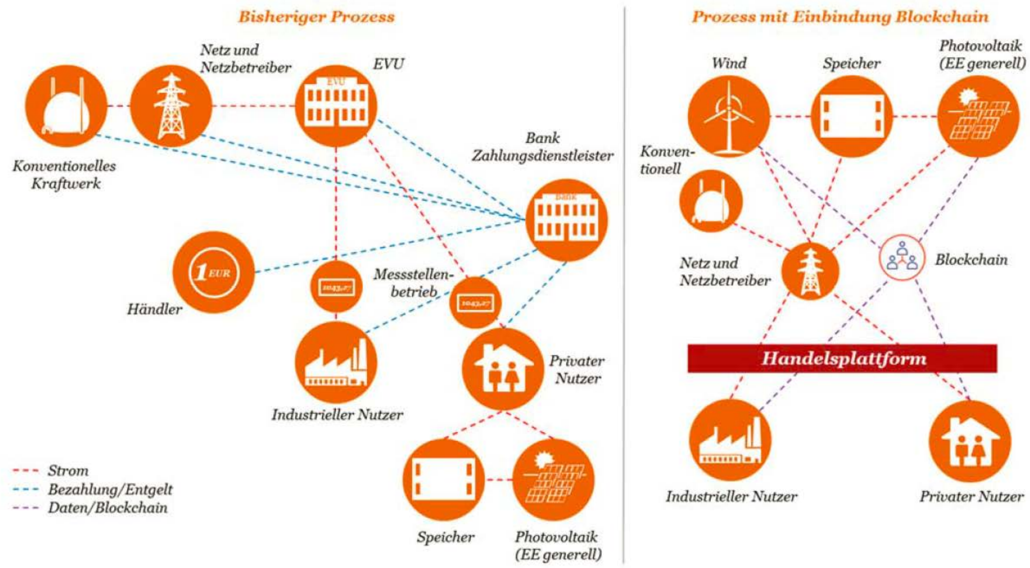

Fig. 7: Transformation of market structure following the introduction of a decentralised transaction model[17]

German start-up Slock.it works in partnership with RWE to offer automatic charging stations for electric vehicles. A vehicle owner parks up and goes shopping while the vehicle is logged and charged automatically at a charging station and billed automatically via blockchain (PwC 2016: 18). Similarly, the start-up Motionwerk has developed an app that allows electric charging stations to be shared using blockchain. Anyone can register their own charging station, set a rate and opening times and then share it with others. The blockchain comes into play at the billing stage, making it possible to consult the payment history stored on the blockchain (Kloth 2017a). In the past, private electric vehicle owners who charge their cars using their domestic electricity supply have not had their own rates. Using blockchain it is now possible to apply different rates within a home grid (ibid.; Strom DAO 2017).

In the view of recently formed company Strom DAO, the development of electromobility need not necessarily place an additional load on the grid. It believes that electric vehicles could even help to balance out the fluctuations caused by renewables if they were charged primarily at times when significant amounts of regional electricity from green sources were available. Strom DAO's vehicle-charging electricity rate creates economic incentives by paying out bonuses of up to 5% per KWh to those who charge their cars during periods of high renewable energy supply. The system operates using blockchain technology.

4 Strengths and opportunities

Sections 3.2 to 3.4 outline a number of advantages of the application of blockchain technologies for the energy transition. The chapters below consider further significant strengths and opportunities provided by blockchain-based technologies in the energy sector.

Blockchain applications offer opportunities in terms of both process applications, where improvements in efficiency are possible, and specific applications leading to the creation of new markets (Interview 1). Blockchain technologies may well render intermediaries in various sectors

[17] PwC 2017: 18

superfluous. They may also lead to the emergence of new business models in the spirit of creative destruction (Schumpeter).

4.1 System integrity and the replacement of intermediaries

In theory, any central authority can modify register entries and refuse to perform transactions. Though this problem may not be particularly pressing in constitutional democracies, centrally stored data can nevertheless be hacked or fall into the hands of undemocratic parties or individuals. Unlike human beings, software treats everyone as equals, is interested only in system coherence and is invulnerable to corruption, embezzlement or informal arrangements (BlockchainHub 2017, Berentsen and Schär 2017: 43). On the other hand, it is important to remember that the amount of computer power required might also lead to new forms of market power concentration.

Blockchain does not so much destroy the role of the intermediary as replace it by a “digital and strictly rule-following middleman” (Drescher 2017: 242). Faith in organisations run by people is replaced by faith in a software program defined by codes. It is important to remember, however, that the software itself has been designed by humans. In the energy sector the loss of importance suffered by intermediaries will affect primarily banks, electricity exchanges, lawyers and metering service providers but also energy suppliers and grid operators. The fewer intermediaries involved in a transaction, the fewer interfaces there are between individuals and institutions where messages can go astray or be falsified.

It is currently impossible to predict whether and to what extent blockchain technologies will result in job losses. All pilot projects to date involve only a small number of participants; there have been no mass applications. It is undoubtedly true, as with the issue of employment and energy transition, that new jobs will be created, contributing to regional value creation, particularly at local level (Mengelkamp et al. 2017a: 6). The possibility of job losses should nevertheless be taken very seriously.

4.2 Transparency

Provided they are designed as public rather than private systems, blockchains provide a high degree of transparency. Physical monetary units such as coins or banknotes have a high degree of anonymity and there is generally no record of who holds them at any given time (Berentsen and Schär 2017: 39). Virtual monetary units can solve this problem – which may also be seen as an advantage in some cases, e.g. authoritarian states – but conversely also face a ‘double-spending’ problem. Digital data can be copied with no great difficulty. This copying is the digital equivalent of printing counterfeit money. This can become problematic In P2P systems, for example when there is an asymmetry of information and if one person transfers his/her property to another person more than once, for example (Drescher 2017: 51 et seq.).

In the blockchain system, by contrast, this problem cannot occur. If a person wants to transfer monetary units to two different nodes simultaneously, both messages will be distributed simultaneously in the network. As the two messages contradict one another, only one transaction will ultimately be integrated into a block and added to the chain (Berentsen and Schär 2017: 57 et seq.). Even if the high level of transparency is occasionally and quite rightly regarded as detrimental to the technology (there may ultimately be data which should not be publicly accessible), the possibility of disclosing data that was previously kept secret is an interesting new feature. In many cases, whether transparency is ultimately deemed useful or detrimental will depend on societal power structures.

How and to what extent transparency is respected will undoubtedly depend on the configuration and the type of data prevalent in the sector in question. Opportunities may well open up for civil-society organisations, for example, which take the social and ecological aspects of economic activity into account. On the other hand, it is also important to note however that many transactions on the darknet are processed using blockchain. In this case it tends to support a lack of transparency.

In the energy sector, green electricity certificates of origin can be used to ensure that green energy really comes 100% from renewable energy sources or that it guarantees a certain percentage of investment in new plants. In the past it has been possible for businesses to use certificates to ‘greenwash’ the coal-fired electricity they produce. Here, too, blockchain technology offers transparency guarantees that mean consumers can be sure their electricity is ‘genuinely’ green (Sieverding and Schneidewindt 2016: 3).

4.3 Increasing efficiency and cutting costs

Blockchain can facilitate efficiency measures and so realise cost-cutting potential. It is never offline and can be used to process transactions 24 hours a day, seven days a week (Drescher 2017: 193). Automation means that personnel costs can be cut, for instance. Today transferring money from one country to another involves up to five intermediaries, each of whom takes a certain amount of time to carry out his/her part of the process and generally demands a fee for doing so (Drescher 2017: 21). Similarly, the use of blockchain eliminates fees and profits for companies which previously operated as intermediaries (PwC 2016: 34). Depending on the sector, it also eliminates the cost of meter reading and billing processes, payment and debt collection procedures, bank-processed payment transactions, contract negotiations and certification (ibid.; Sieverding and Schneidewindt 2016: 2).

There are many ways in which businesses in the energy sector can use blockchain technologies to make savings. Blockchain has the potential to be an efficient data management system which processes transactions quickly and easily. It can be used to save process costs and model internal charging processes simply (Interview 2). It can also be financed by means of initial coin offering, thereby reducing and even eliminating capital costs.

Energy producers can form regional energy cooperatives to market electricity to end consumers and so potentially achieve higher margins thanks to increased willingness to pay for regional products (Wuppertaler Stadtwerke 2017). This may become particularly relevant as EEG funding starts to run out. Smaller producers, too, will be able to sell their electricity at a profit as blockchain makes it possible to trade small volumes (Mengelkamp 2017a: 3). Local trading in electricity in microgrids using blockchain means that any profits generated stay in the local community, support regional value creation and can be reinvested in additional renewable electricity generation, for example (ibid.: 2).

It is still difficult to gauge precisely what the effects this cost-cutting potential might have on consumers in the energy market. Current assessments indicate that though cost-cutting potential does exist, it does not involve significant sums (Sieverding and Schneidewindt 2016: 2). As the majority of the domestic electricity tariff consists of taxes, levies and charges (approx. 54%), grid fees (approx. 24%) and purchase and distribution sales (approx. 21%) will remain the two price levers in the economic sphere (dena 2016: 25).

Though decentralised microgrids in which households trade in electricity amongst themselves could slightly reduce the need for costly transmission grids, the development of many decentralised plants, distribution grids and storage technologies will generate additional infrastructure costs just as the necessary actuator and sensor technology will increase electricity costs.

The scale of potential savings in the field of purchasing and sales will depend on the level of profit margins realised by the blockchain service providers. Although blockchain is an open-source technology, there is no decentralised user interface. For the next few years at least electricity customers will have to rely on the expertise of intermediary businesses to generate bills and carry out other formalities for them.

All the same, increasing decentralisation may be accompanied by even greater prosumer independence from market-dominating energy groups. More competition in the energy market may then lead to lower prices. In addition, the automation achieved by means of blockchain applications would make it easier to control individual consumption and adjust electricity consumption to variable prices, thereby achieving cost reductions (Wiedmaier 2017: 50). Here the major cost-cutting potential lies in the increased use of renewable energies, which could lead to the generation of electricity at marginal costs close to zero. The only factor limiting the possibilities outlined above is that this cost-cutting potential will only be able to take effect if an IT infrastructure complete with digital smart devices is already in place and can be used at minimal cost (dena 2016: 23).

On the issue of whether blockchain technologies can be a success factor in the energy transition, there is still no clear answer, though there are some clues. In some cryptocurrency systems (e.g. SolarCoin) prosumers are remunerated in the relevant currency for the installation of renewable energy systems. This can make it more attractive to install a solar power system (Wiedmaier 2017: 49). Blockchain technology could in certain circumstances even help to promote the development of decentralised energy systems (Interview 1). Some authors also see this decentralisation as representing significant potential for democratisation since decentralisation processes invite participation and encourage consumers to participate individually in the energy market (e.g. Rifkin 2015).

5 Weaknesses and threats

In Chapter 1, on the topic of smart grids, we referred to the risk of eroding the solidarity currently still provided by the wealthy – particularly if they were really to seek complete self-sufficiency. This chapter considers other key weaknesses and threats of blockchain-based technologies in the energy sector.

5.1 Energy intensity

In the final weeks of 2017, allegations that cryptocurrencies such as Bitcoin were “energy guzzlers” (Frankfurter Rundschau 2017) and a “threat to global energy transition” (Spiegel Online 2017a) received widespread media attention. In the course of a “Bitcoin-hype” (Süddeutsche Zeitung 2017) triggered by a rapid rise in the price of the digital currency, the energy consumption of miner networks came under the microscope.

Economist Alex de Vries, who has modelled various scenarios on his Digiconomist.net website and been denouncing Bitcoin – and more recently Ethereum’s – huge demand for electricity for years, estimates the total annual electricity consumption of the Bitcoin computer network at 32.68 TWh, more than countries like Bahrain or Ireland use in a whole year. A family of four in Germany uses approximately 0.000004 TWh of electricity per year (Pannewick and Herbst 2017). Breaking Bitcoin's total consumption down into single units gives an electricity consumption of 235 kWh per transaction, enough to light a low-energy light bulb for over 20,000 hours. The computing power expended to buy a cup of tea is clearly disproportionate to the EUR 2.00 paid for the hot drink in bitcoins. De Vries' calculations are based on the assumption that miners spend some 60% of their income on energy bills and use a range of more or less powerful hardware.

While Marc Bevand has criticised de Vries's calculations, estimating Bitcoin's total electricity consumption at a figure of between 4.12 and 4.73 TWh per year, media websites like ARD and Spiegel Online continue to point to the Digiconomist calculations.

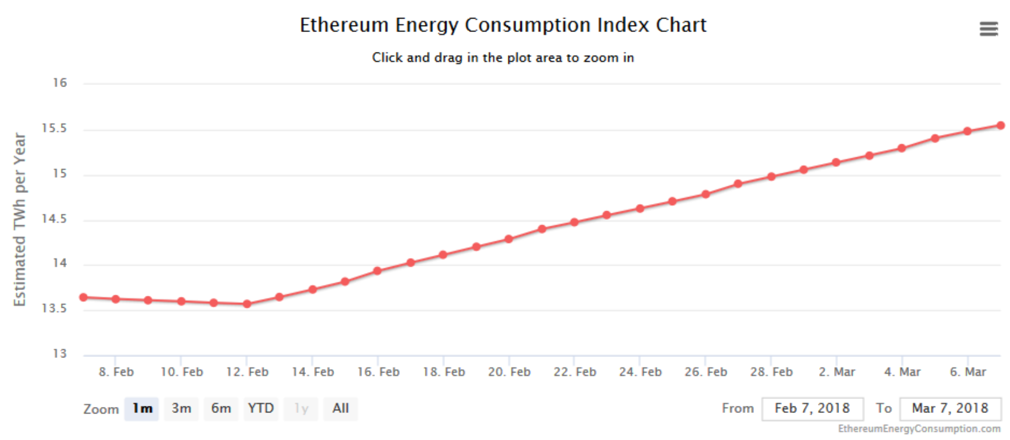

Fig. 8: Increase in Bitcoin electricity consumption from early February to early March 2018[18]

The website has made the same calculations for Ethereum. While Ethereum is less energy intensive than Bitcoin, both per transaction and across its network, it nevertheless consumes much more electricity per transaction than VISA, for example. The figures indicate that Ethereum uses approximately one quarter of Bitcoin's energy consumption.

[18] https://cloud.highcharts.com/embed/ywoqita/ (last downloaded on 12 December 2017)

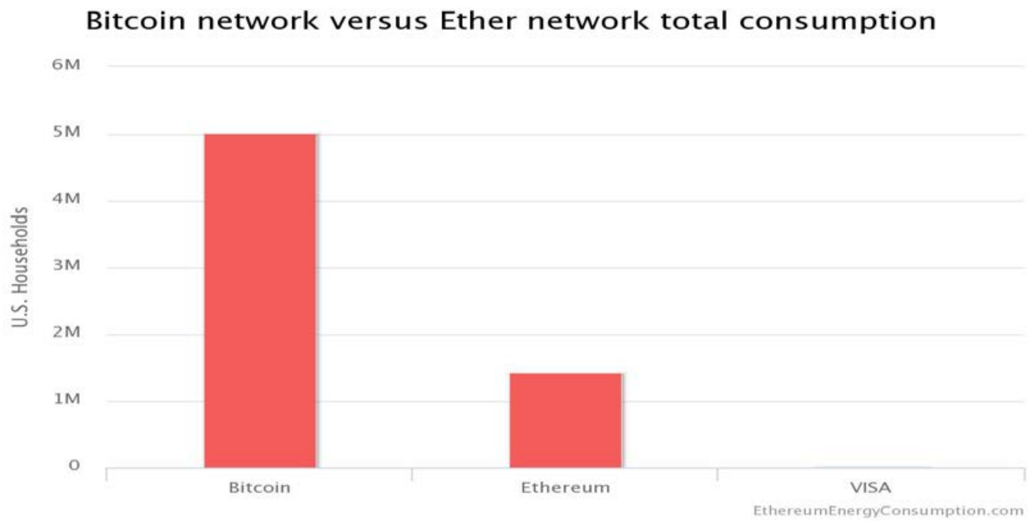

Fig. 9: Total electricity consumption of the Bitcoin, Ethereum and VISA networks per annum in relation to the electricity consumption of an average US household (analysis of the VISA network excludes banking operations)[19]

The mining of coins generates a considerable amount of CO_2 depending on the country of origin. A mining location in Mongolia that sources its electricity from a coal-fired power station releases up to 13,000 kg CO_2 per bitcoin mined. That can be up to 40,000 kg CO_2 per hour (Malmo 2017a). In the German energy mix, a total electricity consumption of some 30 TWh would release releasing over 15 million tonnes of CO_2. To emit the same amount of CO_2 with a mid-range car you would need to drive round the earth 2.1 million times (Pannewick and Herbst 2017). According to these figures, a bitcoin mined in Mongolia would have roughly the same footprint as driving round the world twice, or 30 MWh of electricity generated in Germany. The average German consumes (privately) as much electricity as two bitcoins or one bitcoin transaction every two weeks[20].

Another problem lies in the link between the exchange rate of a cryptocurrency and the amount of electricity used to mine tokens (Malmo 2017a). The higher the exchange rate, the more worthwhile it is for people to enter the network and compete in the mining system. The larger the network, the greater its electricity consumption.

Finally, it is impossible to calculate total electricity consumption accurately in terms of megawatt hours. Total consumption depends on the efficiency of the hardware used and climate damage is in turn dependent on the regional availability of green or brown electricity. Furthermore, there is no register that records how many nodes comprise the system and what their individual computing power is (Malmo 2017a). Though de Vries's calculations are therefore not absolutely accurate, there can be no doubt that the levels of energy intensity currently demonstrated by the Bitcoin and Ethereum networks are entirely inconsistent with a low-emissions future – particularly if in the future blockchains are set to process not 350,000[21] but millions of transactions per day. Under these conditions, making blockchain technologies the foundation of the energy system is clearly out of the question.

Programmers and developers are well aware of the issue of energy intensity. The switch from the proof-of-work to the proof-of-stake consensus method would reduce electricity consumption

[19] https://digiconomist.net/ethereum-energy-consumption (last downloaded on 12 December 2017)
[20] Information provided by Holger Grube, Forschungszentrum Jülich GmbH
[21] For the current number of transactions per day on the Bitcoin blockchain, see Blockchain.info, https://blockchain.info/de/charts/n-transactions (last downloaded on 14 December 2017).

(Digiconomist 2017), but the proof-of-stake method does not fulfil the same security requirements (cf. section 2.2). In the future combinations of proof-of-work and proof-of-stake methods may be able to offer the advantages of both methods and reduce electricity consumption. Ethereum, for instance, is currently working on 'Casper', one such combination based on complex mathematical properties. However, even if Casper proved relatively simple to implement, it is not yet ready for widespread use (Buterin and Griffith 2017: 9).

The criticisms of Bitcoin and Ethereum set out above could apply to almost all blockchain systems. There are individual companies that use **side chains** comprising a small number of computers and make adjustments to the great Ethereum blockchain at regular intervals, so helping reduce electricity consumption (Interview 1). As long as there is a link to the main blockchain, a side chain fulfils the necessary security requirements. **Relay chains** can be used to link several blockchains, making it possible, for example, to pay for the use of an Ethereum DApp with bitcoins (BTC Relay 2017). These systems work with individual items of information from a block rather than the block as a whole and can therefore help to reduce volume and so electricity consumption.

It is, however, obvious that blockchain will be able to play a constructive role in global energy transition only if it succeeds in developing towards significantly lower energy intensity levels.

5.2 Immutability/inertia and critical mass for security

Although blockchain technologies are often described as revolutionary and disruptive, the pace at which advances can be integrated into a system – in the case of public blockchains, at least – is generally very slow. Private blockchains can be modified on a daily basis because the developers can take whatever decisions they want alone, without consultation. With public blockchains, on the other hand, there is no set procedure for modifying essential characteristics once a blockchain is in use. Blockchain immutability means that errors in the code that create security loopholes represent a major challenge (Drescher 2017: 208).

Adaptations may also be desirable as a result of the growth of potential applications and the advent of new technologies (Berentsen and Schär 2017: 72). At the moment everyone in the network can suggest improvements, which are the subject of public discussion in forums or via mailing lists. If there is no clear consensus for a particular suggestion, it is possible to organise a vote with motions being passed by 55%, 75% or 95% (ibid.: 73). Voting rights are allocated on the basis of computing resources and considerable power is therefore concentrated in the hands of the actors with the greatest computing power.

This decision-making process is time-intensive and it is questionable whether all miners have the necessary expertise to anticipate future developments and vote in the interests of the network as a whole. It also attracts criticism because it is dominated by one single group of stakeholders: the miners. Other stakeholders such as consumers and distributors have no voting rights even though they have a stake in the continued existence of the network. They can however play an active role in discussions and so exert some small influence over the development process. Finally, the miners, who have the advantage in the case of voting, also have an interest in increasing the credibility of their currency (ibid.: 76).

There is a greater likelihood that a consensus will be reached quickly in small networks as there are fewer nodes to draw into discussions about possible modifications. On the other hand, it is essential for a network to reach and maintain a critical mass. In a system with 10 nodes, it is easy for half of them to be hacked. A system must be big enough to eliminate the risk of 51% attacks[22] (Drescher 2017: 209). Although Bitcoin is one of the larger networks, it is clearly very significant that the number of nodes dropped from 15,500 to 5,500 between 2013 and 2015 (Berentsen and Schär 2017: 102). A miner with more capital can invest in new hardware more regularly, thereby forcing smaller, less efficient miners out of the marketplace. This represents a massive threat to the decentralised character of blockchain. If an oligopolistic market emerges, a small number of miners will be able to abuse their power and stop forwarding information or consciously discriminate against other nodes (Drescher 2017: 208).

5.3 Scalability and security

Many of the transactions performed every day by a blockchain are financial transactions that can be processed relatively quickly compared with previous transfers. Even though the money reaches its destination more quickly, Bitcoin is only able to initiate seven transactions per second as against over 50,000 by VISA (PwC 2016: 11). Similarly, existing types of blockchain are also slow for most applications in the energy sector (Hesse 2017a). Ethereum's objective is to reach a million transactions per second within the next two years, i.e. to scale up its operation (ibid.). However, not even its developers are capable of assessing whether or not this is realistic. Many of the companies currently experimenting with blockchain applications are either working with the Ethereum blockchain or have built up their own network. These networks generally consist of a handful of nodes and so, even if they could be used successfully, it is often impossible to draw any conclusions as to whether they would work in the companies' complex and extensive core businesses.

The next two or three years will no doubt serve as a test bed for understanding the technology and identifying possible teething troubles. Many of these companies do not know whether blockchain is capable of providing the results they seek or whether the technology will simply be used in a supporting role at the edges of their business. Many remain sceptical. What is certain, however, is that programmers around the world are working on prototypes designed to increase scalability, guarantee security and take into account effects on ecological and social conditions. Whether or not this will be successful remains to be seen.

Once again, blockchain technology is not suitable for storing large amounts of data and transaction data has to be kept as streamlined as possible to ensure that excessively large volumes of data do not slow down the distribution of messages. In a decentralised P2P electricity trading system, for example, this means that transaction data – but not the individual consumer or production collected several times a day – is stored in the blockchain.

In order to take advantage of the advantages of transparency and tamper-proofness it will be necessary to find solutions in the shape of rules, devices and business models able to secure the transfer of data from a specific device to the blockchain. Even if we assume that data is secure and immutable once it is on the blockchain, there is a real and significant threat that information may be manipulated immediately beforehand, at its 'entry point'. Some companies are working on secure solutions to solve this 'oracle problem'. Projects in the energy sector include work on meter data validation at the interface between smart meters and the blockchain (Interview 1). Secure devices need to be developed for transfer points and this represents a major challenge for blockchain technology, which is still in its infancy.

[22] Attacks can also be carried out by miners with less than 51% of the computing power. However, it is unlikely that this will happen and even if such a hack is successful the hacking miners' options are limited: in the worst case scenario, he/she can reverse transactions or prevent certain transactions being added to the blockchain (Berentsen and Schär 2017: 235).

6 Summary of strengths and opportunities, weaknesses and threats

Strengths and opportunities – general	Weaknesses and threats – general
- Replacement of intermediaries - Savings on intermediary costs (personnel, collection proceedings, etc.) - Difficult to corrupt - Extensive data symmetry - No initial trust required between parties - Transparency and traceability - Data and contract immutability - Reduced risk of non-payment - Process automation - Potential for democratisation (?) - Relatively resistant to hacker attacks - Emergence of new business models - Businesses need less start-up capital - Sidesteps the double-spending problem - Constant availability	- Lack of speed and scalability - Increasing centralisation due to mining pools - Oligopolistic mining markets - Those who hold the computing resources potentially hold great power - Necessary to achieve a critical mass - Enormous energy intensity (!) - User interfaces counterintuitive - Acceptance questionable as operating principle abstract - Power concentrated in the hands of a small number of developers - Regulatory framework unclear - Private blockchains damage original attributes - Job losses (?) - Balance between transparency and anonymity - No more human contacts or exchange - Security loopholes hard to identify - Inertia and slow decision-making - Oracle problem (manipulation prior to 'entry point') - Not suitable for storing large amounts of data - Little opportunity for those without internet access or smart phones to participate - 'Lack of compassion' as strict rules preclude exceptions - Data misuse by private blockchains ('360 degree customer view') - Slow integration of progress
Strengths and opportunities – Energy sector	**Weaknesses and threats – Energy sector**
- Transparent consumption patterns - Efficiency incentives - Better resource utilisation conceivable	- Increase energy consumption due to more smart devices - Enormous energy intensity of the technology itself (!)

- Falling electricity costs, price-differentiated models possible - Easier to create incentives for the installation of renewable energy systems - Regional electricity supply may increase acceptance for energy transition and promote community - Increased democracy in the energy system conceivable - Reduction in market power conceivable - Low-volume electricity trading more lucrative - Possible enabler of demand-side management - Green energy certificates to authenticate original of electricity - Promotion of links between sectors conceivable - Payment systems using cryptocurrencies - Competition for centralised P2P networks - Need to expand the transmission grid may be reduced	- Costs linked to the provision of digital infrastructure - Trust in blockchain providers required upfront - Transaction speed too low - Power concentrated in the hands of private blockchains - Power concentrated in the hands of public blockchains due to computing power - Changing roles with new responsibilities - Market players often have less IT expertise - Risk of solidarity erosion in relation to grid costs

Fig. 10: Blockchain: strengths and opportunities, weaknesses and threats[23]

[23] Source: Eigene Darstellung

7 Conclusions and future perspectives

While there is every likelihood that blockchain will change business processes and models, the extent to which it will do this is unclear. It is already changing the roles of the various actors as we can see in the energy sector, for instance, where consumers are now more likely to become prosumers. The roles of distribution and transmission grid operators are also changing. In the future energy companies will provide more services (e.g. Blockchain as a Service, BaaS), digitalisation will open up new ways in which consumers can participate in the market and start-ups will be offering entirely new opportunities in the P2P sector.

However, the use of blockchain technologies will provide interesting opportunities in the energy sector only if we can get to grips with the problem of their enormous energy intensity. This needs to be taken into account in the German Federal government's objectives for digitalisation in the energy sector. Its policy should create a framework that both helps promote the strengths and opportunities set out in this study and addresses the weaknesses and threats appropriately. Only if these weaknesses can be eliminated, or at least considerably limited, will the use of blockchain applications in the energy sector make any sense at all. It is up to businesses to strike this balance between opportunities and threats and civil society to operate as an early warning system for any remaining risks. It can provide important guidance in the economic and political debate.

The technology's ability to get to grips with the problem of energy intensity is central to its successful application within the framework of the energy transition. The same levels of security of supply within the energy system must be retained, even if those responsible for them change (Sieverding and Schneidewindt 2016: 4). Potential savings should deliver benefits first and foremost to consumers. It is also important to ensure that blockchain remains a participative technology that benefits experts and lay people alike. In the short term, at least, we would discourage exaggerated hopes in blockchain and its applications in the energy sector. In the words of Wiedmaier (2017), it should be viewed as "complementary technology, not a substitute" (p. 54). Blockchain has the potential to speed up energy transition but can never replace a sustainable energy policy.

One crucial point, which has less to do with technological limits than with the organisational structures emerging as a result of blockchain, is the lack of regulatory framework. In a decentralised system with no hierarchical structure, who will be held responsible in the event of complications or fraud? In the view of Scholtka and Martin (2017), achieving legal certainty through majority consensus is "for lawyers an opaque and insufficient basis for verification [and] the clear allocation of responsibilities appears questionable at least" (p. 114). Insurance solutions might possibly play a role, with insurance premiums being apportioned among all the actors. We will also have to find a way of integrating blockchain technology into the existing rules and regulations. This raises the question of whether smart contracts can be used in combination with legally binding contracts.

When the internet was being developed, only a small number of enthusiasts believed that the technology would catch on. In all probability even they did not imagine the full extent of what has happened over the last 30 years. It is conceivable that things may evolve in a similar manner with blockchain technology. The first successful applications are beginning to appear. Attributes such as decentralisation, cryptography and consensus-based decision-making offer advantages over other established technologies.

Finally, blockchain should not be used at any price or as a result of peer pressure (dena 2016: 32). There are sectors in which existing solutions are currently still faster, more socially and environmentally friendly and, in the final analysis, more appropriate. The sectors and fields of application in which blockchain can offer added value will emerge gradually. It may be useful to engage in research and development work at an early stage so as not to miss out on technological improvements.

The hype around blockchain may yet prove unfounded. The “peak of inflated expectations” may indeed be followed by the “trough of disillusionment” (see Gartner 2016). Similarly, it may be that a decentralised technology that is functionally equivalent to Blockchain with many if not all of its features but with a different name ultimately prevails. In the final analysis, the social and ecological benefits of applications must play a key role alongside their economic sustainability. Above all, the technology’s enormous consumption of resources should provide food for thought. It is to this question that decision-makers in the economy, politics and civil society should be devoting particular attention as they reassess and address the latest developments in light of the opportunities and threats discussed in this study and any that may emerge in the future.

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Interviews

Interview 1:

- Hasberg, Kirsten. Interview on the 06th of November, 2017 in the Factory, Berlin.

Interview 2:

- Burger, Christoph. Interview on the 24th of November, 2017 in the European School of Management and Technology, Berlin.

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