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Global Energy Game Changers

Blockchain in the energy sector: evolving business models and law

2018 (Issue 8)

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Editorial

Blockchain, distributed ledgers, bitcoin, cryptocurrencies, smart contracts: you may well have heard a lot about any or all of these, without being entirely sure what they are. You may be wondering if they are about to turbo-charge or wreck your existing business model, or to make little difference to it because they seem over-hyped. If so, you are not alone. Poor understanding of these technologies is widespread, but so is a sense that nobody can afford to ignore them.

The energy sector is no exception to the general excitement. In March 2018 Greentech Media reported that in the preceding 12 months energy sector blockchain startups had raised US$324 million: 122 were then in operation, with a new one launching on average every week. And it is not just startups that are interested in blockchain: some of the largest companies in the energy industry (and other sectors, notably financial services) are also putting significant resources into exploring this area.

What is driving all this activity? In some cases, somebody has identified a specific potential use case for the technology that could either significantly improve the efficiency of existing business processes or open up new markets. In other cases, announcements seem to be prompted by little more than a general sense that blockchain is the latest manifestation of a wider process of "digital disruption" that nobody can afford not to at least seem to be engaging seriously with.

Anyone who remembers the dotcom bubble of the 1990s may be forgiven for a feeling of déjà vu in relation to blockchain (although there are some significant differences, not least in the way that blockchain businesses are raising funds, as we shall see below). Blockchain is not magic: as with any large group of experimental new ventures in a free market, many of today's individual blockchain projects will inevitably fail or be superseded. This would be true even if it were not also the case that blockchain in its current form may be a less ideal technology for some of the use cases proposed for it than some of its advocates are prepared to admit.

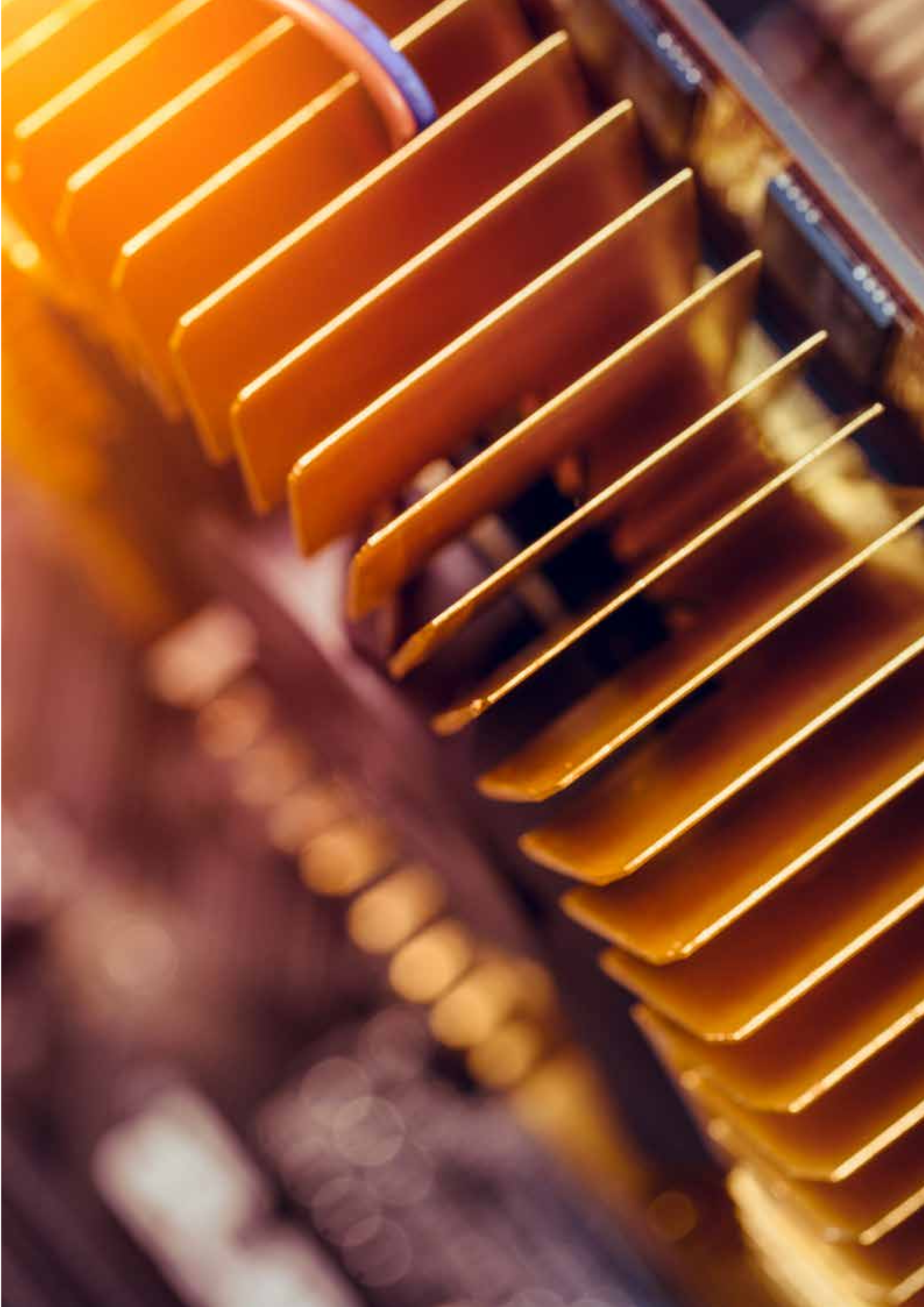
But the fact that it burst is not the only important point about the dotcom bubble. Some of the Internet-based businesses that grew up in the late 1990s have become extremely successful. Moreover, as they did with the Internet in the 1990s, businesses have fixed specifically on blockchain not just because of the problems it claims to solve but also because of some of the ways in which it claims to solve them. There is an undeniably strong and widespread appetite for products that live up to the blockchain hype and, if blockchain in its current form cannot deliver all of them, then sooner or later either blockchain itself will evolve to a point where it can do so or some other technology or combination of technologies will do so. And any solution that shares the same attributes as are now claimed for blockchain will by definition raise many of the same legal and other issues as blockchain, so it is not too early to start thinking seriously about them.

That is what we try to do in this volume. We begin with a general, non-technical account of what people mean when they talk about blockchain; the kinds of applications that have been identified for the technologies concerned; how blockchain businesses raise money; and some of the generic legal implications of the technology.

This is followed by a series of articles on different aspects of how the technology is being, or could soon be, applied in the energy industry—and some of the specific legal issues arising. These are all based on publicly available information about the projects concerned (supplemented in a few cases by correspondence with the companies involved). We have endeavored to keep our commentary up to date, but this is a fast-moving field that has seen a lot of developments even in the few months during which the articles have been written.

Overall, we conclude that whatever part of the energy sector you are focused on, you do need to take account of what blockchain might be able to do in your market. In theory and in the long run, the possibilities are endless. But in the short term you need to examine any attempt to sell you a blockchain solution very carefully—to understand what it can and cannot do, to make sure that it is feasible and that there is not an easier non-blockchain solution. At the same time, you may wish to be on the lookout for regulatory or commercial moves that could, probably inadvertently, make it harder to exploit potentially fruitful future blockchain opportunities.

As indicated in the disclaimer at the end of this volume, none of its contents constitute legal or other advice, neither should they be relied on in the making of any investment or commercial decision. However, if anything in this volume makes you want to start a discussion, please get in touch.



Blockchain basics: technology

Online commentary about blockchain and related matters first began to proliferate a little over 10 years ago. But the language and underlying concepts in this area still retain an aura of mystery. It therefore seems appropriate to begin by giving a brief account of some of the basics.

If you have already read about the technology and understand it, by all means skip this section. We thought it was important to include it for the benefit of readers who are less well versed in the background because, unless one knows a bit about the technology and its associated financing techniques, it is hard to make sense of some of the ways in which people are proposing to apply it in the energy sector and elsewhere. Before we begin, we offer two warnings.

- This is an area with a language all of its own, and the meaning of some of the terms that are used is contested. Some terms are given different meanings by different writers and others are the subject of intense, quasi-philosophical debate. We have tried to steer clear of all this—without intending by doing so to take any express or implied position in such controversies as whether "blockchain" should be preceded by "a" or "the", or spelt with a capital "B". We have also simplified our description of the technology and of many of the individual projects we refer to in the interests (we hope) of readability. For those who want more detail, our text provides numerous hyperlinks to more information and comment.
- A glance at the "White Paper" documents produced by blockchain startups reveals disclaimer language that seems to be informed by more than a lawyer's usual caution. Everything that they say is a "forward-looking statement" based on "current beliefs", rather than a fact; actual results may differ materially from the business's current expectations, which should not be relied on for making financial decisions, and so on. We are lawyers rather than technologists, but our sense is that the health warnings should be taken at face value: many of these projects may well take longer to mature and in the first instance may well deliver slightly less than their authors appear to hope.

Distributed ledgers

The starting point is a concept whose name may not immediately sound very exciting: distributed ledger technology (DLT). At present, all sorts of quite simple transactions that are carried out in bulk require a number of different parties (e.g. buyers and sellers, and their respective banks) to keep their own records of each transaction or to verify those kept by others (e.g. by means of an audit). These records are often generated separately from whatever contractual framework governs the transactions in question, and from the systems under which they are paid for. Opportunities abound for inconsistencies to arise by accident, or for deliberate fraud to occur. In some cases, these problems are controlled (and costs added) by building systems around a central, trusted party.

The basic proposition of DLT is very simple. If all parties are operating from a shared set of records—the distributed ledger—and this is constructed in such a way as to reduce or eliminate the introduction of false entries, and does not need to be kept by a central authority, then, at the very least, transaction costs could be materially reduced. Moreover, if a DLT system were sufficiently powerful in processing terms, it could help

underpin the much-anticipated "Internet of Things" (IoT) and other forms of transaction between machines. This is because one aspect of IoT is likely to be a huge increase in the number and frequency of transactions being entered into by machines with each other. In some sectors (including perhaps some energy sectors, as we will see below) these transactions may have low individual values, but together they may account for a significant share of the market.

A distributed ledger, then, is conceived as a way of storing and transmitting data, such as records of transactions, in a way that is cheap and decentralized. In principle, this is shared among a network of participants, each of which is known as a "node," that send and receive data to each other in such a way that each participant has an equally up-to-date and valid copy of the resulting ledger.

This brief description of DLT immediately raises a number of questions. Does every participant need access to a record of every transaction? Why do the participants trust each other and the data provided? Is the technology anything more than a glorified shared database / spreadsheet? To begin to answer these questions, we need to consider the context in which the technology has developed.

Blockchain—what's in a name?

Blockchain is a particular version of DLT whose name is used, not strictly accurately, as a way of referring to that technology more generally. This usage partly reflects its role in supporting bitcoin (see below). It also helps that the name itself offers the non-technically-minded a reassuringly physical metaphor for conceptualizing how the underlying technology works.

Blockchain's distributed ledger is built up of a series of "blocks." Each block contains details of timestamped batches of validated data (typically representing a series of transactions), and "hashes" (cryptographic "digital fingerprints" or unique identifiers, in which input messages of any size are converted into outputs of a fixed size, and it is virtually impossible to determine the input from the output). The hashes link each block to those that come immediately before and after it in such a way as to prevent them from being altered, or a new block from being inserted between existing blocks. There is no way to alter an entry that has been made: it can only be reversed, and those reversals should only happen under rare circumstances. Accordingly, distributed ledgers are sometimes said to be "tamper-evident" rather than strictly "tamper-proof."

Before a block is added to the chain, the individual data entries of which it is made up and the block itself are subject to a series of authentication and validation processes.

- Each message is protected by digital signatures: it has a private key (known only to the sender) but also a paired public key (the recipient and anyone else with access to this can verify the message).

- Before a transaction is submitted for inclusion in a block it is verified by the initiating node, which has selected the transaction from a pool of waiting transactions, and others in the network.

- The creation of the blocks themselves adds a further level of security, and secondary verification of the transactions in each block takes place before it is added to the chain.

These verification processes may take a number of different forms, but all depend on there being a consensus between participants as to the criteria to be satisfied before authentication or validation takes place. They may, for example, be based on the equivalent of a majority vote (e.g. the agreement of participants holding a certain share of total network value), or on the operation of a dispute resolution algorithm that is activated when one node generates a different output from others in the network. The key point is that, once the technology has done its work, every participant's separate copy of the ledger will be equally valid: the ledger is "distributed" because there is no central master record.

Public / private, permissioned / permissionless: different varieties of blockchain

There are a number of variants on this basic structure. In particular, a blockchain may be "public" (open) or "private" (closed)—or possibly somewhere in between—and in either case it can be configured to be "permissioned" or "permissionless".

- In a fully public blockchain, anybody can participate (sending and receiving data, and being involved in consensus processes), subject only to the controls imposed by the consensus mechanisms. At its most basic, the integrity of the system is guaranteed by its size and the apparent impossibility of anyone having the computing power necessary to falsify a majority of copies of the ledger. Access control rules may be applied to limit the "read" and "write" privileges of participants so as to protect commercial confidentiality. (Anonymity or participation on a pseudonymous basis may also provide some protection in this regard.) Different nodes may have different roles by virtue of the software they run—for example, in relation to bitcoin (see below), the whole group of users is a much larger class than the miners who make the blocks.

- In a fully private blockchain, the participants are likely to be either members or customers of a single organization: access is more tightly controlled and governance much less decentralized. Digital certificates and policies are used to control access. It is likely that only one organization will be able to write entries and have access to all the information in them, using a "private key," while, for other participants, permission to read them (or parts of them) will also be restricted (e.g. to those involved in a given transaction, using a "public key").

- Halfway between the completely public and completely private blockchains is what is sometimes called the consortium model—for example, a network might be run by a group of financial institutions that reserve to themselves the ability to write data entries (subject to, e.g., a majority-based consensus mechanism) and operate nodes (improving overall network costs and the speed of validation activities), but who allow all their customers, or any third party, to read data entries (subject to certain limitations, as in a private network).

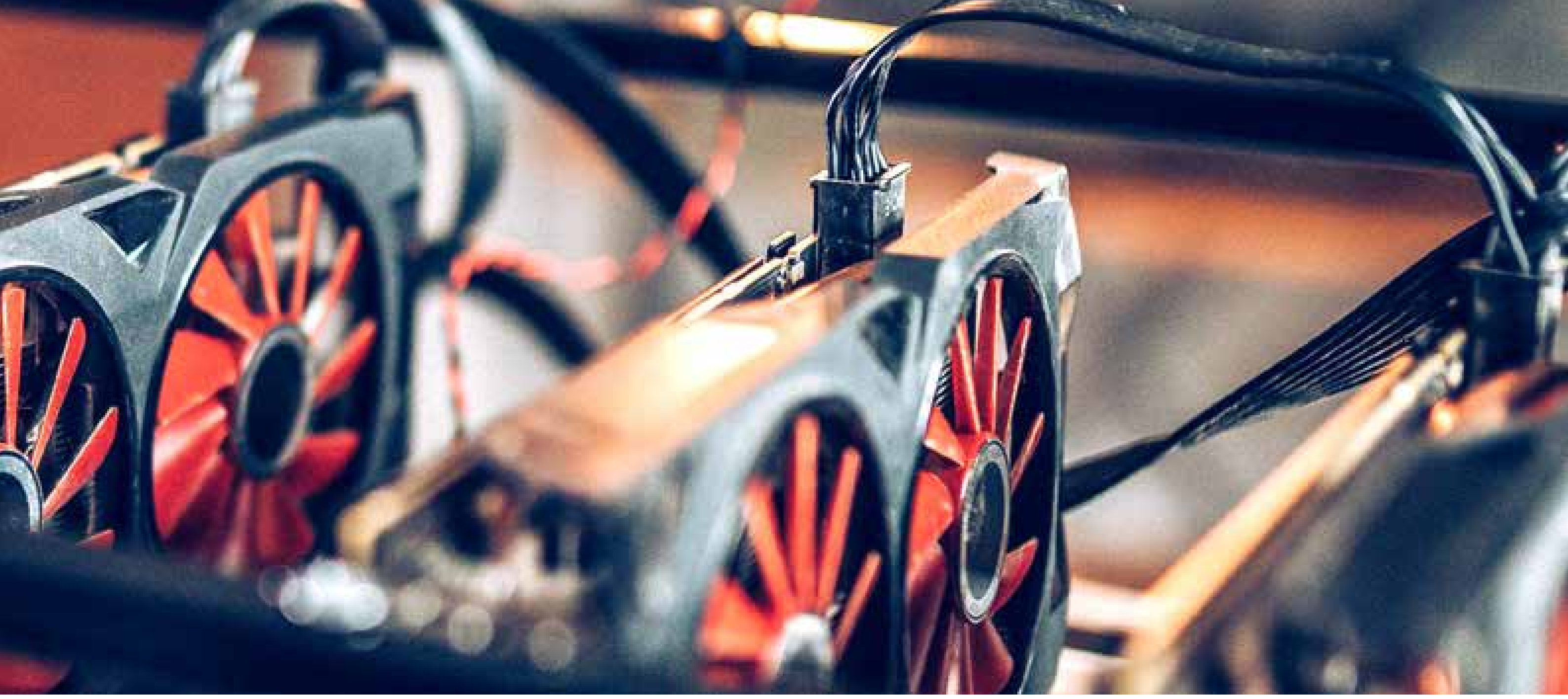
- The terms "permissioned" and "permissionless" are sometimes used almost interchangeably with "private" and "public" and, when they are not so used, they are not always given the same meanings. One distinction that the use of these terms can draw is in relation to who can validate a transaction: for example, in a permissionless public blockchain, anyone can download the protocol to do this; in a permissioned public blockchain, a prospective validator of transactions must first meet specified criteria. In the consortium context, "permissioning" may refer to the kinds of transaction that a participant in the network is and is not permitted to initiate without reference to one of its controlling organizations.

Which is best?

Public / permissionless blockchains rely more heavily on algorithms and iterative computer processes to determine whether a transaction is validated: they are often said to be "trustless" systems because the participants are, in effect, relying on the technology rather than any knowledge about or prior contractual relationship with each other as the basis on which they "trust" each other.

It is a matter of debate which approach provides more security, and which kind of network participants prefer will depend on what they want to use the technology for. Some may find an arrangement where users know who their counterparties are inherently more secure, pointing towards permissioned or private systems. In a recent speech, the Chancellor of the High Court of England and Wales, Sir Geoffrey Vos, suggested that there would "inevitably be a rather enhanced risk of fraud if we move headlong towards ... the use of public blockchains for financial transactions." Others point out that, in a permissioned or private network, security may be more easily and seriously compromised by hacking just one participant who has all the key access rights or permissions, suggesting that public blockchains can have advantages from a security point of view. However, the anonymity of participants—or use of pseudonyms to identify them—that often feature in public blockchains, is clearly inappropriate for commercial contexts where businesses involved will often be subject to "know your customer" (KYC) requirements for regulatory purposes such as the control of money laundering. Some projects envisage combining a public blockchain for transactions with a separate administrative or "side" chain that is private or permissioned to manage, e.g., access rights.

Another question to be asked in relation to any very private blockchain project is to what extent it represents an improvement over existing computerized transaction systems built around a single organising entity. Such a blockchain could be said to lack the defining DLT feature of decentralization, and it may be thought that there are other, and perhaps better, ways of running a network that has a single, trusted organization at its center.



Equally, a public blockchain with a large number of nodes may raise questions about whether it is necessary, useful or efficient to have the same large amounts of data held in multiple places. Moreover, since most of the information concerning past transactions will be only of historical importance and will not need to be actively used, the system may be unnecessarily slowed down by the need for any new or restarted node to synchronize with the whole chain (and exchange and validate huge numbers of blocks). Such considerations may point towards the desirability of fragmenting the blockchain so that "historic" and "live" transactions are treated in different ways.

Corda—an example of a "consortium blockchain"

As compared with a fully private network, the consortium model appears to exhibit more of the benefits of using blockchain with fewer of the perceived downsides of a fully public network. Purists may be disturbed that the blockchain in such a model is not democratically controlled by all users but, for many, it may offer the best of both worlds. One of the prime examples of the consortium approach, Corda, put together by a number of banks and financial institutions and software firm R3, is instructive in this context.

In its own words, R3 was "born out of a common frustration with multiple generations of disparate legacy financial technology platforms that struggle to interoperate, causing inefficiencies, risk and spiraling costs." However, according to R3, Corda is not merely "not Blockchain", but not even DLT. As Corda's FAQs explain, its transactions are not aggregated into blocks, and its ledger is said to be "shared" rather than "distributed." At a relatively early stage in Corda's development, its Chief Technology Officer pointed out that, on the face of it, blockchain was not well suited to the world of banking. However, its key achievement was "the emergence of platforms, shared across the Internet between mutually distrusting actors, that allow them to reach consensus about the existence and evolution of facts shared between them." In the same article, he went on to explain what Corda takes from each of the key elements that have enabled blockchain to create such platforms.

- The "shared facts" that matter in dealings between banks are essentially financial agreements (Bank A owes $X million to Bank B, Banks X and Y are parties to a credit default swap on certain terms, and so on). Currently, the parties record details of agreements, and updates to them, on different systems, and inconsistencies arise in their records of the same agreement.
- If the parties are using the same system, the costs and difficulties that currently arise can be avoided. But only the parties to a given agreement (rather than all participants in the network) need to be able to see the system's records of

it: "the only people who need to be in agreement about a fact are the stakeholders to that fact." Consequently, users can "write their validation logic in time-tested industry-standard tools" and Corda defines "who needs to be in agreement on a transaction's validity on a contract-by-contract basis."

- As with other DLTs, Corda seeks to avoid two valid but mutually incompatible transactions being active on the system at the same time, but the "traditional blockchain" approach to this is only one of a number of "uniqueness service" implementations it uses. Corda also takes a traditional blockchain approach to authenticating transactions and ensuring their immutability.
- Corda stresses that it is a system designed to deal with agreements, or what it calls "state objects governed by contract code and associated legal prose" and acknowledges that as such the system will not be able to resolve all potential disputes between participants by itself.

In short, what Corda promises is to deliver, in a form that is the best adapted to the needs of business (or more specifically financial institutions), all the things that blockchain generally promises: disintermediation and the driving out of paper / paper surrogate communications like email: the collapsing of multiple steps of transaction and settlement processes into a single process, and increased security and transparency (including to regulators, who can be given privileged access to the blockchain)—all saving costs and time and reducing risks.

Cryptocurrencies

Blockchain itself (with a capital "B") is indelibly associated with Bitcoin (BTC), the cryptocurrency for which it provides a ledger. What is a cryptocurrency? The online Oxford English Dictionary defines it as "a digital currency in which encryption techniques are used to regulate the generation of units of currency and verify the transfer of funds, operating independently of a central bank." (This is a very fair starting point, although it should be noted, by way of immediate qualification, that central banks could start to issue their own cryptocurrencies so as to give non-banks access to central bank "digital money," and, in the view of some commentators, enable central banks themselves to understand their economies better and reduce systemic risks within them.)

A cryptocurrency is also a species of "virtual currency" within the meaning given to that term by the Financial Action Task Force in a report of 2014: virtual currencies, like "fiat currencies" (i.e. "real money", such as dollars, euros or yuan) function as a medium of exchange, unit of account and store of value. However, unlike fiat currencies, they do so only by agreement within a community of users and not as a result of any action by a state. They are distinct from "e-money", which is simply a digital representation of fiat currency that is used to transfer value electronically. They are not legal tender (a valid and legal offer to pay, when tendered to a creditor) in any jurisdiction.

On the other hand, some businesses, apparently including some electricity utilities in Japan and Germany, will accept them as payment for goods supplied to customers. In the absence of regulation to the contrary, there is no legal reason why, as a matter of private contract, two parties should not agree that payments between them are to be made in a cryptocurrency, or why the failure of one party to make a contractually required payment should not be enforceable as a debt claim through the courts or a contractually agreed alternative dispute resolution mechanism by the other party. Existing dispute resolution mechanisms may need to be adapted to cope with cases where one party does not know the identity of the other, or one or both "parties" are machines acting in some sense autonomously, rather than as the agents of identified human / corporate contracting parties. On the other hand, a blockchain purist solution would be to leave everything to be finally decided by an algorithm on the principle that "code is law".

Bitcoin

Bitcoin is one of many cryptocurrencies, each supported by some form of blockchain. As a medium of exchange and a store of value, they all tend to have similar advantages and disadvantages.

- Among the advantages are said to be transaction speed and low barriers to entry (although the first of these may depend to some extent on your point of comparison). In the words of the alleged, pseudonymous, creator of the bitcoin protocol, Satoshi Nakamoto, in one of the earliest (2008) expositions of how it would work, because cryptocurrencies are "based on cryptographic proof instead of trust," they allow "any two willing parties to transact directly without the need of a third party [such as a bank]". As a result, users are said to benefit from not incurring many of the costs and other burdens typically associated with being a customer of a bank or using a conventional payment system, or the exposure to political and macroeconomic risks associated with all fiat currencies to some extent (and with some fiat currencies to a very large extent).
- Among the disadvantages of cryptocurrencies are that some are not built to deliver fast, cost-effective payments and that they tend to undergo significant and unpredictable fluctuations in value. This volatility presents a problem for users, not least because most potential counterparties still do not accept bitcoin as a means of payment (so that they must first be converted into fiat currency—which may not be straightforward—to be economically useful). It also somewhat undermines one of the claimed advantages of cryptocurrencies over fiat currencies—although, as we will see, some have proposed to compensate for cryptocurrency volatility by creating cryptocurrencies backed with commodity values (including energy commodities) in a manner reminiscent of the historic backing of paper money with gold. A further drawback in some cryptocurrencies and token programs (on which see below) is a tendency to favor / potentially over-reward early adopters / insiders, for whom a significant proportion of the capped total amount of the currency / tokens is reserved.
- One holds bitcoin by means of an address and a key: two numbers, the second of which associates the bitcoin uniquely with its owner. Keys are kept in a "wallet," which may be either "hot" (i.e. running on a computer linked to the Internet) or "cold" (any other method of recording the keys, including writing them out on a piece of paper). If you lose the key, you lose the bitcoin and there exists no recourse mechanism for getting it back.

Bitcoin enjoys a degree of notoriety for a number of reasons. In addition to the recent volatility of its exchange rate with fiat currencies, it appears to be well suited to, and in some cases to have been used for, facilitating illegal or morally questionable transactions. Of particular relevance for our present purposes is the fact that the process of "mining" bitcoins relies on "proof of work" that takes the form of solving complex mathematical problems. By deliberate design, this is in large measure a process of trial and error. It takes a lot of computing power, and therefore also consumes large amounts of electricity. In effect, "miners" are competing to embed validated transactions into blocks and so write the distributed ledger, and they are rewarded

for creating a new block in the chain by receiving a certain quantity of bitcoin (this decreases over time, but is currently 12.5 BTC, or more than US$80,000 at the time of writing (end of September 2018)).

Estimates suggest that all bitcoin mining activity globally consumes more electricity than many countries (by one count, a bit more than Algeria but less than Kuwait and 43 other countries). ING calculates that each bitcoin transaction consumes as much energy as 200 washing machine cycles (or enough to heat a house for a month). In Canada, there is controversy over proposals by Hydro-Quebec to limit supplies of power to bitcoin-mining customers. Since more than half of all bitcoin mining is done in China, where coal is the dominant fuel for electricity generation, there are legitimate concerns about the environmental, as well as economic, impacts of cryptocurrency mining activities.

Although the bitcoin system is meant to be a world without banks and the transaction costs that come from dealing with them, the reality is not so straightforward. Since the mining process is competitive, users pay fees to get their transactions processed and those fees will typically be higher if the user wants the transaction to be processed more quickly. Like the value of bitcoin, the level of fees charged by miners fluctuates over time—although, in principle, competition among miners should exert a downward pressure on fees.

Moreover, in comparison with other payment systems, bitcoin works quite slowly. The "average confirmation time," which varies with market conditions, appears never to have been less than five minutes, to be frequently more than 20 minutes, and on a number of occasions to have been several hours (see graph). Taking another measure of transaction speed, it appears that PayPal can process more than 10 times as many transactions per second, and Visa several hundred times more. However, research by the European Central Bank and the Bank of Japan has found that DLT-based solutions could at least meet the performance needs of a Real-Time Gross Settlement system, and blockchain-based platforms such as Stellar, whose currency is the Lumen (XLM) have already improved dramatically on the transaction speeds of bitcoin.

Finally, although bitcoin exchanges solve some of the problems of securing one's own bitcoin wallet, they are often not regulated or insured and, while blockchain itself may so far have proved unhackable, bitcoin exchanges have not: at least two of them (Mt Gox and Coincheck) have suffered significant and costly hacking attacks. Customers are used to having recourse through their banks, the traditional payment systems, or an Ombudsman: a true "buyer beware," "code is law" based system is daunting and likely to have limited appeal to many consumers, or commercial participants, outside the ranks of "true believers" in code. The potential adverse consequences of a strict "code is law" approach are illustrated by the failure to take corrective action in the case of the DAO hack.

ICOs and tokens

Cryptocurrency is a large subject in its own right, and the debates around it are becoming, if anything, more complex, fueled in part by the increase in volume and (ostensible) value of initial coin offerings (ICOs). ICOs are an (often) unregulated hybrid of IPO and crowdfunding that are associated with the launch of new blockchain-based ventures that are known as dapps (pronounced "de-apps") provided that they meet certain formal criteria. ICOs are increasingly favored by tech startups, who use them to allocate "tokens" to investors (hence also "initial token offerings" or ITOs), usually in exchange for cryptocurrency rather than fiat currency. Holders of the tokens are then eligible to exercise rights and/or receive rewards that relate to the underlying product or service that the business is promoting (making the token in effect a kind of "smart contract"—on which see further below).

The precise definition of these rights may give them characteristics more or less similar to those of a conventionally issued debt or equity security. However, owning a token tends to carry risks similar to those associated with holding a conventional equity share but without conferring any comparable right to participate in the governance or, in many cases, the profits of the company. And compared with issues of debt security in conventional capital markets, or non-blockchain crowdfunding platforms, many token programs have a less robust legal base and a higher level of commercial risk.

For some participants, these drawbacks may not matter. Some businesses reserve a significant proportion of tokens for a privileged group of individuals, such as founders and other employees, who do not have to pay for them. And early investors in some cryptocurrencies have made such spectacular "virtual" gains that their attitude to investing amounts of those currencies may be rather different from how they might approach an investment of a comparable value of fiat currency. If you bought 10 BTC when they were worth a few US$ each and they are now worth several thousand US$ each, but you find it hard to sell them, either for practical or for emotional reasons (the value may rise still higher), using one or two of them to buy tokens in a promising ICO is likely to be psychologically much easier than investing the currently equivalent amount of fiat currency in that ICO.

We will look further at cryptocurrencies and tokens in connection with specific energy sector examples later in this volume. For the moment, however, it is enough to note two points. First, the potential drawbacks of cryptocurrencies are in a sense a consequence and another aspect of the downsides of public blockchain. Second, there is nothing inevitable about the linkage between distributed or shared ledgers and cryptocurrencies. There is no need to integrate payment processing into a blockchain whose primary purpose is simply to communicate data or synchronize records: payment can be handled separately, without blockchain participant accounts becoming accounting units. Moreover, at least for transactions that take place in private or consortium model networks, if the participants would prefer to use fiat currencies, they can: they will just need to make the usual, separate arrangements for payments to be sent and received.

Hot topics

Blockchain and cryptocurrencies are a constantly evolving field. The more uses are proposed for these technologies that go beyond the original role of blockchain as the infrastructure supporting bitcoin, the more the vision of entrepreneurs runs ahead of what the technologies can currently deliver. For a frank summary assessment of some quite fundamental areas that remain under-explored, see the R3 December 2017 report, *Top Ten Obstacles Along Distributed Ledgers' Path to Adoption*. The author's open-minded approach can be seen from the contents page: "10. Usability: Why use distributed ledgers? 9. Governance: Who makes the rules? 8. Meaningful comparisons: Which is better? 7. Key management: How to transact? 6. Agility: Which algorithms do we use? 5. Interoperability: How to talk to each other? [There are a number of R3 papers on this, including one with the title The Myth of Easy Interoperability. With a nod to The Lord of the Rings, this issue is sometimes referred to as the problem of whether there can or should be "one blockchain to rule them all".] 4. Scalability: Why store every transaction? 3. Cost-effectiveness: What is the cheapest way? 2. Privacy: How to protect data? 1. Scalability: Do we need full agreement?"

It is worth noting, however, that the above list of "obstacles" is one prepared from a blockchain developer's point of view. A useful point of comparison is the list of "hurdles to adoption" in a February 2016 paper by Euroclear and Oliver Wyman, Blockchain in Capital Markets: The Prize and the Journey. Although scalability features on both lists, the latter reflects the kind of issues that potential users of blockchain, particularly those operating in regulated industries, will need to see addressed further before adopting the technology: "regulation and legislation: fitness for purpose"; "the need for a robust cash ledger"; "common standards and governance"; and "operational risks of transition; managing anonymity".

A further illustration of the developing state of the technology is Direct Acyclic Graph (DAG) networks, also known as Tangle. One feature of the classic blockchain / bitcoin system is that only one block can be created at a time, and each block contains a number of transactions which are likely to have no connection with each other except having been generated at about the same time. DAG / Tangle offers an alternative approach. This was first exploited simply as a development of the idea of "side chains" that allow different kinds of transactions to be created on different chains simultaneously, but a number of projects now envisage taking it further to provide a "blockchain without the blocks"—and without the miners and the somewhat slow transaction processing speeds of classic blockchain.

These features have led to claims that DAG / Tangle has the potential—which classic blockchain currently appears to lack—to cope with the huge number of small value transactions that would be unleashed once the IoT takes off. Consequently, among DAG / Tangle-related ventures one finds names like IOTA and IoT Chain. A number of authors have identified DAG / Tangle as "Blockchain 3.0"—on the basis that the improvements in blockchain associated with Ethereum, such as sharding (which involves splitting the blockchain in various ways) can be seen as "Blockchain 2.0". Needless to say, DAG / Tangle applications are still at a very early stage, and there is no shortage of other competitors presenting themselves as superior versions of blockchain—for example "Third Generation Blockchain", AION, or BTL, with its application platform Interbit, which is said to be both faster and more secure than blockchain in its earlier forms, enabling the joining of multiple blockchains, whilst retaining its advantages of limited IT requirements and reduced development costs, combining the advantages of blockchain and cloud computing.

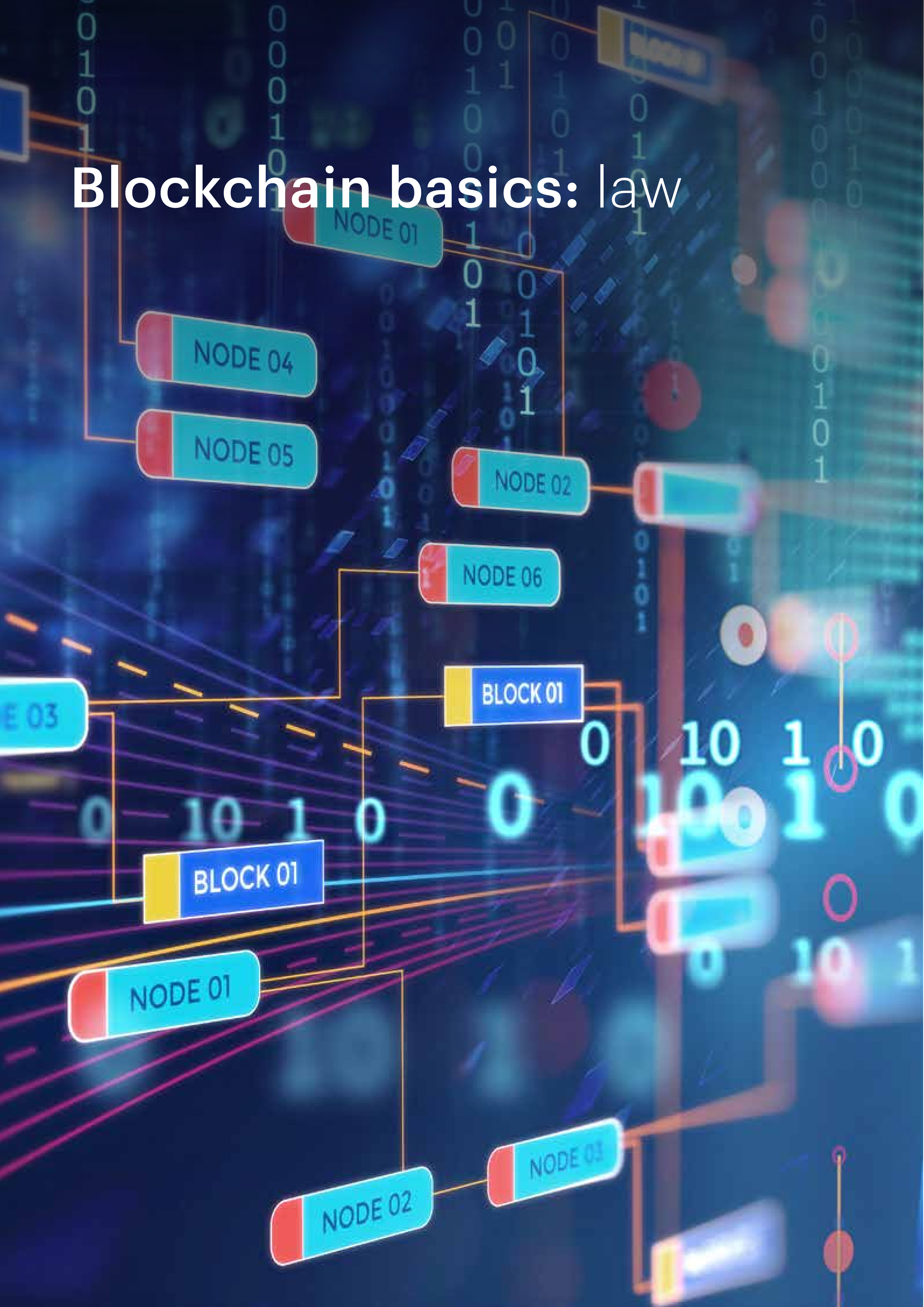
Suggestions for further reading

There is a huge amount of online and e-book writing about blockchain—and a few titles are also available in old-fashioned paper-based form as well.

Readers looking for a more nuanced and detailed account of many of the topics touched on in this article, further background, and some consideration of security issues and the wider economic significance of the technologies concerned, may find useful two reports by analysts at Credit Suisse, The Trust Disrupter (August 2016) and Blockchain 2.0 (January 2018). The risks and opportunities for systems using blockchain and smart contracts are explored in a very balanced report of the same name published by Data 61 (CSIRO) in Australia. Useful survey-based snapshots of the blockchain and cryptocurrency ecosystems are provided by Garrick Hileman and Michel Rauchs in their 2017 Global Blockchain Benchmarking Study and Global Cryptocurrency Benchmarking Study. However, none of these has much to say about blockchain's implications for the energy sector, except in relation to the power-intensive nature of bitcoin mining. By contrast, for those who read German, the Bundesverband der Energie- und Wasserwirtschaft's *Blockchain in der Energiewirtschaft* provides an excellent introduction both to blockchain in general and to its potential uses in the energy sector.

Finally, if you either find yourself becoming obsessed by blockchain and wondering if there is no commercial problem it cannot solve, or have already formed the view that it all sounds too good to be true, but can't quite put your finger on why, you may wish to test your faith or feed your prejudices, as the case may be, by turning to David Gerard's entertaining and well-researched July 2017 book, *Attack of the 50 Foot Blockchain* for a bracing dose of scepticism about all things blockchain.

Blockchain basics: law



The final basic concept underlying many uses of blockchain is that of the smart contract. It is often said—not without some justification—that smart contracts are neither smart nor contracts. Nevertheless, in a forward-looking survey, we have chosen to put them at the start of our discussion of blockchain and law rather than at the end of our discussion of blockchain as a technology.

Smart contracts

Smart contracts are generally said to have been first defined by Nick Szabo in 1994 as "a computerized transaction protocol that executes the terms of a contract," that would aim to "satisfy common contractual conditions ... minimize exceptions both malicious and accidental, and minimize the need for trusted intermediaries" as well as "lowering fraud loss, arbitration and enforcement costs, and other transaction costs." It is worth pointing out that smart contracts were thought of some time before blockchain (as can be seen from the date of Szabo's definition), and that they can exist entirely independently of blockchain. But they are perceived as a good fit for each other: proposals for the use of smart contracts have multiplied considerably in the context of efforts to reinvent various forms of business activity around blockchain-based processes.

A traditional contract records the arrangement between parties in written legal form. A smart contract replaces the traditional written agreement using executable computer code both to record that agreement and to automate its own execution to some extent, for example by transferring payment or property. It can be thought of as a high-tech version of the principle behind a vending machine (if the correct coins are inserted into the slot, tip the bottle of water into the trough; if the bottle will not tip, or if there are no bottles, return the coins) but, it is to be hoped, with more consistent results than such machines sometimes produce without recourse to physical violence by the customer. Some smart contracts use blockchain technologies for payment and audit trail functions. Ethereum, which describes itself as a "blockchain app platform" and has its own cryptocurrency, the ether, is particularly associated with the running of smart contracts, using a language called Solidity. Most of the blockchain projects reviewed later in this volume are Ethereum based.

How smart is smart?

In theory, a smart contract should require no management, will monitor its own performance and can create whatever audit trail is required. In practice, we are only at the start of the process of automating contractual relationships in this way, and most "smart contract" systems are likely to involve a significant traditional legal drafting / human intervention element for some time to come.

In the long run, the possibilities for streamlining back and middle office processes in terms of cost, speed and availability are potentially enormous. One area of particular interest is where the performance of a contract takes place over a period of time and involves the collection of data, and there is a value in the parties having a shared record of that data because it has a direct impact on what happens next between the parties under the contract. This aspect of smart contract functionality is well captured in an introductory video produced by legal tech developer Clause, in which Dentons' legal tech accelerator, Nextlaw Labs, has invested.

However, in practice, a number of factors may limit where and how smart contracts may be deployed.

- One potential limiting factor is whether an agreement that is both legally binding and practically useful can be formed and/or operated without intentional human intervention. English contract law, for example, starts from the assumption that a contract embodies the intentions of two or more parties, and many contracts are designed to deal with a range of possible situations in which the parties may find themselves by allowing one or other of them to choose between different options. Smart contracts, as generally conceived, are not actually very "smart". They are not artificially intelligent or examples of machine learning: they are designed to bring about a particular outcome every time a specific condition is exactly fulfilled ("if X, then Y"), and will not necessarily readily accommodate reference back to the human decision-makers involved at critical junctures ("if X in form reasonably acceptable to the Seller, then Y"). To the extent that they involve such reference, much of the point of automating the contract may be lost. At the very least, parties may wish to agree in a conventional contractual framework how the automated system will operate. Such a framework may be as important for identifying the parties with whom each participant is prepared to enter into smart contracts as for supplementing their terms. Legislation governing the form or terms of particular types of agreement may also be a barrier to the deployment of smart contracts, particularly those involving individual consumers.

- Another set of limitations relates to the extent to which coding can do the job of conventional legal drafting. For example, while there are already smart contracts that can automate a transfer of title when a particular condition is met (such as payment), the coding would be unable to address the richer context and subjectivity that might be included in or underpin many traditional contractual provisions. It is difficult to address issues such as "satisfactory quality" or "reasonable endeavors" and nearly impossible to deal with issues relating to the broader context of the transaction such as frustration. Work commissioned by ISDA in this area points to non-operational provisions in a contract (such as those on governing law and jurisdiction) as areas where the conditional logic on which computer programs run is less likely to work.

- Automatic execution and the immutability of blockchain mean that, if a result that the parties do not want has occurred, they may have no alternative but to unwind it by a separate conventional contract—always assuming that they share the same view of what the "correct" result should have been. The combination of immutability and the need to achieve consensus across a large network of participants can also create difficulties in addressing bugs in a smart contract program. In at least one well-publicized case (The DAO), this seems to have contributed to a situation in which a hacker was able to steal US$50 million.

- Although some smart contracts will be self-sufficient in the sense that all the data that they need to operate will come from within the blockchain, many will require external data inputs—information about what is happening in "the real world"—to trigger their operation. The software agent program that provides such external data is known as an "oracle". However secure a blockchain and its associated smart contracts may be in themselves, because an oracle by definition interfaces with external data, separate steps will need to be taken to ensure that the data concerned is accurate and that the oracle is not being manipulated. To put it another way, the "trustless" automated system of smart contracts will still often require users to trust humans when it relates to the physical world.

- A related point is that, where sale and purchase are concerned, a smart contract will be better placed to self-execute when execution essentially only involves the transfer of title by making an entry in a register or—to the extent that physical delivery is involved—movement of goods through a more or less automated network such as an electricity grid.

There is a great deal of work still to be done before smart contracts become a generic or commoditized product. It seems unlikely that we are about to enter a world in which machines form and perform legally binding agreements without human intervention or the existence of an underlying conventional contractual framework. Overall, it seems unlikely that significant commercial blockchain applications of smart contracts will arise unless they are underpinned by a conventional contractual framework that deals with those aspects of the legal relations between participants that are less apt to be coded and automated and embodies the agreement of the human (or corporate) participants to abide by the rules of the smart contract game for those that are suitable for coding and automation. But the partial automation of some aspects of existing contractual relationships could become commonplace in areas of commercial activity where there are no regulatory barriers and the subject matter lends itself to standardized treatment. We explore later in this volume how this could include trading of power and other commodities such as oil.

Blockchain, cryptocurrencies and smart contracts: the legislative and regulatory agenda

There has so far been relatively little done in any jurisdiction by way of systematic legislative or judicial consideration of blockchain, cryptocurrencies or smart contracts. There are some notable exceptions to this, but these are often fairly limited in scope.

In the US, the Report of the Joint Economic Committee of Congress on the 2018 Economic Report of the President devotes an entire chapter to the implications of blockchain in a number of policy areas, with some particularly interesting comments on taxation and money transmission.

At state level, measures have been enacted or proposed with a view to facilitating the use of blockchain and/or smart contracts in Delaware, Arizona, Nebraska, Tennessee, Wyoming, Illinois and California.

In the UK, the Law Commission, an independent statutory body that advises the government on law reform, is about to embark on a study of smart contracts. The Commission's most recent Annual Report notes the need to "ensure that English courts and law remain a competitive choice for business" and finds "a compelling case for a … scoping study to review the current English legal framework as it applies to smart contracts … to ensure that the law is sufficiently certain and flexible to apply in a global, digital context and to highlight any topics which lack clarity or certainty."

The application of laws regulating the public offering of securities as it applies to ICOs and token sales is one topic that has already received some attention but, although most White Papers and announcements of ICOs do their best (with varying degrees of finesse) to put themselves outside the scope of any applicable securities regulation, the issue remains live.

- The SEC's report of an investigation into The DAO is a good example of a regulator more or less successfully applying existing statutory provisions that were drafted long before anyone had dreamt of blockchain to consider the lawfulness or otherwise of the activities of one of a supposedly completely new category of Decentralized Autonomous Organizations.

- Also noteworthy in this context are the ICO Guidelines recently promulgated by the Ministry of Finance in Lithuania. The guidelines suggest that tokens that grant rights such as participation in company management, receiving a share of profits, income or interest on funds invested, or the ability to recover such funds

and receive additional income through redemption of the tokens, are likely to be considered as securities. As such, they may be subject to a range of regulations, including laws on securities, crowdfunding, money-laundering, collective investments and markets in financial instruments. Many of these are governed by EU-wide regimes and so are of relevance beyond the vibrant Lithuanian blockchain scene. The guidelines also make some important points about the tax and accounting treatment of tokens.

- One recent survey highlights a number of jurisdictions where ICOs are prohibited or significantly restricted. Prominent among jurisdictions that took action to curb ICOs in 2017 were China and South Korea, although there are some indications in both cases that prohibition was a prelude to the development of regulation. In Japan also, the Financial Services Agency has been turning its attention to crypto exchanges.

The relatively limited amount of legislative provision or regulatory action specifically applicable to blockchain to date means that to work out how to use any of these technologies to support any particular commercial model from a legal point of view one needs to go back to basics to try to analyze how existing legal concepts and rules can be applied to them. We sketch out some starting points for such analysis below. Such analysis is both the necessary precursor to any serious legislative or regulatory intervention and an essential step in the commercialization of any significant blockchain project that is not supported by a comprehensive regulatory framework.

Blockchain and contracts: an energy sector perspective

Contract law will be fundamental to any commercially significant blockchain venture in the energy sector. To put this in context, we set out below a non-exhaustive list of ways in which blockchain and smart contracts could be deployed by parties in energy transactions (taking separately steps such as contract formation, record of contract, performance, validation of performance and settlement).

- Two parties enter into a transaction in a conventional way, and record the transaction using blockchain. The parties will then still perform the transaction in whatever is the relevant way.
- Two parties (by their actions at the time) enter into the transaction using blockchain as a platform on which one of them offers the transaction and the other accepts the offer.
- The transaction is made using blockchain, without any action at the time by the parties, based on the fact that pre-specified conditions are satisfied at the time. Contractually, this could be characterized either as the implementation (upon satisfaction of the conditions) of a contract already entered into or as the creation of a contract on the basis that the occurrence of conditions amounts to acceptance by one party of a standing offer by the other.
- A transaction is made, between two or more parties, as part of a wider scheduling or system management function using blockchain, for example optimizing power flows on an electricity distribution network on behalf of (or even instead of) a distribution system operator. This implies a multiparty contract, with complex and potentially layered or sequenced "trigger" conditions; it will raise questions of interdependency of transactions, and transparency and validation of the conditions (which of course may also be solved in the blockchain).
- The transaction is not only entered into, but is also performed, by an operation using blockchain (where performance is "dematerialized"). An example would be giving notification to a market operator of an energy transfer within a balancing regime (such as an "energy volume contract notification" or "NBP trade" within the British power and gas markets). As well as the issues of contract formation, there is an inherent agency relationship to be created here (with the relevant market operator).
- Alternatively, the transaction is physically performed on an automated basis, for example by the technology remotely directing the operation of valves or switching equipment to implement a contracted energy flow.
- Performance of the transaction is assessed / verified by blockchain, for example on the basis of meter readings / allocation statements / other performance data being directly fed in. This could extend to the implementation of financial adjustments / remedies where performance deviates from what was contracted for.
- The transaction is financially settled using blockchain, i.e. payment by one transaction party to another is made automatically upon the transaction being created, or upon its being performed. This may be done using either fiat or cryptocurrency; and credit risk may be managed by prepayment arrangements (a sufficient credit balance for the paying party being one of the conditions to transaction formation).

- The transaction is made and performed (or performance assessed) simultaneously using blockchain—in effect a combination of some of the above points. An example would be where the trigger for a transaction is a meter reading, so that the energy flow which the transaction concerns has already occurred and been measured at the time the contract is formed. This could be seen as effectively an option, which is exercised by the outturn result of its subject-matter.

No doubt there are other possibilities and in many cases a combination of the above will apply. Aside from the basic question of what contract framework is required to underpin or enable these blockchain-based transactions, they raise other contract law issues in areas such as how they interface / interact with other "external" contracts; cross-default; the timing of transaction formation and insolvency issues; the basis on which parties can withdraw from or modify contingent commitments; nature and definition of contract breach; suitable force majeure definitions; and remedies, penalties and mitigation where contract outcomes for breach are "automated."

The above is only an outline sketch of issues, but it suggests that, when establishing a new blockchain venture in the energy sector, the participants, as well as having to think hard about the kinds of issues that always take up a fair amount of negotiating time in any complex commercial project, may have to spend some time re-thinking some quite basic contractual concepts in order to embody their business model in a robust legal framework.

Blockchain: other legal considerations

Contract law is, of course, not the only area of law where careful thought is required when considering a blockchain project.

Blockchain began as a system for supporting the issue of, and transactions in, a new form of currency which exists within the blockchain itself. If blockchain is to be used as evidence of or a means of transferring the ownership of or entitlement to things that exist in the "real" world outside the blockchain, a supporting framework of law is required to mesh with the code. Up to a point, a group of businesses that are operating in a jurisdiction that generally allows parties freedom as regards the substantive provisions of contracts can agree "rules of the game" that may form a self-sufficient system—in which, for example, it is agreed that digital transfer of a token confers ownership of a specific physical asset on the transferee. However, even in that case, participants would need to consider whether there are circumstances in which, in order for their project to be fully effective, they will need third parties, who have not agreed to their rules, to take notice of, and modify their own behaviour in accordance with, for example, property or other rights as recorded in a blockchain.

Any new project will obviously need to be carefully analyzed against applicable intellectual property and data / privacy law. For example, under the EU's General Data Protection Regulation (GDPR), businesses can face heavy penalties for non-compliance with rules on the processing of (broadly defined) "personal data." Blockchain applications that fall within the scope of the GDPR—perhaps particularly those based in the EU or aimed at individual EU consumers—will have to grapple with the fact that GDPR was designed with centralized rather than decentralized networks in mind. Suggestions have been made as to how the GDPR could be interpreted so as not to stifle blockchain-based business models involving individual consumers and how projects could be designed so as to comply with it. But, as the regime has only just come into force, it is likely to be some time before there is any authoritative ruling on how it applies to the handling of personal data in a blockchain context.

Competition law is another area to watch in the development of blockchain projects. One of the potential attractions of many blockchain business models is greater market liquidity and transparency, but participants and antitrust authorities alike will need very robust assurance that such transparency does not include commercially sensitive information about prices, for example, being visible to others in a way that could dampen competition. At the same time, in any sector where blockchain platforms come to account for a substantial part of the market, there will be either a single dominant platform or a number of competing ones. Any platform or group of platforms that occupies a dominant position will need to ensure that there is nothing in its structure or behavior that tends towards abuse of its market power in relation to either customers or competitors. On the other hand, where a number of different platforms provide similar functionality, care will need to be taken to ensure that participants are neither prevented from participating in more than one platform nor unfairly disadvantaged if they do so (questions of interoperability, for instance, will need to be considered in this context). Principles of antitrust analysis developed in cases relating to credit card providers and other "two-sided markets" may be relevant. The OECD has produced an issues paper on blockchain and competition policy identifying a number of possible areas of concern.

The idea of being in a position to raise antitrust concerns might seem like no more than a "nice problem to have" for many of today's blockchain startups. But it may be better to address potential competition law issues from the outset, rather than be forced to modify a business model by a competition authority, or legislative action, at a later stage when there could be much more at stake. After all, if blockchain fulfils its promise, some platforms are likely to grow very quickly, and they will do so in an environment in which competition authorities have become more sensitive to the potential downsides of a variety of online and technology based business models.

Oil and gas: maritime trade and trade finance

The oil and gas industry was not, at first, among those most enthusiastic about all things pertaining to blockchain. Yet now, if you run an Internet search on "blockchain" or "distributed ledger," coupled with the name of almost any major oil and gas company, you will soon find at least one or two stories about how the company is looking to exploit blockchain technology—often in collaboration with one or more of its peers, with a view to facilitating international trading of oil and gas. What is going on?

Bills of lading and letters of credit: a well-established system ...

Every day, millions of barrels of crude oil and oil products are bought and sold internationally. Much of that oil travels by ship and, as with other commercial cargoes, shipments entrusted by a seller (or shipper) to a carrier for delivery to a buyer at a certain location (or locations) are often the subject of a bill of lading.

Bills of lading have been used for hundreds of years and, over the course of time, they have acquired three principal functions. They are evidence of receipt of the goods by the carrier (who issues them) and of its contract of carriage with the seller and (subject to construction of the terms of the individual bill of lading) they can act as a document of title to the goods. Moreover, at the time they are issued, they may or may not name the recipient to whom the goods are to be delivered, making them respectively non-negotiable or negotiable.

These features of bills of lading enable them to play a powerful facilitating role in physical international commodity trading (as distinct from the purely financial trading in commodities that takes place largely on organized exchanges or trading platforms, serving to reduce participants' risk of exposure to volatile commodity prices and improve liquidity in the market).

- They can enable a cargo to be bought and sold several times while the ship is at sea: depending on the form of bill of lading issued, this can be done by transferring possession of the bill and/or (if it was issued without details of a nominated recipient being endorsed on it) endorsing it with the new recipient's details.

- They play a key role in financing the buying and selling of the goods through the mechanism of a letter of credit (LC): (i) the buyer and the seller agree the sale and purchase of some goods; (ii) the buyer's bank issues an LC to the seller's bank, to the effect that the buyer's bank will pay the seller's bank the price that the buyer and seller have agreed for the goods, on fulfilment of certain conditions, including receipt by the buyer's bank of the bill of lading; (iii) the seller loads the goods onto the carrier's ship and receives the bill of lading; (iv) the seller passes the bill of lading to the seller's bank; (v) the seller's bank pays the seller the agreed price; (vi) the seller's bank passes the bill of lading to the buyer's bank, which pays the agreed price to the seller's bank; (vii) the buyer pays the agreed price to the buyer's bank; (viii) the buyer's bank passes the bill of lading to the buyer; (ix) the buyer presents the bill of lading to the carrier and receives goods.

- The LC system works because it reduces the need that would otherwise exist for the buyer and the seller (or the buyer's bank and the seller's bank) to trust each other: nobody needs to pay the purchase price without receiving the bill of lading that will give them title to the goods. In particular, from a legal point of view, the banks in the system are financing the transaction by taking a pledge over the goods. A pledge is a form of security created by transferring either physical possession of goods (as in the case of a pawnbroker) or possession of a document of title which gives the lender control over the process of transferring title to the goods. Since the holder of a bill of lading is entitled to take possession of the cargo at the discharge port, the deposit and endorsement of a bill of lading allows the holder to transfer title to the cargo. Accordingly, depositing a bill of lading with a creditor constitutes the transfer of possession necessary for a pledge to be created. Because pledges are a form of security recognised in almost all legal systems, they are well suited to short-term international trade finance, particularly when dealing with commodity cargoes that can only readily be distinguished by the fact that they are on a particular vessel.

... but not a perfect one

Bills of lading are pieces of paper, issued in triplicate. At each stage in the process outlined above, they have to move physically from one party to the next in the chain. This seems a little archaic in the 21st century. In any event, the bill of lading / LC system, for all its conceptual elegance and centuries of robust practical application, is not without flaws.

- It is quite easy for minor irregularities, such as endorsing the bill with the name of the wrong corporate entity, to give rise to practical and legal difficulties.
- Along the chain of documents between sellers, banks and buyers, inconsistencies may creep in, for example between successive letters of credit and the original bill of lading. This may be accidental, or it may be the result of amendments to reflect changing commercial circumstances (e.g. where the goods have been found not to match the original specification).
- Even in a case where all the paperwork is in order, if the goods are bought and sold several times between their shipping by the original seller and their arrival at the port of delivery (perhaps with a fresh LC each time), the slow physical progress of the bill of lading may result in it not having caught up with the goods by the time they arrive.
- The absence of a bill of lading can be addressed by the issuing of a letter of indemnity (LOI). LOIs may be issued in favor of intermediate buyers by sellers, indemnifying them against any loss they may suffer as a result of not being able to present a bill of lading. Equally, a recipient to whom a carrier delivers the goods may indemnify the carrier against losses that it may suffer as a result of not having delivered against the bill of lading.
- However, in neither case is the LOI a wholly satisfactory substitute for the bill of lading. Finance provided against an LOI lacks the key element of security afforded by a bill of lading. A carrier who relies on an LOI, perhaps particularly if at the same time it is making delivery at a port other than that referred to in the bill of lading or to a person other than the then true owner of the goods, may find that in so doing it becomes liable for breach of contract (to the seller) and possibly in tort (conversion) to the true owner. Moreover, having relied on an LOI rather than a bill of lading it may have breached the terms of its insurance cover.
- There is plenty of opportunity for one or more of the originals of the bill of lading to go missing by accident. There are also opportunities for theft and various forms of fraud.

Numerous reported cases have come before courts around the world, arising from these kinds of scenarios. No doubt plenty more have been resolved by arbitration or other means. Where large and valuable hydrocarbon cargoes are involved, substantial sums are at stake in such cases and large and experienced players are by no means immune to the kinds of problem outlined above. So how could blockchain, the modern "trustless trust machine," help to solve the longstanding weaknesses of LCs and bills of lading—mechanisms that in earlier ages were themselves developed to facilitate trade between counterparties who had no reason to trust each other?

Blockchain and the evolution of e-bills of lading

There is no shortage of apparent enthusiasm for attempts to replace the paper-based heart of international trade with an alternative, blockchain-based, system.

- The Dutch bank ING has been developing a prototype of what it calls Easy Trading Connect, on which it has carried out demonstrations, including a series of transactions involving Société Générale, commodities trading house Mercuria and a cargo of African crude oil that was sold three times whilst in transit. The participants were reported to have significantly increased transaction speeds and estimated blockchain could realize 30 percent cost savings.

- In addition to ING's product, other projects in this area include a joint venture between IBM (which promotes its own version of blockchain, Hyperledger) and leading global shipping company Maersk, which has also worked with Microsoft and others on ways of using blockchain to make shipping insurance more efficient. Since the technical and legal issues involved in moving away from paper bills of lading are much the same for oil and gas as for any other cargo, other projects in this space may also be relevant to the oil and gas sector: for example Wave, which is reported as having worked with BBVA to reduce the documentation process for an international shipment of tuna from 7-10 business days to 2.5 hours.

- Trials of blockchain-based physical oil or gas trading have also been reported as involving a variety of oil majors, including Statoil (now Equinor), as well as financial sector parties such as banks and trading houses. BP has been working with platform developer BTL on its OneOffice system, and after initial trials involving Eni and Wien Energie the group has now expanded to include Gazprom, Petroineos, Mercuria, Vattenfall and others.

- One blockchain trade documentation start-up, CargoX, has reported that it reached the US$7 million limit that it had set for its ICO offering in less than eight minutes in January 2018, attracting support from 2,000 investors in 95 countries. In July-August 2018 it demonstrated its "Smart B/L" system in respect of a shipment of garments from China to Slovenia.

On the other hand, the idea of getting rid of paper bills of lading is not unique to blockchain-based ventures, and the notion of an "e-bill of lading" predates the current buzz around blockchain. Bolero (originally an acronym for Bills of Lading Electronic Registry Organization) began life in 1994 and went live in 1999 (and was the subject of scholarly legal analysis within a year). Two other e-bill of lading providers, ESS and E-Title, have been operating since the middle of the last decade. All have made considerable progress in the market, assisted in particular by their acceptance by influential shipping insurance bodies. Nevertheless, use of paper bills of lading still remains common, and the interest in the new blockchain ventures (including on the part of Bolero and ESS, as enhancements to their existing services) suggests that e-bills have yet to conquer the world.

There seem to be a number of reasons for this. One is that e-bill of lading systems only replace paper completely where all the parties involved have agreed to the rulebook of the service provider: as soon as the chain of transactions relating to a given cargo involves a party outside the group of those who have signed up to the rules, paper comes back into play. Another is cyber-security worries. Other commonly cited concerns are that e-bills may not be acceptable in some jurisdictions and that the international law that could potentially underpin them, in the form of the UN convention known as the "Rotterdam Rules," agreed in 2008, has so far been ratified by only four of the 25 countries that are parties to it (20 ratifications are needed for the convention to enter into force, but not all commentators are persuaded that this would be a positive step). It remains to be seen whether more national governments or legislatures will make an effort to adopt legislation at a national level that follows the principles of UNCITRAL's recently adopted Model Law on Electronic Transferable Records (MLETR), which would be helpful in this context. Both the Rotterdam Rules and the MLETR address in principle a number of the key aspects of how an electronic document can be functionally equivalent to a paper bill of lading, and they do so in terms that are also applicable in the blockchain context.

So how can blockchain solutions improve on pre-existing e-bill of lading regimes? CargoX focuses on three ways in which it considers its approach superior to that of its non-blockchain-based competitors.

- CargoX does not require a central trusted authority to run the system. Clearly, blockchain is by definition a decentralized system. It is not clear whether the need for a central authority has proved a drawback for Bolero, ESS or E-title. However, it must at least be true that a blockchain-based solution that is not constructed around a central authority has the inherent advantage of blockchain technology: the resistance to hacking

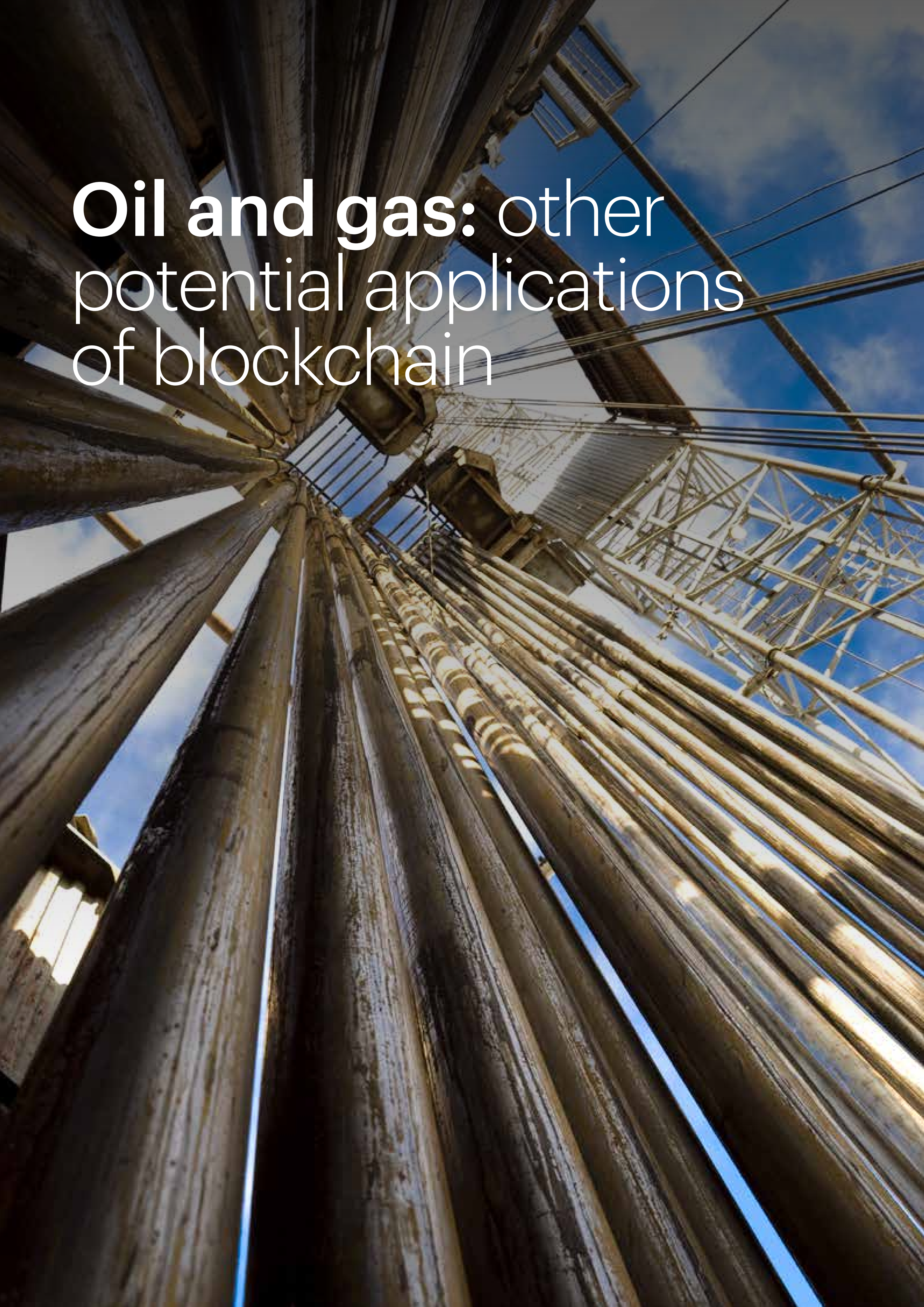
of the blockchain itself, and the security that comes from records being kept in identical form at multiple nodes.

- CargoX observes that "an online settlement of value" has not been possible with existing e-bills of lading, but does not really elaborate on this. It is not clear why, in principle, a non-blockchain e-bill of lading platform should not also facilitate payments.
- CargoX also says that non-blockchain regimes lack transparent rules governing e-bill of lading exchange processes, but the evidence for and significance of this are not drawn out.

In some ways, the new transaction processes described by CargoX and others do not appear to be all that revolutionary. Just as e-bills of lading mimic the form of paper bills of lading, so, recognizing the tried and tested merits of bills of lading, the latest generation of would-be disruptors aim to replace them in a formal sense (by substituting a more digital version of the e-bill and introducing some smart contract functionality) but do not set out radically to reengineer long-established ways of doing business in maritime trade. There are even points in CargoX's White Paper when it seems unclear in what sense paper has been replaced (e.g.: "[The transfer] function allows the parties to exchange a B/L contract, thus electronically exchanging ownership of the physical B/L document and rights pertaining to [its] holder."). In any event, it has been noted that the mere use of blockchain as a means of dealing with e-bills of lading, whatever other, practical, advantages it may bring, cannot in itself remove any of the underlying legal concerns about using an electronic rather than a paper document.

One of those concerns, which has been noted for some time in connection with non-blockchain e-bills of lading, is the difficulty of making them work as security for finance in common law regimes. As noted above, at present, the basis on which paper bills of lading are often used in a financing context is the law of pledge. This works because of the way that the piece of paper represents title to the underlying goods, making possession of the physical piece of paper an effective form of security for a bank. By contrast, an e-bill of lading or other transport document that only exists in electronic form, whether or not on a blockchain, is something of which it is not possible to take physical possession. This means that the creation of security over a cargo by a deposit of such a document would need to be replaced by a different form of security, such as a mortgage or charge, the use of which (unlike a pledge) requires registration in order to be effective in many jurisdictions. In an industry where the owners of cargoes often have multiple banking lines and are securing different cargoes to different lenders (increasing the risk of problems with identification of the goods that are the subject of the security interest), finding a way of making security arrangements involving electronic documents work as efficiently as a pledge involving a physical bill of lading may require action at an international level.

Oil and gas: other potential applications of blockchain



It is not only in the specific context of maritime trade facilitated by bills of lading and letters of credit, as considered in the previous article, that blockchain should be able to make oil and gas trading and transportation less "paper-intensive", and the associated record-keeping less prone to human error.

Trade, transport and storage

For example, BTL's White Paper on blockchain in the energy sector points out how blockchain can eliminate the need for time-consuming reconciliation processes, such as are required when gas moves through and between pipeline networks, because it is in the nature of a distributed ledger to which all the relevant participants have access to "bake in" reconciliation from the outset. The same point was evidently not lost on the North American gas trading platform NGX, which has collaborated with Nuco on a blockchain-based "prototype" of a service that would provide real time tracking of natural gas flows at delivery points and optimize settlement, having the potential "to enhance delivery and payment processing, mitigate the risk of, and expedite remediation of, supply shortfalls, and provide secure transactional data."

Another use of blockchain, this time by providers of physical as well as commercial infrastructure for hydrocarbons seeking to enhance their offering, was recently announced in Fujairah, home to the Middle East's largest commercial storage facility for refined oil products. This is part of the ongoing relationship between S&P Global Platts and the Fujairah Oil Industry Zone, which aims to enhance Fujairah's position in the market and to establish a benchmark pricing index. At the heart of this project appears to be the replacement of the "manual and unstructured" processes by which the 11 terminal operators at Fujairah communicated inventory data. The parties hope that the new technology will also allow dynamic display of (better quality) data, improve security of data transmission and storage and simplify the certification of asset ownership.

But facilitating paperless trade in hydrocarbons is only one aspect of what it is said that blockchain can offer the oil and gas industry.

Big Data and Big Oil

It only takes a few moments' thought, even by someone not particularly familiar with the inner workings of the oil and gas sector, to appreciate that it is home to some of the world's most complex and high value supply chains. The industry must deal constantly with a huge range of suppliers of goods and services, providing the many inputs into their exploration, production, refining and marketing activities—everything from hydrocarbons themselves to steel tubes to geophysical consultancy. Oil and gas companies are often heavily dependent on oilfield services companies and other specialist contractors, and each project is a nexus of multiple, overlapping and decentralized supply chains. Managing the supply chain effectively is critical to success: there are so many interdependencies that failure of a single supplier to deliver the right product in the right place at the right time can easily be very costly (e.g. if production is interrupted as a result).

What does this mean in practice? The supply of even a single item often involves multiple parties (manufacturers, importers and exporters, freight forwarders, couriers, import and export terminals, carriers and banks) and payments. Large amounts of paperwork are involved (contracts, invoices, bills of lading etc). Often there will be as many, or almost as many, IT systems involved as there are parties, including a range of transport, customs and warehousing management systems (TMS, CMS, WMS) and enterprise resource planning (ERPs), to name a few. Each stakeholder will keep its own records, which are not usually accessible to the other stakeholders. At various points in the process, the previous stages will require to be verified, often multiple times by multiple persons. Aside from the obvious inefficiencies, in terms of both time and financial cost, the process is vulnerable to human error and even open to abuse and manipulation.

The immutable nature of blockchain records makes it an obvious medium, either on its own or in combination with geospatial technology, for tracking ownership of goods and materials, particularly through a complex process where they may change hands multiple times. In addition to tracking the ownership of the goods, blockchain could provide an instantly verifiable status update on the procurement process, and correlations with purported delivery could be used to corroborate transactions or flag them for investigation. If each purchase order, change of order, bill of lading, receipt etc is recorded (and/or carried out) on the distributed ledger, each participant can have an up-to-date awareness of progress, and any delays will be highlighted early and to all stakeholders.

Smart contracts could further streamline the process as the satisfaction of a specified condition at one link in the chain triggers fulfilment at another: for example, if an audit certificate is issued, payment in respect of the goods is released to a counterparty. The decentralized aspect of blockchain could also make it a suitable platform for organizing cooperative arrangements between manufacturers, distributors and end-users in relation to the stocking and distribution of spare parts (accurate decentralized records of who holds what parts where should optimize the use of scarce resources).

It comes as no surprise that IBM has identified supply chain management as a promising area for blockchain, or that it has attracted the attention of ports (see for example the position paper on a digital Port of Rotterdam), logistics companies and procurement managers in equal measure.

For the oil and gas industry, the development of supply chain use cases for blockchain coincided with a period of lower oil prices that brought increased focus on controlling supply chain costs, particularly in the upstream sector. In some areas there is also a growing awareness of the benefits of collaborative approaches that may require more sharing of data between competitors. At the same time, the industry's attention has been drawn to the gains to be made from digitalization generally. A 2017 White Paper produced by the World Economic Forum and Accenture urged senior oil and gas executives to "make digital a priority," having identified US$ hundreds of billions of value, as well as significant environmental benefits, to be unlocked by "digital transformation" (admittedly none of it specifically from blockchain, whose potential it noted but considered it too early to quantify).

In short, with data being regularly described as "the new oil," the complexity of the "old" oil (and gas) industry's supply chain arrangements means that it is well placed to be a target for those seeking to devise and market blockchain solutions that promise to unlock new efficiencies and value.

Perhaps the most conspicuous blockchain venture specifically targeted at the industry so far is PetroBloq, a joint venture between Petroteq and First Bitcoin Capital established in late 2017, which aims to be "the first Blockchain based platform developed exclusively for the supply chain needs of the Oil & Gas sector". It is already reported to have signed up as a potential customer Mexican giant Pemex (which also has the distinction of owning "the first gas station to accept crypto" as payment). In addition to energy product and commodity trading, amongst the areas where PetroBloq envisages adding value are "sharing digital blockchain information in joint-operating agreements," which could "reduce, if not eliminate, the need for reconciliations between companies and for data hubs controlled by third parties," disrupting "current processes for balloting partners on new projects, performing joint interest billing, and reporting production revenue;" and smart contracts ("simply put, this potentially game-changing technology will provide knowledge of who gets paid how much, as well as insight into who along the chain is performing as explicitly mandated by agreements").

A little more recently, in June 2018, Diamond Offshore Drilling of Houston launched its Blockchain Drilling™ Service. This comprises a "Supply Chain & Logistics Manager" to provide "transparency, provenance and immutability across the entire supply chain," a "Well Planner" to display "actual versus planned time-to-depth data with detailed events," a "Spend Monitor" to aggregate well construction costs against budget, a "Dynamic Critical Path" to show "real-time bottlenecks as they develop" and a "Performance Tracker" to monitor operational KPIs. Ondiflo, a joint venture between "order to cash" specialist Amalto and blockchain technology company Consensys, is also focused on parts of the oil and gas supply chain, with a particular focus on logistics and IoT. In January 2018, Geospatial Corporation announced its development of a "cloud-based locational software platform," using blockchain and GIS that would allow energy companies "a secure way to manage contracts, assure provenance and track asset maintenance."

Many supply chains in the industry are as much—or more—about data as about the supply of physical products. The product supplied may itself be data (e.g. seismic surveys), or the supply of physical products may be closely linked to the provision and processing of data, such as the huge amount of information now capable of being produced by sensors on oil rigs. One can imagine, for example, setting up a smart contract function to order a new drill bit when data received from a particular sensor indicate that the existing bit will soon need to be replaced.

Another oil and gas sector player focusing on data-related supply chain applications of blockchain is BHP Billiton, which in 2016 was reported to have announced that it was exploring the use of blockchain to record movements of wellbore rock and fluid samples, secure real-time data generated through delivery, and manage the collecting of samples and the sharing of the results of analyzing them. Like others in the extractive industries, BHP Billiton deals with samples through international networks of geologists and shippers, who collect samples and conduct analyses for it around the world. Having an efficient and secure system to track samples and share the data derived from them, which feed into strategic business decisions, is commercially very important. Whether blockchain is the only, or currently the best, way to build such a system is another question. There are those who suggest that blockchain may be a good way of storing small amounts of data (like the details of a bitcoin transaction) but that it is a bad way to store very large amounts of data (like a geophysical report). Of course, some of these critics have their own, non-blockchain products to promote.

Another area where blockchain is seen as being able to add value in supply chains is in relation to what might broadly be termed provenance or certification. For example, applications are being developed to provide assurance about food safety / traceability, or producers' compliance with sustainability and other ethical criteria. In the diamond market, the source of the stone is of primary importance, and suppliers / distributors are under extreme pressure to verify that stones have not been sourced from conflict zones: the use of blockchain in this context was first promoted by startup Everledger and has now apparently been embraced by De Beers. Similarly, concerns about the circumstances in which some cobalt is produced have led BMW to explore ethical sourcing arrangements for the cobalt to be used in its electric vehicle batteries with Circulor. In the marine bunkering sector, Blockchain Labs for Open Collaboration (BLOC) has announced the establishment of a consortium to address traceability and transparency in the marine fuel supply chain.

At the heart of these applications is the ability to get reliable certification about individual items or quantities of a commodity, and to track them as they move through global supply chains. There is potentially a large range of attributes of oil and gas cargoes that could be marked in this way, including details of chemical composition, compliance with international sanctions regimes, local content rules, or ethical or environmental standards. The last of these categories could be particularly significant in the context of future carbon-pricing regimes, which might, for example, differentiate between two otherwise identical quantities of gas, one of which had been produced in a way that minimized fugitive methane emissions and another which had not. The recent announcement of the purchase, by utility New Jersey Resources, at an above-market price, of shale gas certified as responsibly produced by Independent Energy Standards Corp. shows the potential market demand for hydrocarbons produced to specific environmental standards even in the absence of legislative carbon-pricing.

In the end it may be simply the highly collaborative nature of oil and gas projects and their tendency to be structured as contractual joint ventures that will drive some applications of blockchain in the sector. It is not difficult to imagine ways in which the working of joint operating agreements and other kinds of contracts, such as lifting agreements, that are commonly entered into by those who jointly own or use particular assets or infrastructure could be enhanced by a combination of blockchain and smart contract provisions. The arrangements between such parties are full of requirements about the sharing of information, engaging in collective decision-making, making nominations and payments, and gaining or losing entitlements in specified, objectively ascertainable, circumstances. The implementation of all these kinds of provisions could potentially be made more efficient by being facilitated using blockchain and wholly or partially automated with smart contracts. The advantage of applying blockchain in this context is that it ought to be possible to achieve useful results without initially having to get agreement from a large number of parties (as might be the case with wider supply chain initiatives) or to secure any changes in law or regulation.

Blockchain and the state

As well as frequently being in joint ventures, upstream oil and gas companies are often in direct legal relations with a government or state-owned body—for example as a result of licensing, concession or other regulatory arrangements. Giving a state-owned counterparty or regulator an appropriate level of access to blockchain-based arrangements between the commercial parties to a project could improve transparency and significantly reduce the burden of complying with a range of reporting requirements in relation to, e.g., the implementation of development plans.

There are of course many other potential applications of blockchain arising in the context of state involvement in the oil and gas industry. In Chile, the National Energy Commission has begun to use blockchain as a way of providing additional assurance of the integrity of a number of the sets of data published on its Open Energy platform. A number of land registries around the world, perhaps most notably the Swedish Lantmäteriet, have considered using blockchain as a way of improving the quality and speed of the essential public service that they provide—for example, enabling security interests or restrictions on title to be registered more quickly. In jurisdictions where rights to petroleum are conferred by, e.g., a license from the state rather than a lease from a private landowner, having a decentralized digital system for recording interests in licensed areas, and updating the record to reflect the effect of transactions among joint venture participants and between them and third parties, could have considerable advantages over current paper-based systems, in which it is common for documents to go missing, making absolute certainty in tracing title unattainable. It is arguably not a very big step from using a decentralized digital system to record individual interests in licensed areas to using such a system to create and transfer interests.

Finally, and on a rather different note, we cannot leave this brief survey without mentioning the Venezuelan government's establishment of a cryptocurrency intended to be backed by oil, the Petro. It is too early to tell how far or fast the Petro project will succeed in its ambitious objectives, but the idea of a cryptocurrency backed by a commodity is not a new one, and, if the notion of state sponsored cryptocurrencies gains traction more generally, other hydrocarbon rich countries with less than robust conventional fiat currencies may consider following Venezuela's example.

Blockchain and the changing shape of electricity markets

Many of the applications of blockchain in the oil and gas sector owe their attractiveness to the capacity of the new technology to enable existing markets to operate in some ways much as they always have done, but more efficiently and realizing some further economies of scale. There is some scope for that kind of development in the electricity sector, too. But the greatest excitement about blockchain in relation to electricity has arisen in areas where it is thought that the use of blockchain could facilitate fundamental changes in industry structure.

Broadly speaking, the invention of blockchain has come at a point when the electricity industry is in the process of moving from highly centralized market structures with relatively few potential participants to a much more decentralized structure with extremely large numbers of participants. At present, the full transition to that radically decentralized future market structure is being held back, partly by technical limitations, partly by economic factors, and partly by regulatory constraints. The hope is that blockchain will remove or reduce the technical limitations and some of the economic obstacles, and either get around the regulatory obstacles or create unstoppable momentum for them to be removed. Further, on an optimistic view, this will both make electricity markets more efficient and help to accelerate a more general transition to a low carbon economy.

In this article, we set out the background to the energy transition and some of the obstacles holding it back in some detail, and then consider why, in theory, blockchain may be able to overcome some of them. In the next article, we look in more detail at a series of specific projects and consider what they can tell us about the technology's potential to disrupt the electricity sector.

Setting the scene for a revolution

To understand the excitement around blockchain in the electricity industry, it needs to be seen in the context of the evolution of the industry's structure. (You can skip over this section if you are familiar with conventional electricity market structures and how they have changed over the last 20 years.)

Over the course of the 20th century, a standard model for the electricity industry developed which was generally characterized by the following features.

- Large "central" generating stations were typically fueled by combustion of fossil fuels, nuclear reactions or the flow or water. All these technologies are more or less susceptible to varying their output to match fluctuations in demand in a predictable way ("despatchable") and, according to the ease and speed with which such variations can be made (and the cost of doing so), they are classified as "baseload," "peaking" or "mid-merit" plant.
- High voltage transmission networks typically serve all or a large part of a given country (almost all power systems being organized on essentially national lines). Only the very largest end-users of power are directly connected to these, and they feed into lower voltage regional and local distribution networks from which most end-users take their power. Distribution networks were built on the assumption that they would

invariably be carrying power from the points where they connected to the transmission network to users, who would simply consume that power (after it had been stepped down to lower voltages).

- In most economies, economic growth invariably led to increased demand for electricity, which was met by building more central generating capacity and/or more extensive networks.
- The separate functions of generation, transmission, distribution and supply (i.e. the retail supply of power to end-users) are regulated in different ways. Most end-users of power can only engage with the market through a supplier (following European usage, we use the terms "supply" and "supplier" in the electricity-related articles in this volume to designate the retail utility function of selling electricity to end-users—noting that in some jurisdictions the same legal persons or corporate groups may also have other functions in relation to electricity, such as distribution). Although end-users may be able to choose from which supplier they buy their power, everything about their interaction with the rest of the power system is ultimately determined by that supplier's behavior and choices.
- The network functions of transmission and distribution are often required to be carried on separately from the inherently more competitive / contestable functions of generation and supply and/or are subject to economic regulation to ensure that operators do not abuse their "natural monopoly" position. In some systems, operation of the network (i.e. maintaining a continuous balance between supply and demand, and planning network development) is to a greater or lesser extent separated from the ownership of the physical network assets. Where "vertical integration" of any of the four primary functions in the same entity is permitted, the market tends to be more heavily regulated (e.g. in respect of prices and access terms).
- In order to keep the power system functioning within its design parameters, it is necessary for the amount of power being generated and exported onto the system to match exactly what is being consumed at any given moment. If this balance is not maintained, the frequency on the electricity network will move outside the parameters within which it has been designed to function, causing physical damage and/or interruptions in supply.
- The increasing development of new ways of "storing" electricity in bulk (to supplement the traditional technique of pumped hydroelectric storage) provides additional ways of maintaining system balance. Unlike other forms of generation or consumption, storage has the advantage of being able to help maintain the balance either by exporting or importing power. But storage does not remove the need to maintain system balance.

- The need to maintain system balance means that trade in electricity can never just be a completely free market like the trade in other commodities (including oil and gas, which can be readily stored, and transported either with or without a network of pipes to flow through). Broadly speaking, either interaction between generators and suppliers has to be centralized (either by centralized procurement of long-term power purchase agreements (PPAs) or through a central spot market organized as a pool system) or the results of non-centralized, bilateral trades between them have to be supplemented by a separate and centralized balancing system. In such a system, penalties are imposed on suppliers or generators who find they cannot perform in the way that they have said that they will at a particular time (e.g. because a generating unit is unexpectedly offline, or their demand for power is higher or lower than expected) and the system operator can invite generators and suppliers to produce or consume more or less than they had planned to do at a given time so as to make up for shortfalls or surpluses of power in the network.

In the 21st century, the standard model outlined above has begun to change.

- Concern about the environmental impacts of burning fossil fuels, and in some contexts about the cost of such fuels and the high costs of nuclear power programs, has caused governments to subsidize the production of electricity from renewable sources—which in turn has stimulated significant reductions in the costs of solar panels and wind turbines. The newly prominent renewable technologies, particularly solar PV, can be deployed on almost any scale, from a few kW to hundreds of MW. At the same time, small-scale gas or diesel-fired containerized generating units have become cheaper and more efficient.

- As a result, instead of millions of end-users consuming power produced by a fairly small number of generators and retailed by a fairly small number of suppliers, there are now hundreds, thousands or (where, e.g., residential solar installations are widespread) even millions of generators, often feeding power in from the ends of the distribution network towards the transmission network rather than the other way round.

- Increasingly, end-users (residential or commercial) are in a position to generate their own power some of the time (whether from renewable or other sources), and are responding to a range of incentives to do so—from net metering and per kWh subsidies for renewable generation to network charging regimes that offer rebates for not taking power from the grid at times of high demand and "capacity mechanisms" that reward those who provide additional capacity either by exporting power or reducing their demand at times of scarcity. Such mechanisms are increasingly introduced in response to the increased penetration of "intermittent" or "variable" wind and solar power: the larger the proportion of the generating mix that cannot simply be turned on/off or up/down on demand, the greater the need to introduce other sources of flexibility into the system. These may be either more flexible forms of generation (e.g. small-scale gas peaking plant) or demand-side response (DSR) by end-users who are prepared to respond to the system operator's signal by either reducing their demand absolutely or simply substituting onsite generation for power imported from the grid for a period of time. A parallel development is increased demand for a range of ancillary services procured by system operators, where generators or DSR participants modify their behavior, e.g. to maintain system frequency: the same generating or consuming (or storage) assets are often able to serve both the capacity mechanism and ancillary services markets.

- Both the wholesale power markets and their various ancillary offshoots are largely designed for large commercial players—or at any rate not for households and small businesses. To facilitate the interaction of the smaller distributed energy resources (DERs—i.e. those that directly connect to the distribution rather than the transmission network) with these essentially wholesale markets, a new class of business, aggregators, has grown up, who can group portfolios of DERs into larger, "virtual," units capable of operating on a commercial scale either to export power ("virtual power plants") or to provide DSR services often in response to grid operator tenders for "ancillary services."

- The spread of renewable technologies and the development of increasingly efficient forms of smaller-scale gas-fired generating equipment have driven a decentralization of power generation capacity—so that it comes in (on average) smaller packages, which are geographically more dispersed than was the case under the traditional, centralized, model.

- The development of energy storage technology, particularly in the form of batteries, has increased the potential for different kinds of interaction between generators, end-users and the grid. For example, if consumers' consumption of power is metered on a "smart meter" so as to record when and at what times of day they have consumed power, rather than just how much they have used over a much longer period of time, they can be put on a tariff that allows them to benefit from the daily fluctuations in the level of wholesale power prices—by, e.g., drawing power from the grid at times when the market price is low because

demand for power is low and using it later to avoid drawing power from the grid at times of high demand (when both the wholesale price of power and the charges for using the network are higher).

- One of the main drivers behind the development of battery technology has been the desire to decarbonize automotive transport by replacing cars and trucks powered by the internal combustion engine with electric vehicles (EVs). EV batteries, like other forms of storage (and particularly if aggregated), can perform systemically useful flexibility functions (e.g. absorbing renewable power for which there is no immediate use, or providing ancillary services), but they also introduce a new element. In contrast to other sources of power system flexibility, the electricity that they import from or export to the grid will not always be recorded at the same fixed metering point.
- The more small-scale variable renewable generation and storage (including EVs) is connected to a power system, the greater the risk that it is not being operated in a way that is optimal for the system as a whole or even for those who own it.

Following the logic of decentralization

These developments seem to open up the possibility that at some point in the not-too-distant future, electricity markets could start to operate in very different ways from the 20th century model. Descriptions of the much more decentralized and diverse electricity markets of the future tend to imagine a blurring of the traditional boundaries between producers and consumers of power, in the sense that it becomes a realistic prospect for many more end-users to supply all or most of their own needs from their own generating equipment: hence the coining of the terms "prosumer" and "active consumer." The latter term was used by the European Commission in its November 2016 Clean Energy Package of proposals to reform EU electricity markets, which place considerable importance on prosumers. A report published by CE Delft in September 2016 estimated that, by 2050, 83 percent of households in the European Union (187 million homes) could, because of the technology they would own, be in a position to contribute to renewable energy production, DSR and/or energy storage.

Prosumers can be anything from a single household with a solar panel on the roof, or an EV, to an industrial or commercial installation with its own generation resources and microgrid that can operate in either "island" or "grid-connected" mode. But they will not necessarily just want to be able to interact with a retailer or grid operator. They may well want to be able to trade with each other, and it is probably in the public interest that they should be able to do so. It is often pointed out that high levels of prosumerism could put pressure on the sustainability of the existing grid infrastructure: if a high proportion of households become more or less self-sufficient in power through, e.g., a mixture of solar and battery storage, and choose to go "off-grid," who will fund the network? The burden will fall on those who are, for various reasons, less able to be prosumers—unless you give the prosumers an incentive to carry on using the grid in order to trade.

Consuming electricity that is generated from sources that are not merely renewable but local has a powerful emotional appeal to some end-users, and there could also be significant economic incentives to do so: on both of these, see the UK's Piclo, which has had some notable successes in matching local buyers and sellers of power, apparently without the use of blockchain. The economic incentives for locally sourced supply of power would of course be sharpened if there were more sophisticated locational charging for network system use than is found in most networks today, so that end-users always paid a higher price for consuming power from more distant sources—minimizing the amount of power lost in transit in all cases.

And the decentralization process doesn't stop there. Even an individual household is not a single homogeneous entity. It consists of individual appliances that consume or (in some cases) can store or generate power. Increasingly, these will be produced with the capacity to participate in the IoT —which in this context means that they will be able to respond to remote signals, and even (within set parameters) to take "decisions" about their behavior as consumption / storage / generation units. If a distribution system operator needs to reduce demand for a short amount of time, it may be able to do so by sending a signal to appliances such as freezers or air conditioning whose owners are happy for them to be turned off for a few minutes, either in return for a small payment or as part of the terms of their eligibility for a particular retail electricity tariff. Or the solar panels of a house whose occupants are not at home during the day (or the same house's battery after it has been charged by such solar panels) may sell power to the oven or washing machine in a neighboring house, enabling its owners not to draw power from the wider grid and potentially to be rewarded for doing so.

Blockchain: the "killer app" for the new power market paradigm?

Instead of all of a household's power needs being fulfilled under one contract with a single retailer, the household as a whole, and/or different generating and consuming assets within it, could potentially be interacting with a range of counterparties. This huge increase in the number of interactions between a vastly increased number of active, and direct, participants in the electricity market is not quite ready to happen yet in most markets. There are various reasons for this, for example regulatory barriers or the fact that the necessary metering technology has yet to be rolled out. But many people in the industry seem to think that blockchain can help to usher in the new paradigm.

At the risk of unfairly underestimating thousands of colleagues and potential clients, we think that the reasons why most people identify blockchain as having this potential are not based on any very detailed understanding of the technology. Instead their reasons are more intuitive—but that does not by any means mean that they are not right.

Most developed electricity markets already allow dozens or hundreds of wholesale buyers and sellers to trade power, but they do so by using mechanisms that are not designed for, well-adapted to, or even permitted to be used by, huge numbers of non-professional market participants at the retail level (let alone by individual domestic appliances on a semi-autonomous basis). Blockchain is favored as a potential enabler of mass decentralized peer-to-peer (P2P) trading because it appears to be a way of securely linking very large numbers of counterparties who have no reason to trust each other (and may not even know who each other are) but are happy to do so because they trust the underlying technology.

Trust, of course, is not enough. For example, even with promptings from a user-friendly app, it seems unlikely that more than a small proportion of the potential population of prosumers would wish to spend a lot of their time consciously deciding whether to take advantage of opportunities to

make or save what individually are likely to be small amounts of money by buying, selling or storing small amounts of power hour by hour and minute by minute.

Yet a truly decentralized market model may only work efficiently on a large scale if the participants are making a lot of decisions very quickly and very frequently, potentially choosing between a large number of options. Suppose a prosumer household has calculated that, on an average weekday, it will be able to generate and store sufficient power using its solar PV and battery during "office hours," when the sun may be shining but there is usually nobody at home, to supply its electricity needs during the evenings and early mornings. They therefore sign up to a contract under which they pay a small standing charge to an electricity supplier under which they are entitled to export any surplus they generate but do not need (at the spot market price given by a specified index), but pay wholesale market prices plus a margin for each kWh for any power that they import, and an additional charge per kWh for importing or exporting during periods of peak grid usage, which reflects the higher level of grid usage fees paid by the supplier during such periods. On any individual weekday, they may find that their electricity needs or their ability to generate either exceed or fall short of the average, and, on these occasions, buying from or selling to one or more other prosumers may leave them better off than buying from or selling to their supplier at the default rates set in the contract. Those other prosumers in their turn will have a number of opportunities to choose from. And that is before one considers, for example, possible responses to numerous one-off requests from the supplier or grid operator to make small changes in what would otherwise be the household's pattern of export, import or storage, for which the household may be rewarded, or the possibility of using spare battery capacity to buy ultra-cheap power from an offshore wind farm during the night (to be used or sold to others later).

One can readily imagine that even the most committed prosumers would prefer to let a piece of software interact with this potentially wide range of counterparties, taking all the necessary individual decisions on their behalf

in accordance with specified parameters. These might include, for example: a defined level of risk appetite; a preference to use renewable and/or locally sourced power (provided that it does not cost the household more than a specified benchmark to do so); or an instruction to offer surplus power to specified friends and relations (perhaps at a special rate) before selling it to commercial or unknown individual purchasers. More than one of the businesses reviewed below propose a hierarchy of trading preferences, which would presumably be expressed through smart contracts. In some cases, these preferences might simply equate to finding the cheapest supply (taking account of both the energy price and any additional costs—e.g. grid charges, which will vary to a greater or lesser extent with the seller's location and other factors, such as whether the participants in a trade are customers of the same retailer or aggregator). In other cases, more subjective factors may need to be accounted for (e.g. a preference to be supplied from local sources, or by "friends and family," even though these may not be the cheapest options).

It is envisaged that blockchain would facilitate this sort of arrangement not just by its ability to link multiple participants who do not necessarily trust each other, and to keep secure and accurate records of all the resulting transactions, but because it is hard to envisage an extremely decentralized market working efficiently unless it is underpinned by something like smart contracts. If we hypothesize that an energy supplier or aggregator supplies each household with some kind of intelligent software agent program that takes account of their predefined trading preferences and decides which transactions to enter into and executes them as a service provided to the household, we can imagine that a number of possibilities may open up—for example:

- One set of smart contract terms with that service provider would be the means by which the household's trading preferences and parameters are expressed (since all of these are likely to be reducible to commands of the "if X, then Y" type).
- Another set would be used in the individual trades with third parties, in a variant on the simple scenario outlined above.
- A third set of smart contract terms might be attached to a particular appliance such as a refrigerator or washing machine, whose power consumption is excluded from the household's electricity supply contract because its manufacturer has bundled the supply of power with the price of the equipment, and has entered into power supply arrangements for all its appliances.
- Some of the opportunities to buy or sell power presented to the household might take the form of mini-auctions and a smart contract would instruct the agent on the parameters according to which it could bid in these.
- A further smart contract might cover the household's EV when it is away from the house but plugged into a charging network, with commands, e.g. allowing third parties to draw power from the

battery as long as sufficient charge is left in it to get to the destination specified by the driver (and starting at the time specified) when leaving the vehicle.

Conceptually, then, it can be seen why many see blockchain as the key to unlocking a bright new future in the electricity sector. It seems well placed to facilitate a world of much more localized power systems (microgrids) and many more active (or semi-active) market participants, engaging in P2P exchanges of electricity, where a much larger range and number of assets is involved in providing "flexibility" for the system, and there is a need to manage very much larger volumes of data.

What's stopping the blockchain revolution?

A blockchain-based market transformation is not necessarily something that can be expected to happen quickly, easily or universally—for example:

- It is not entirely clear that the forms of blockchain technology currently available are actually capable of dealing with the kinds of transaction volumes that could be involved and processing them fast enough to enable individual intelligent agents to take advantage of new trading opportunities as quickly as they would present themselves.
- Issues around interoperability and standardization are likely to arise. Is it possible to get the full benefits of the new world unless all those who wish to participate can interact with all other willing counterparties, and could this be achieved without there being a single monopoly provider of the technology (a situation that would carry its own risks)? Such a widespread service, with links to the operation of an essential service (electricity supply) as well as millions of user accounts, will also present a very demanding test for the security of public blockchains or the scalability of private blockchains.
- Moreover, even when the technology is ready, it is only likely to be taken up (and products incorporating it are only likely to be launched by service providers) in markets where, e.g., penetration of rooftop solar PV and other structural factors, including customer preferences, mean that there is a critical mass of potential prosumers / active consumers.

These are in a sense all generic issues which will be relevant to some extent in any mass-market application of blockchain. It is also important to appreciate the nature and scale of the challenges that the technology faces specifically in the electricity market. Take, for instance, the buying and selling of power between end-users who don't currently participate actively in the wholesale markets. Why has P2P usually been hard to achieve in the past, and why will blockchain make it easier?

It is fair to say that, in a number of small schemes, blockchain is already providing some of the infrastructure to allow P2P trading. These projects have been set up in cases where buyers and sellers are linked by a system that can somehow be segregated from the public networks and the wholesale market mechanisms by which power is traded over them, constituting a microgrid. The classic example is the Brooklyn Microgrid created by LO3 and Siemens in 2016: a hugely important experiment, but not one whose methods would necessarily be easily replicable everywhere outside of the microgrid context. Ideally, P2P trading should not only be available to households and businesses that are literally neighbors.

This is where one has to consider regulation again. The electricity sector is organized in different ways in different jurisdictions. In markets where the purchase of electricity from generating installations is a monopoly, it may be impossible for any two private parties to agree to buy and sell power to each other. But even in liberalized markets, it is usually hard, if not impossible, for them to trade with each other unless they either become parties to whatever contractual and regulatory arrangements support or embody the wholesale market, such as a pool or balancing system (see above), or do so through a third party supplier who is already integrated into those arrangements. In a microgrid context, it may be possible to direct the electrons set in motion by the equipment of a generator, A, to a particular consumer, B, and trace their journey to the meter that measures imports from the grid at B's premises. But when power moves across the public transmission and/or distribution networks no such direction or tracing is possible.

As an illustration of the limitations of existing systems, suppose a developer wishes to build a wind farm on a hill. Some residents of the village at the bottom of the hill oppose the development. In order to gain permission to build the wind farm more easily, the developer promises every household in the village discounted electricity during all periods when the wind farm is generating.

- If the households happen to be supplied by a single retailer, the developer could enter into a PPA to sell its power to that supplier at a discount to wholesale market prices and the supplier could give a discount from its standard tariff to its customers in the village. This, of course, will only work if each household has a "smart" meter that allows each kWh of electricity it consumes to be matched to a specific period of use, so that the discount is only applied in respect of the electricity consumed in periods when the wind farm is generating.

- But what happens in periods when the output of the wind farm is less than the consumption of the village? Do only some households get a discount? Does everybody get a smaller discount? Does the developer pay the supplier the difference between the price it has agreed with the supplier and a benchmark of market price during the period concerned?

- Some households in the village may have elected to be supplied on a "green tariff" that promises that all the electricity supplied to them (from the local wind farm or otherwise) will be generated from renewable sources. Ultimately, the compliance of the supplier with that promise can only be verified by monitoring the total amounts of power supplied to its customers on such tariffs over time and comparing them with its purchases of electricity that carries some official mark of being renewable (such as a renewable energy certificate (REC) or guarantee of origin, the registration of a generator under a feed-in-tariffs program or the independent purchase of RECs separate from the electricity whose generation gave rise to their issue, where the market rules and their own contract with customers allows this).

- All this can be provided for contractually, but a more basic challenge is how the supplier reconciles the administration of multiple sets of transactions—the wholesale ones with the developer and other sellers of power, and the retail ones with each household—that will be executed and recorded on different systems, and billed and settled at different times.

- These kinds of arrangement will be much harder to make work if the households in the village have contracts with a number of different retailers, as is likely to be the case in a competitive market, and may exercise their freedom to switch supplier at any time.

- The developer could possibly avoid some of the potential difficulties by becoming a retailer itself (or setting up a retailing affiliate) and offering its terms of supply only to those households that switched to being supplied by it. But to do so it would need to engage with all the regulatory requirements imposed on suppliers. In the UK, for example, these are somewhat more onerous than those that apply to generators—and many smaller renewable developers choose to avoid engaging directly even with the regulatory regime for generation by interfacing with the wholesale markets through a third party supplier and operating under a statutory exemption from the requirement to hold a generating license. There is a system of exemptions from the requirement to hold a supply license whilst acting as a supplier but the exemption criteria are hard to fulfil where the supply is not delivered over a direct wire.

- It comes as no surprise that, in the UK, one developer found that the most efficient way to engage positively with local residents on a financial basis was to avoid all the above and simply pay them a fixed cash sum towards their electricity bills each year.

The kinds of complexities faced by our hypothetical wind farm developer in dealing with the neighboring village are multiplied exponentially in the future market scenario where, instead of one generator operating on a commercial scale dealing with a few hundred consumers (all conveniently located in more or less the same area) on a fairly simple basis (when I am generating, you will be supplied with my power), there are thousands or millions of prosumers, all wanting to be able to buy from and sell to each other whenever it is individually advantageous for them to do so.

Can blockchain enable prosumerism to achieve its full potential, and the decentralized market model to reach its logical conclusion? This will depend on whether blockchain has the transformative capacity to motivate market players, consumers and regulators to overcome barriers that have proved hard for, e.g., commercial renewables developers trying to establish community supply schemes in some jurisdictions to overcome. In the next article, we review some existing electricity sector blockchain businesses as a way of providing the beginnings of an answer to these questions.

Blockchain and decentralized power: case studies

Conjoule presents itself as a blockchain-enabled P2P electricity trading platform. Its strapline is: "We all get more value when energy is local, connected and shared." Starting in two German cities, Mülheim, and Essen, Conjoule offers households with solar PV the opportunity to choose which of a number of local businesses and institutions (e.g. schools) they wish to supply with electricity.

Blockchain as a means of facilitating specific supplier value propositions

Conjoule offers households a financial incentive as well as a "warm feeling," claiming that, by saving on energy transport costs, they "can offer … more than the regular feed-in tariff for your energy." This model could also be seen as a kind of distributed or crowd-sourced manifestation of a different current trend in the renewables sector, namely the formation of "corporate PPAs"—power purchase agreements between a renewable generator and a corporate end-user, in which suppliers often play an essential intermediary role, with multiple buyers and sellers rather than a single buyer and seller.

Conjoule has been developed in innogy's Innovation Hub and has received €3 million initial funding from the Japanese utility Tepco: clearly this is a model that is of interest to incumbent electricity market players as well as disruptors. Indeed, any retail supplier of power could in principle do something similar by purchasing surplus power from one set of customers and selling it to another set of customers who are connected to the same distribution network. In so doing, it removes the need to purchase an equivalent amount of power from a wholesale counterparty, and does not incur any transmission system charges that it would have been required to pay for importing it into or exporting it from the distribution network where the buying and selling customers are located (distribution network charges may well still be payable in most cases).

To make the arrangement work for all parties, the supplier needs to find a margin between a buying price that is more than the sellers would otherwise receive for their surplus and a selling price that is less than the buyers would normally pay to be supplied at the relevant time (unless, of course, either party is prepared to pay a premium or sacrifice revenue for the sake of participating in a "green" or "local" electricity market). How easy it is to do this will depend in part on a range of factors. For example, if the sellers can benefit from state-sponsored incentives in the form of feed-in tariffs (FiTs)—admittedly something that, at least for new installations, is now often no longer the case even in those jurisdictions where they have previously been offered, such as the UK and Germany—how do FiTs currently payable to most eligible generators compare with wholesale or retail power prices? Can generators contract out of the FiT arrangements to sell their power to a third party? Are the FiTs financed out of general taxation or a levy on suppliers? How are FiT payments calculated? For example, are exports metered or estimated, and in the latter case would the seller be better off with a metered export under the "P2P" platform or with FiT payments based on estimated export figures?

Of course, the kind of arrangement described above is arguably not P2P in the strictest sense, since the supplier acts as an intermediary, but there is a good reason for this. In most electricity markets, a generator that wishes to trade power on its own account must (unless it is going to do so entirely over a private wire network) participate in industry wholesale market arrangements that were designed for the centralized industry of relatively few, relatively large and sophisticated players. As we have already seen, even commercial renewable

generating stations often avoid engaging with these by entering into arrangements (such as PPAs) under which all their interaction with the market is mediated through a supplier. So it would not be practicable or cost-effective for individual households, for example, to get to grips with the pool bidding mechanisms, grid charging arrangements, collateral requirements or imbalance charges that they would need to master if they were to participate directly in wholesale electricity markets without the assistance of a supplier. This means that, for now, many blockchain-related electricity sector businesses either have to acknowledge that they cannot fully realize their plans without significant regulatory change or find ways to work around the limitations of the existing regulatory regime as a setting for P2P transactions.

A second important point to note in connection with such supplier-mediated schemes is that it is debatable whether, in their simplest form, they need to use blockchain or gain anything by doing so. If both sellers and buyers are customers of the supplier, there is presumably no "trust gap" for the technology to bridge, and all the relevant records are kept on the supplier's metering and billing data systems. But the position is likely to be different if the arrangement is to incorporate the more dynamic elements set out in the hypothetical P2P scenario outlined in the previous article, with vast numbers of very small decisions being made (and implemented) all the time on an automated basis in relation to a large range of potential counterparty opportunities.

Who will develop successful platforms that fully exploit the possibility of P2P electricity trading? Will it be today's incumbent utilities, having mastered the new technology, or a technology provider that has learnt how to deal with wholesale energy markets (and any regulation associated with residual electricity retailing functions)—or a combination of the two? Incumbents enjoy some obvious advantages, but there are both commercial and economic efficiency arguments in favor of independent (or at least collaborative) platforms.

Another German experiment of the supplier-intermediated P2P variety is Elblox / Tal.Markt, a collaboration between energy trader Axpo, municipal utility Wuppertaler Stadtwerke and Blockchain Source. One can see why incumbent utilities might think that it makes sense to begin to provide a P2P offering now, so as to maximize their existing competitive advantage. This may be the thinking behind the incumbent South Korean utility Kepco's blockchain offering. It is no doubt aware that, in any liberalization of the supply market, it is likely to face competition from new, blockchain-enabled, entrants such as Singapore-based Electrify, and that research projects have indicated how consumers could gain materially from their services. Perhaps somewhere between the traditional utilities seeking to profit from the new technology and the tech-led startups are companies like Drift of the US, a proponent of "disaggregated P2P."

A notable example of the startup category of suppliers looking to use blockchain to provide a distinctive proposition to customers, which can also serve as an introduction to the use of cryptocurrencies by electricity sector blockchain startups, is Irene Energy. Irene Energy is developing "the next generation back-office platform for the energy industry." This platform is based on a proprietary micro-payment and real-time settlement technology built on the Stellar blockchain and is fueled by its Stellar-based token, Tellus (TLU). Irene Energy's focus on back-office technology is designed to disrupt the "rigid and costly back-offices" that are a common pain-point across the energy industry with poor data availability, multiple legacy systems and diversity of contracts creating expensive IT "monsters." Irene Energy targets all players in the energy space with its "simple, cheap, scalable, streamlined and easily implementable back-office platform." Drawing a contrast with startups that present themselves as P2P platforms, Irene Energy "doesn't intend to re-invent power markets but to disrupt the existing industry."

Irene Energy is pursuing four key use cases:

- offering an open and scalable billing solution to suppliers that is more powerful than older generation software: the billing solution has no set up costs or membership fees and offers unique advantages in terms of flexibility, agility and regulatory compliance;
- becoming an independent energy supplier that showcases the power of the billing solution and introduces differentiating factors for customer acquisition including gamification, cheaper fares and a direct link between producers and consumers;
- developing an "Uber-like" electricity marketplace tailored to close-to-grid regions in developing countries: combining its core technology with smart plugs, Irene Energy seeks to reduce financial and contractual frictions and bring better access to cheaper electricity;
- launching a gamified initiative in developed countries—"Connect"—to funnel donations to all African ventures that seek, like Irene, to leverage micro-payments to ease energy poverty.

In relation to the billing solution, utilities may elect to adopt the billing solution to offer differentiating factors to end-consumers, while at the same time realizing significant cost savings—thanks to the solution's "unique economics." The billing solution will be "offered to client utilities as an open-access platform unlocked by Irene Energy's tokens." In that simplified scenario, upon adopting Irene Energy's billing solution, the client utility buys or leases Telli. It can then use the platform using its Telli, and upon leaving Irene Energy, the supplier can sell back its Telli at market prices (or close its lease).

All of the use cases rely on Irene Energy's platform and its underlying tokens—hence representing as many avenues to increase token utilization.

At the time of writing, Irene Energy is engaged in a process of fundraising comprising a "pre-sale" and a "main sale" ICO, with Telli being sold in exchange for another cryptocurrency (in this case, Lumens, since Irene Energy uses Stellar), as a result of which a fixed (large) number of tokens will be issued to investors, and a defined proportion of the issued Telli will be retained for the benefit of early backers, current and future employees of the company, working capital and other purposes. Potential investors are told that holding a Tellus does not confer anything akin to a shareholder or bondholder right in respect of Irene Energy: Telli "will be redeemable as payments for future Irene Energy services but under no circumstances can they be expected to be bought back by Irene Energy in any sort of monetary transaction." In other words, this kind of token is an example of an asset class that may appreciate in value due to increased token utilization, but that value may only be unlocked by either selling the token or using the token in a specific kind of transaction. For example, you might have bought 10,000 Telli at €0.07 in the pre-sale and find that, some time later, for that initial outlay equivalent to €700, maybe approximately the cost of one year's supply of electricity at the time, you can actually buy yourself two years' worth of electricity because of the appreciation in value of the Tellus.

Blockchain facilitating grid services—and e-mobility

P2P, supplier-mediated or otherwise, is only one way in which DERs can participate more actively in electricity markets. Two projects involving TenneT, which operates transmission networks in both the Netherlands and part of Germany, demonstrate other ways in which blockchain can facilitate active consumer participation and at the same time reduce the overall costs of network operation.

In Germany, TenneT has collaborated with German energy storage provider sonnen (acting as an aggregator) and IBM to use blockchain to enable large numbers of household batteries to provide ancillary services collectively. As described by TenneT, "intelligent management" of the batteries adapts to the situation in TenneT's grid, allowing them "to absorb or discharge excess power in a matter of seconds when and where required" thereby reducing transmission bottlenecks in the grid.

These bottlenecks can arise for a number of reasons, but among the largest causes is that Germany suffers from a shortfall in connection capacity between the northern areas, where wind farms generate large amounts of renewable electricity, and the southern areas, where demand for power is concentrated. Transmission operators such as TenneT therefore find themselves obliged to pay hundreds of millions of euros in compensation for curtailment or redispatch of their output at times when the grid cannot handle it. A scheme such as the TenneT / sonnen / IBM one is therefore advantageous to a system operator if it can, as a result, avoid redispatching (i.e. curtailing the output of) renewable generators, and the costs to it of using households' batteries are less than it would have had to pay as compensation to the generators.

Meanwhile, in the Netherlands, TenneT has collaborated with Dutch supplier and energy services provider Vandebron to provide a similar service, but in this case using the batteries in EVs rather than buildings. (Separately, Vandebron also provides a supplier-mediated P2P service.)

EVs more generally appear to offer a promising use case for blockchain. As the TenneT / Vandebron project shows, they are potentially a valuable grid services resource. They can also be involved in P2P electricity trading. But their mobility presents a challenge. Unlike a household battery, they do not have a fixed point of connection to the grid: they will be connected wherever they are plugged in to a charging point, which may be in any number of locations. If they are being connected in order to get a rapid charge in the middle of a journey, the EV driver is likely to be interested only in buying electricity, but if the EV is parked by a charging point for several hours—whether at the driver's home or place of work, or in, e.g., a shopping center car park—there is a good chance that there may be opportunities for power to flow in both directions.

In this context, blockchain should be able to help in a number of ways. A smart contract could enable drivers to specify, when parking the EV, and connecting to the charging point, that they are happy for the battery to discharge as well as charge as long as they are paid, or receive credit, for any net discharge during the time it is plugged in, and are left with a specified amount of charge in the battery (e.g. sufficient for their next anticipated journey). At the same time, blockchain ought to be well suited to tracking and managing, from both the driver's and the charging point owner's / electricity supplier's point of view, the multiple relationships that arise when an EV is connected to charge points that may be owned, and supplied with electricity, by a wide range of different parties.

For example, California-based (but now Enel-owned) EV charging specialist eMotorWerks was reported in August 2017 to be testing a system developed by an innogy Innovation Hub product, Share&Charge, that can enable drivers who are otherwise unknown to each other to use each other's charging points (at a price set by the owner) in a kind of "Airbnb for cars" service. (See also the November 2017 interim Eurelectric report, *Freedom of Charging: Opportunities and Challenges of Blockchain Technology for seamless Electro-mobility*.)

Tech-led platforms providing opportunities for existing and new market participants

Among the more ambitious projects being put forward for deploying blockchain down to the level of individual electricity consumers, a rough distinction can be drawn between those that present themselves as platforms that will facilitate more efficient interaction between the full range of existing market players and those that either seem intent on displacing some of them or otherwise are focused on objectives that go beyond the ambitions of those in the first category. We consider here some businesses that provide good examples of the first category's approach.

UK-based Verv started as a supplier of innovative hardware. It has developed a "home hub" device (the VHH—retail price around £250), which uses high frequency sampling and machine learning to distinguish the "signatures" of individual appliances within a customer's home and so disaggregate their consumption, whether or not they are IoT enabled. The VHH can enable the customer to make more informed choices about power usage and the efficiency of (and in some cases the desirability of replacing) individual appliances. It also enables Verv to get a very much more granular picture of household consumption patterns than can be derived from a typical smart metering device, which in turn makes it possible to make much more accurate predictions about use in a given period.

More recently, in collaboration with community energy organization Repowering London, Verv has been trialing what amounts to P2P trading of power in a single block of flats in Hackney. Individual residents can now purchase power from solar panels fitted to the roof: previously, the power that they generated could only be supplied to the "common parts" of the block or exported onto the grid. When the energy generated is more than is required for the common parts, the residents (many of whom are on low incomes) can save money as compared with their existing supplier's tariff by purchasing some of the surplus at a rate which also guarantees a better return on the investment in the solar panels than would normally be achieved by exporting their power to the grid.

The Hackney project is a precursor to the launch of a nationwide trading platform (VTP) that will enable P2P trading between individual generators (including prosumers) and end-user customers—regardless of where they are located—as set out in the White Paper that supports the ITO of Verv's VLUX (VLX) tokens. Amongst the features of the VTP network are the following.

- The VTP can automatically match generators' offers to sell with end-users' bids to buy power, based on their anticipated generation and consumption and defined pricing parameters (i.e. no human intervention is required for individual trades). One of the ways in which the VTP can take account of customer preferences, and ensure best value, is by entering into arrangements that take account of a hierarchy of locational preferences. For example, in a given trade where the selling generator is located on the same distribution network, and/or interfaces with a distribution network through the same supplier as the buying end-user, it should be possible to reduce the transaction costs (e.g. no transmission network charges to be paid), meaning that the seller may be able to achieve a higher price, and/or the buyer a lower one, than would otherwise be the case.

- For technical reasons, the best pricing is more likely to be available to those end-users who are equipped with a VHH.

- Once a potential match between a buyer and a seller for a given period has been identified, a smart contract is formed, such that payment for the power is required at the point when the VTP system recognizes that the buyer has consumed the relevant amount of electricity.

- At the level of the platform itself, trading is carried out in VLUX. For this reason (and also because it simplifies the interface of the VTP mechanisms with the existing regulatory architecture of the GB wholesale market), Verv envisages that individual generator sellers and end-user buyers, who may prefer to deal only in fiat currency, will interact, not directly with each other, but through "local aggregators". The local aggregators may, for example, be suppliers, commercial electricity generators or community groups. They will be obliged to purchase VLUX on a public exchange, but they will only have to purchase more VLUX if the community of VTP participants they are working with or the volume of power that the community is trading through the VTP increases (with any increase in the fiat currency value of VLUX presumably being capable of offsetting the need to purchase more VLUX in such cases to some degree).

- Although payment is not triggered until the power that is the subject of a VTP trade is delivered, buyer and seller will not be matched, and a smart contract will not be formed, unless the network knows that the buyer's account has the necessary funds to make the payment when it is due. This means that buyers must prepay for their power in fiat currency unless the local aggregator does so in VLUX (thus assuming the end-user credit risk in anticipation of being able to recover payments through regular post-consumption billing) or there is an existing billing relationship with the energy retailer—in which case the energy can be traded on credit via the retailer as is currently the case, with the retailer taking responsibility for that billing relationship.

- Each local aggregator and the end-user households it is dealing with will form a "community." The number of households in such a community will be capped at 500, so as to "limit the size and complexity of the blockchain ledger." Local aggregators can of course have relationships with more than 500 VTP participating households, but will need to do so through more than one community. The White Paper states that communities are expected to be organized on a local basis in order to maximize the benefit of avoided transmission costs.

- Further applications of the VTP network may include uses in relation to EV charging, the provision of services to DNOs / DSOs and microgrid development, and also, critically, the sale of energy data.

In Australia, Power Ledger state on the front of their White Paper that they "believe empowering individuals and communities to co-create their energy future will underpin the development of a power system that is resilient, low-cost, zero-carbon and owned by the people of the world". Among their recent achievements have been a heavily subscribed ICO, successful community-based trials, a range of awards, and international collaborations. Over time, they envisage that their platform or "Ecosystem" will enable a range of different applications including P2P trading, wholesale market settlement, distributed market management and carbon trading. What is their proposed approach?

- Power Ledger's initial proposition is based around P2P trading, with a strong emphasis on serving prosumers and their potential end-user customers (including those whose ability to produce power is limited by—for example—living in a block of flats).

- The Ecosystem is based around two kinds of token, known respectively as POWR and Sparkz. Sparkz are pegged to the smallest denomination of a local currency and effectively provide a stable (digital) currency base to value a unit of energy against. POWR allow users to operate in the Ecosystem: they are described as being "like a limited software licensing permission," on a kind of pay-as-you-go licensing model (in the sense that heavier use of the platform requires a participant to acquire more POWR).

- Two different P2P models are envisaged: one where prosumers and consumers trade directly

with each other, and one where third parties such as suppliers, referred to as Application Hosts, act as intermediaries. To begin with, there will often be a regulatory driver for adopting the latter model: outside of a microgrid context, the regulatory architecture generally does not facilitate small prosumers trading directly with each other and other small end-users at present. Even where this is not the case, customer preference may still favor this model, as it will be a more straightforward option for those consumers who are less inclined to involve themselves directly in the complexities of blockchain.

- A stylized representation of the transactions in the mediated P2P model would be as follows: (i) an Application Host, A, purchases a quantity of POWR tokens and places them in "escrow" in a "smart bond"; (ii) in return for doing this, A receives the corresponding quantity of Sparkz; (iii) A sells Sparkz tokens to consumer customer C for an amount of fiat currency; (iv) C, through the intermediation of A, buys units of electricity generated by prosumer customer P in return for the corresponding quantity of Sparkz; (v) P receives those Sparkz, and may either retain them to buy electricity or exchange them with A for fiat currency.

- This arrangement will benefit P and other prosumers if it helps to develop P2P trading so that participation in the Ecosystem enables them to get a better price for their electricity than they otherwise would. They are given some protection from counterparty risk, because, in the event of A's insolvency, they should be able to make a claim under the "smart bond" (to the extent that the POWR tokens escrowed in it have an equivalent market value). And in respect of any period in which they are net importers rather than net exporters of power, they should be able to reduce their electricity bills by the amount they have earned in Sparkz.

- Many consumer customers like C may also be prosumers and as such will share these benefits. If they are not prosumers, the main potential value of the Ecosystem to them will lie in its ability to deliver power from renewable, local, sources at a competitive price (for example, because a preference is given to sellers on the same network, thus reducing buyers' exposure to some network charges). Depending on their arrangements with their Application Hosts, the price that they pay for this may be having effectively to prepay them for the power they consume by paying them fiat currency in exchange for Sparkz.

- For Application Hosts like A, any such prepayment arrangement would obviously be advantageous in terms of cashflow and credit risk. In any event, Application Hosts who are suppliers, if they can provide a user-friendly and seamless interface with the Ecosystem for their prosumer and other consumer customers, may retain those customers' loyalty in cases where they have the option of moving to direct participation in the Ecosystem (which on a large scale could put a supplier Application Host out of business). There should also be opportunities to make some margins on the various transactions and exchanges they are intermediating. Finally, there is nothing to stop them from continuing to operate as "regular" suppliers (even in respect of consumers on whose behalf they are buying power from prosumers in the Ecosystem), so a decision to become an Application Host need not bring with it any general or fundamental shift in business organization and strategy.

Australia should be a good place to build a P2P business. There is a lot of sun and a lot of solar generating capacity on private houses: in parts of the country a third or more of households have rooftop solar. (For a thorough but fairly cautious assessment of the prospects specifically of "virtual peer-to-peer energy trading using distributed ledger technology" in Australia, see the useful report on that subject published by the Australian Renewable Energy Agency and others in October 2017.) On the other hand, there are some regulatory barriers: in parts of the country, retail electricity markets have yet to be fully deregulated (i.e. opened up to competition), and the position on network tariffs and the ability of DERs to offer ancillary services to grid operators also needs to be improved in order to maximize the kind of opportunities represented by a model such as the Power Ledger Ecosystem.

Our final example of a tech-led platform that seeks to unlock new sources of value rather than to replace existing market participants is represented by the work of Electron in the UK and GreenSync in Australia (although the latter professes to be agnostic as between blockchain and other technologies). The underlying insight here is that the potential of DERs will be greatly enhanced if:

- there is a single, comprehensive, register of all the assets that can contribute to the decentralized electricity economy, which fixes them with their own digital identity; and
- those DER assets that are capable of carrying out actions that have value for more than one participant in the market can contract with and be rewarded by each of them simultaneously.

Take the example of what may be called "flexibility services." In electricity systems with increasing levels of penetration by intermittent or variable renewable generating sources, the ability to be flexible in either producing or consuming power potentially gives any asset value. A grid-connected battery is perhaps the paradigm case, with its ability to provide a range of services, many of which have more than one direct beneficiary. If a battery "soaks up" surplus power when supply exceeds demand on the system, it can benefit both system operators (who may, for example, avoid the costs of curtailing generation from wind farms) and the generators of the surplus power (who may ultimately get a better price for their power). Benefits also accrue over different timescales (e.g. on the one hand helping to keep the system in balance at a particular moment, on the other hand avoiding the need for the network operator to incur capex by reinforcing its infrastructure—and at the same time potentially allowing distributed generation in that part of the network to avoid export constraints). But, at present, the battery's ability to derive revenue is limited in two ways. First, many potential customers for its services do not know it is there: it is not visible to them. Second, it can only monetize its potential value to potential counterparties through a series of bilateral negotiations or auction processes.

Most electricity systems are characterized by multiple existing asset registers. In some cases, the same (or similar / related) information has been collected several times for different purposes. Many of these registers have not been effectively digitalized, and they are characterized by duplication and frequent inaccuracies. Most of the existing registers are in one way or another centralized for historical reasons. Blockchain opens the possibility of a decentralized approach, which could be cheaper and more accurate, as well as eliminating duplication and error. And if all relevant assets are recorded on a register to which all their potential flexibility services customers have access, it could be relatively straightforward to hold multilateral, multi-dimensional auctions to discover the value to different participants of actions that the owner of an asset might undertake. The COO of Electron, Jo-Jo Hubbard, has offered a vivid, non-technical analogy for this process: imagine that the diners at a crowded restaurant are having their evening ruined by the performance of an exceptionally bad street musician—collectively, they would probably be prepared to pay enough to make him go away, but how, quickly and without any of them paying more than they want to, do they organize this? In place of the diners and the musician, think of electricity system participants and a group of domestic fridges which could be turned off for a few minutes to benefit them in various ways, or a battery that could be installed in a particular location and operated within specified parameters: the asset register and multilateral auction platforms linked to it could provide similar ways of making sure that the asset owners maximize the value of a particular action or asset whilst the other system participants pay a price that is based on as close to "perfect information" as is consistent with fair competition, and as such should represent best value for them.

It is clear that industry players are excited by the prospect of the kind of digital infrastructure that Electron and GreenSync are aiming to develop: both of them have put together broad consortia including an impressive range of market participants to take their projects further.

Two US-based projects

In addition to the projects reviewed in some detail above, there are some other notable blockchain-based ventures which aim to provide a platform for token-based power trading and/or to establish new, disruptive, supplier businesses. We briefly mention two of these here.

- Grid+, largely founded by people from Consensys, aims to start supplying power in Texas and a number of US markets, undercutting incumbent suppliers through blockchain-derived efficiencies (including a tokenized prepayment system). It will incorporate P2P trading. The Grid+ offering to customers will include a "smart agent" device that will provide consumers with a user-friendly interface for the acquisition and storage of tokens, as well as a means of optimizing their sale and purchase of power and exposure to wholesale market prices.

- Exergy is also US-based, but envisages a global field of operations. It has "developed, manufactured and deployed a grid-edge hardware element as a meter and distributed computing node, but also as an asset control switch." Its ledger system is based on that developed by LO3 to run the Brooklyn Microgrid. Projected use cases include P2P, microgrids, distribution system operation and EV smart charging.

Power to the people: more energy blockchain use cases

We finish this survey of the developing energy blockchain landscape by looking at a number of applications of the technology that fall outside the scope of the previous articles.

Wholesale power trading and grid integration

In electricity, as in oil and gas, there have been demonstrations of wholesale trades using blockchain. In these wholesale markets, the benefits of blockchain are similar to those anticipated in oil and gas trading, or its benefits in securities trading: potentially very significant, but arguably not leading to a revolution in market structure, rather than cost savings for existing players, with some thinning out of intermediary roles and evolutionary (but still significant) change in existing business models.

For example, a 2016 paper by Michael Merz of German software developer Ponton, which has set up the enerchain project, shows (amongst many other things) how the use of blockchain as a vehicle for carrying out and recording details of electricity trading could in principle eliminate the need for a number of existing separate market functions, such as the publication of price indices and the separate notification of trades to a transmission system operator as part of the balancing process in bilateral contracts markets. It is also possible that, coupled with other developments, it could result in faster and cheaper settlement of trades.

At the last count, 40 other companies—mostly European utilities or energy traders—had associated themselves with the enerchain project, so it is clear that the industry sees blockchain as having potential in this area, even though it is one in which organized exchanges play a significant part.

In a separate project, Ponton has been exploring with a group of Austrian DSOs how blockchain can be exploited to facilitate grid balancing and services in a world where balancing actions are much more likely to be delivered by very large numbers of small-scale resources, often through contracts with aggregators, than by one or two large power stations or offtakers—and where balancing responsibilities may be pushed down to distribution system operators rather than all resting at transmission system level. The results, according to Ponton, are "mind-blowing," including reducing settlement time from more than a month to 15 seconds: the further development of the associated Gridchain software will be worth paying attention to.

Incentivizing (investment in) renewable power generation

A number of projects aim to use blockchain to provide a more efficient and/or effective link between renewable energy projects and potential investors than current market structures. Some of these are particularly focused on connecting investors with projects in developing economies.

A generic outline of these schemes is as follows: (i) investors buy tokens, creating a pool of capital and establishing a platform; (ii) developers and communities propose projects for funding; (iii) token holders and/or the platform operator decide which projects to back; (iv) platform funds are invested in / lent to projects (or entities procuring power from them); (v) the offtake from the project is de-risked by a prepayment / pay-as-you-go regime for end consumers. An example of a business based along these lines is ImpactPPA. Possible variations on the elements of this basic structure include:

- What are the characteristics of the funding provided—debt or something more like equity? In the case of debt, on what terms? When and how can individual investors exit the scheme?

- The extent of investor token-holders' rights to influence decision-making on investments—can individual investors decide to invest or not invest in a specific project; must they ultimately go with the results of voting by all or a defined group of investors; or are all individual preferences ultimately advisory, with the platform operator having the final say?

- Is there is a "supplier" offtaker between the generation project and end-users (which in turn may largely be a product of the sectoral regulatory architecture in the relevant jurisdiction), and can it be obliged to pass on prepayment obligations to its customers?

- Perhaps most fundamentally, who owns the generating projects? In the Sun Exchange model, investors "buy [individual] solar cells and lease them to be installed in commercial and industrial solar projects and mini-grids" for as little as US$10 each. Again, this is effectively a disaggregated debt-finance model, with individual investors receiving "rental income" on their assets. This greatly reduces the "entry level" contribution for financing solar generation assets whilst also using the capabilities of blockchain to maintain a link between the individual investor's contribution and a specific asset, rather than simply pooling small contributions into an undifferentiated larger lump of financing for a project as a whole.

Another approach is to establish a platform that intermediates between, and provides services to, a pool of (often retail) investors on the one hand and particular renewable electricity generating projects on the other. The generators, prior to commissioning of their plant, invite the investors to submit bids in an auction to purchase, at a discount to wholesale prices, amounts of their future power production in tokenized form (but with bids being subject to a floor price set by the generator). Each token represents 1kWh of electricity to be produced at a specific time. The investor who holds the token has the option of either taking the power for their own use (provided that the project is in their "home market" or one that is at least interconnected to it) or cashing in their investment by selling it.

This is the core of the business model of WePower, which is active in Lithuania, Estonia, Spain and Australia. It too can be seen as a debt-based model: the debt is repaid in kind when the power is generated. Like the P2P-focused ventures discussed in the previous article, such platforms need to work around the current limitations on the ability of individuals cost-effectively to trade small amounts of power on existing wholesale markets (e.g. by acting as a supplier so as to provide investors with an interface to the market). The timing of the auctions may be a key factor: they perhaps need to be held far enough away from commissioning of the projects to justify a significant discount to wholesale prices, but close enough to it for investors to be certain enough that it will happen.

Both of the above models are forms of crowdfunding. They aim to broaden the pool of personal capital available to invest in renewable projects beyond the existing class of high net worth individuals who invest in them through private equity and similar funds with high minimum investment thresholds; to offer platform investors higher rates of return than they might otherwise be able to make for a comparable level of risk; and to increase the returns for equity investors in the underlying generation projects, by enabling them to fund a higher proportion of their overall capex through crowdsourced debt or the proceeds of token sales (which may also reduce the dilution that they might otherwise see of their control over the projects). They also claim to simplify the processes of investor due diligence and transaction structuring, or at least to reduce the number of parallel and overlapping strands within them, partly by adopting standardized approaches (and perhaps partly by expanding the base of investors / lenders to individual projects so much that—compared with a conventional project structure—there are actually fewer parties involved who have the resources or sophistication to take an interest in the contractual and regulatory details of the transactions they are supporting). Finally, both models have the advantage of de-risking the offtake from the generators' point of view.

The role of blockchain in implementing such business models is clear: for example, they both rely heavily on tokenization, and the transparency of distributed ledgers provides a good framework for documenting multiple, potentially individually quite small, transactions between multiple participants who may be located in different jurisdictions and have no other ready means of connecting with each other. The kinds of additional "rewards" available to investors and other users of the platforms are also typical of the blockchain economy—for example the Sun Exchange program includes the issuing of SolarCoin, whilst tokens representing renewably generated electricity are at the heart of the KWHCoin project. The designs of both tokens reflect to some extent the so-called DeKo Thesis (originally promulgated in 2011) that "electrical energy in the form of a delivered kilowatt can be a more stable asset for backing currency than gold or debt".

But the success of these models may depend at least as much on the platform operator's mastery of the traditional skills of power project financing and development as on the attractiveness to platform investors and generators of the blockchain aspects of the set-up. The challenges include:

- identifying projects that are sufficiently robust from a standard due diligence point of view (permits, land rights, grid connection etc) at a point in their development when investment through one of these platforms is likely to add value from the developer's point of view without unduly complicating their existing contractual arrangements;
- apportionment, between platform investors and providers of more conventional debt and equity finance, of risks associated with failure by the generator to complete the project on time or at all, or to generate as or when it was expected to;
- in the Sun Exchange model, additional questions as to what sub-divided ownership of assets means in terms of the enforcement of security if rental payments are not made, or shortfalls in payments need to be allocated between investors—although Sun Exchange is developing a novel insurance product to mitigate the risks of project failure for investors.

Implementing these new models in a legally robust way for the first few projects is likely to be relatively costly because of their novelty. Their success will depend in part on how quickly "first-of-a-kind" contract design and drafting can be turned into a lower-cost, but still effective, "cookie cutter."

Finally, a different way of incentivizing investment in renewable electricity generation (which also plays a part in the future plans of some of the companies referred to above, such as WePower) is through the issue of the (usually tradable) instruments variously known as "green certificates," "RECs" or "guarantees of origin." More than one venture has been established with ambitious plans to harness the power of blockchain to improve what are seen as deficiencies in some of the existing national or state-based REC schemes by creating a standardized, internationally fungible, form of certificate. Examples of this include Swytch and Greeneum.

Beyond electricity projects: carbon credits and energy efficiency

One of the principal attractions of blockchain as regards not only the REC-style schemes but also a number of the projects reviewed above is its potential for transactional transparency and its ability to connect parties who may not otherwise have had the opportunity of contracting with each other and enable them to verify that their counterparties

have acted as required in circumstances where such verification might otherwise not be possible or straightforward. The same is true in relation to our last category of blockchain use cases, which includes but also goes wider than the electricity industry.

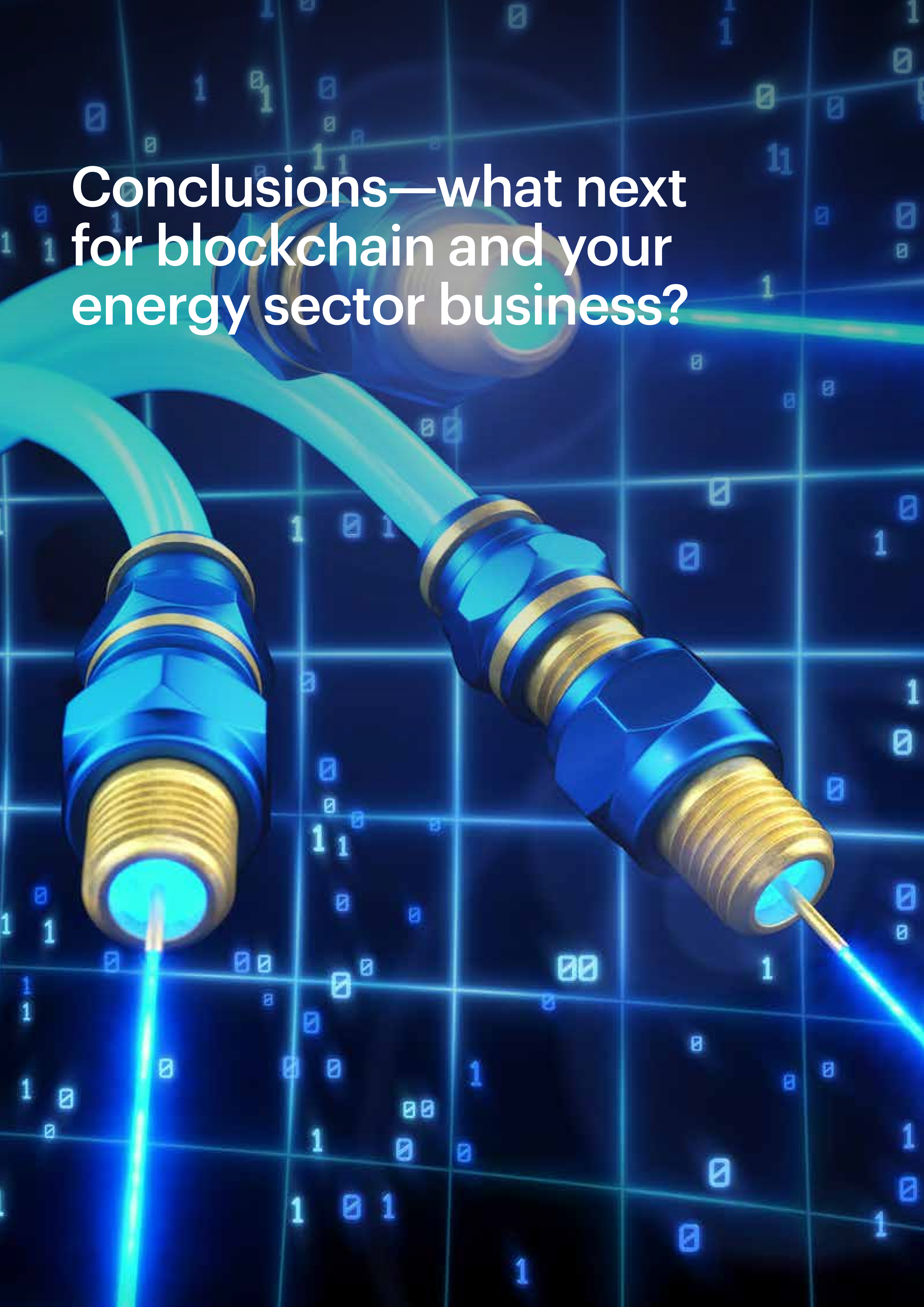
The global action on climate change that began with the Kyoto Protocol has gathered pace with the establishment and development of national and international carbon markets against the background of the UNFCCC Paris Agreement. In addition to classic "carbon credits" (the right to emit greenhouse gas) issued under cap and trade and other carbon reduction schemes, such as the allowances issued under the EU Emissions Trading Scheme, other instruments (voluntary emissions reductions and certified emissions reductions) attest to the offsetting of emissions, and the REDD+ scheme incentivizes developing countries to reduce deforestation and manage forests sustainably.

A number of projects aim to improve the functioning of carbon markets with blockchain. Climatecoin aims to develop "the most disruptive, peer to peer, decentralized, blockchain-based carbon credits trading portal in the world." Moving beyond existing carbon credits, the Poseidon Foundation aims to create its own carbon trading products and platform that would allow individuals, as consumers, as well as businesses, to control their own carbon footprints. New Era Energy, CarbonX and Veridium all have broadly similar ultimate objectives, but slightly different approaches to achieving them.

Away from formal carbon credit markets, Gainforest provides smart contracts to link farmers in the Amazon and those willing to pay them to reduce deforestation in a defined area for a certain number of months, while Qiru uses blockchain to track timber as a means of combating illegal logging.

Finally, there is the possibility of using blockchain to create platforms that would enhance the development of market-based incentives for energy efficiency. As the American Council for an Energy-Efficient Economy has pointed out, among the major challenges with energy efficiency schemes are documenting the counterfactual (what would have happened in the absence of the energy efficient action that was taken); verifying that the energy efficient action was taken; and capturing the value of the energy efficient action to multiple stakeholders and passing it on to the person who took the energy efficient action. These are all things that blockchain could do. (For example, in the case of capturing value to multiple stakeholders, see the electricity demand-side response applications and the Electron platform discussed in the previous article). One company that is exploring a token-based approach to rewarding energy efficient behavior is Energi Mine.

Conclusions—what next for blockchain and your energy sector business?



Some would dismiss all the excitement around blockchain as hype driven by corporate herd-instincts and individuals looking for ways of leveraging their cryptocurrency assets. Others would argue that many of the more innovative and exciting blockchain business propositions in the energy sector are precisely those least likely to come to fruition any time soon—for example, because of the need to work around the limitations that existing regulation in the electricity industry places on true P2P transactions, or to overcome the maritime commodity trading community's attachment to paper bills of lading. So why should you bother with blockchain now? Isn't it all just too speculative and risky?

The authors of an article in the January-February 2017 *Harvard Business Review* argue that blockchain is a "foundational" rather than a "disruptive" technology. They compare blockchain and TCP/IP (transmission control protocol / Internet protocol): TCP/IP's impact has been revolutionary, but it has taken time to emerge, having been around since 1972, when it was introduced as the basis for ARPANET, the US Department of Defense precursor to the commercial Internet.

Accordingly, while they note that "blockchain could slash the cost of transactions and reshape the economy," they also believe that "transformative applications are still far away." Nevertheless, "it makes sense to evaluate their possibilities now and invest in developing technology that can enable them" and to identify ways in which blockchain can facilitate new business models. They end by saying: "No matter what the context, there's a strong possibility that blockchain will affect your business. The very big question is when."

We are not in the business of making predictions about exactly when or in what form blockchain will start to have a really big impact in the energy sector. But, for us, the following points stand out.

- The energy sector is already being significantly disrupted by other rapid shifts in technology (digitalization, decentralization, decarbonization) and regulation. Those trends are only likely to become stronger and grow more quickly over the next decade and beyond, and some of them are a natural fit for blockchain applications.

- The energy sector is characterized by companies that are trying as hard as their counterparts in any industry to change fundamental structural features of the markets in which they operate—and some of those changes appear to be a good fit with blockchain.

- In contrast to some other industries, previous ICT-related innovations (such as TCP/IP) have not introduced significant or widespread changes in the business models of much of the energy sector. Whilst this could be taken to indicate that the sector is unusually resistant to such change, it could also suggest that it is overdue a transformative technology-driven shift.

- Although it was not prominent among the areas initially highlighted as being those in which the blockchain future would first materialize, the energy sector has seen a huge amount of new blockchain business activity over the last year or so. Whatever obstacles may stand in the way of turning that activity into sustainable businesses, and however overblown the claims made by some of those involved may be, it is far from being the case that it is all froth.

If blockchain has real commercial potential anywhere (which is not a small assumption), there are opportunities to develop some particularly strong potential blockchain use cases in the energy sector. Anything we can say about these opportunities is necessarily highly provisional at this stage.

Some of the challenges faced by blockchain ventures in the energy sector are the same as those in other sectors. Can the technology deliver what it promises? Will it be superseded by something better before it does so? Can businesses profit from blockchain without alienating consumers, many of whom may fear exposure to risks they do not fully understand, such as cryptocurrency volatility, and/or do not believe to be adequately controlled? How readily will existing contract law and dispute resolution regimes accommodate smart contracts?

Some of the more exciting potential applications of blockchain in the energy sector are clearly also those that are likely to take more rather than less time to be developed on a large scale—for example, "true" P2P electricity trading, which is also unlikely to develop at the same pace in different markets. The ease of interface with existing regulatory structures will vary from one jurisdiction to another, as will the extent to which other features of the market favor such developments (e.g. the size of the potential prosumer base). And there may be surprises: African telecoms have gone "straight to mobile," and African power generation is doing something similar (leapfrogging the centralized power generation model with distributed, often renewable, electrification, supported at the smallest scale by innovative digitalized mobile payments technology (as discussed in a previous volume). Some African markets could see successful blockchain-based electricity trading platforms before the electricity sectors in some much more developed economies do.

But, as we have also seen, long before blockchain establishes completely new business models as the norm in some sectors, there is the potential to use it to make significant cost savings and start to turn it to commercial advantage within existing market structures and regulatory frameworks. That is what those involved in many of the projects we have reviewed in this volume are doing. Engaging with the new technology need not mean trying to run before it can walk, or signing up to a long-term visionary goal: there are plenty of ways of working more incrementally within existing constraints, as the examples we have given in areas like wholesale energy trading and the gradual enhancement of services provided by and through existing electricity suppliers show.

Even these "less ambitious" applications raise substantive issues on the legal and regulatory side, as we have noted. These will not resolve themselves, and many of them are too complex and important to be left to either technologists or government and regulators to address on their own.

Of course, blockchain itself may not be the key that unlocks all the benefits of transformative digitalization that the advocates of blockchain-based projects in the energy sector are targeting. But, if so, that key is more likely to be found, and to be understood and effectively exploited, by those who are looking now at blockchain models than by those who just wait for someone else to invent the future. When the revolution comes (blockchain driven or otherwise), our hunch is that it won't be like the Internet in the sense that at a certain point every business of a certain kind (i.e., most kinds) realized that it had to have a functioning website, and you could maybe save some money by waiting until people had worked out how to design a reasonably good website cost-effectively. The blockchain (or similar) shift will happen differently in different sectors and markets, and most of the energy sector examples ultimately point towards the dominance of the consortium model. There are likely to be advantages in joining those consortia sooner rather than later.

Every energy sector business must make up its own mind how it wants to approach blockchain. We hope this volume provides some useful background to help you with that decision-making process. It is not for us to say what your decision should be, but in conclusion we would offer two negative suggestions. Never completely close your mind to the possible uses of blockchain. And never assume without very good evidence that blockchain can defy what you have always thought of as the laws of legal or commercial gravity

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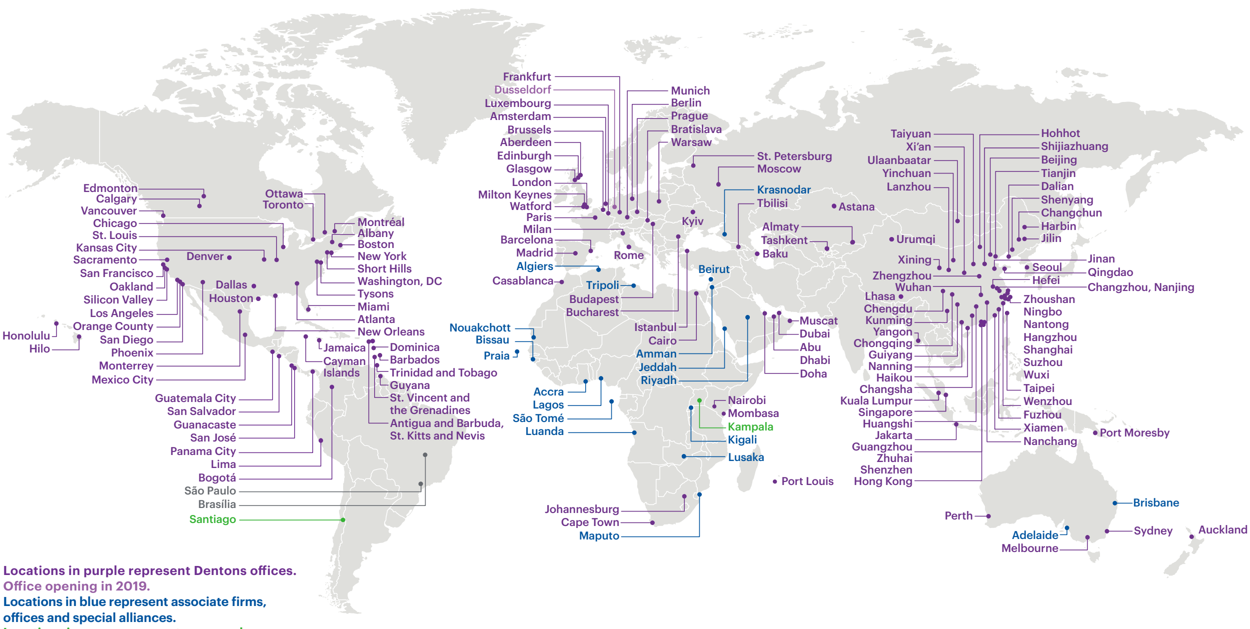

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