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PEER-TO-PEER ENERGY TRADING TASK FORCE

DLT Standardisation Efforts in Peer-to-Peer Energy Trading Applications: Expert Interviews and Lessons Learned

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Executive Summary

As the energy sector faces unprecedented challenges and opportunities, we are witnessing important innovations in market structures and business models driven by four key forces: decarbonisation, deregulation, digitalisation and decentralisation. Specifically, leveraging the potential of IT infrastructure and distributed ledger technologies (DLTs), several innovators have been experimenting with peer-to-peer energy (P2P) trading models, whereby households can exchange electricity directly. P2P energy trading can provide more direct access to renewable energy, contributing to the wider power system flexibility needed to manage larger shares of intermittent renewables.

Nevertheless, the application of novel technologies such as DLTs to critical national infrastructure raises a set of significant challenges in terms of reliability, security, scalability and consumer protection. Standards can play a key role by promoting a shared understanding of the technical foundations of the technologies and providing guidance on the challenges faced by the sector. However, when analysing current standards for the use of DLTs in the energy industry we found energy trading examples to be scant. This report aims to fill this knowledge gap through the empirical analysis of seven case studies using DLT applications for P2P energy trading. Case studies play a key role in providing a realistic perspective of how DLTs are being used in practice and can be used to guide standards developments in the field.

First, findings have highlighted a set of specific technical and regulatory challenges related to the use of DLTs in P2P energy trading that have largely influenced innovators' decisions in pilot design. Particularly, there seem to be evident trade-offs across aspects pertaining to decentralisation, immutability and privacy that present practical problems to those running pilots – ultimately hindering their scalability. These sector-specific complexities, particularly since energy trading uses large amounts of granular (personal) data, should be accounted for when developing standards in this area.

Second, due to challenges around data privacy, pilots seemed to focus on running activities supporting energy trading rather than enabling it, such as the recording, certification and storage of transactions and devices. Interoperability with legacy power systems was identified as a priority area for standards, particularly to integrate local energy markets.

Finally, it has been found that involvement and awareness of standards among participants are generally lower than expected. The fact that most standardisation bodies operate behind closed doors and are financed by their members through an access fee has been identified as a major barrier for the engagement of smaller actors such as start-ups and community energy groups. This raises questions as to whether standardisation efforts might be overlooking important technological developments happening within smaller organisations. As such, more thinking could go into how to enable wider access and ensure that expertise is leveraged across all types of market players.

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Introduction

The Future of Local Energy Markets

Energy industries globally are facing unprecedented challenges calling for radical re-thinking of existing power system operations and market structures. The driving forces behind these developments are often referred to as the four D's: decarbonisation, decentralisation, digitalisation and democratisation. Large coal and nuclear power plants are giving way to smaller distributed renewable energy generators, leading to the emergence of new market players. The rise of intermittent renewable generation on the low-voltage grid increases operational challenges but also presents new opportunities. Recent advancements in IT infrastructure, as well as the uptake of smart meters, enable the development of new business models that can be leveraged to increase the overall performance of the grid in the face of these challenges, with a potential for net social and economic benefits.

Peer-to-Peer Energy Trading

At the residential level, we see an increasing number of households installing distributed energy resources (DERs) such as solar photovoltaic (PV) or energy storage systems, through which they actively participate in the energy market. So-called *prosumers* could make their surplus electricity available to the market for a fixed fee. Alternatively, they could sell electricity directly to other consumers in what is known as peer-to-peer (hereinafter referred to as P2P) energy trading (Liu et al. 2019; Parag and Sovacool 2016). P2P energy trading enables households with small-scale energy generation resources to sell electricity directly to, for instance, their neighbours or a business within their local community. This decentralised approach could allow households to bypass energy utilities and retailers and engage in direct electricity transactions with the help of online marketplaces. Integrating P2P energy trading into the existing energy market could contribute to flexibility, congestion management, grid ancillary services and improve accessibility to renewable energy- thereby helping meet climate targets (IRENA 2020). Figure 1 shows how P2P energy trading between households takes place.

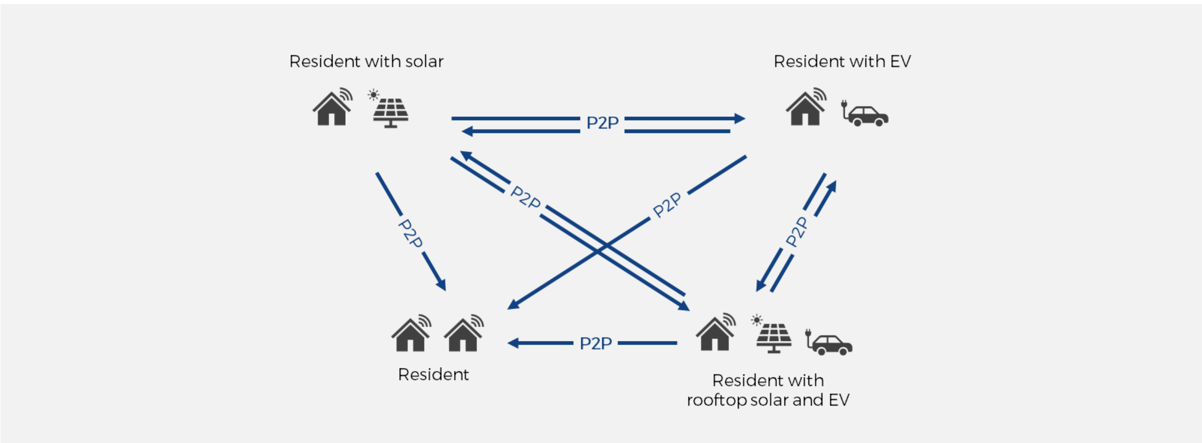

Figure 1 P2P trading market (adapted from Liu et al. (2019))

P2P energy trading is currently at a pre-competitive stage and developed in the form of pilot projects that have been launched worldwide. P2P is seen as a potential business model placing consumers at the forefront of the transition to net zero. The European Union's Renewable Energy Directive (RED II) recognises the right for energy consumers to trade energy, including within a community setting. However, legislation is vague as regards key topics of consumer protection, including governance, interoperability and data privacy (European Parliament 2018; de Almeida et al. 2021). Standards could play an important role in filling these gaps, enabling these business models and protecting consumers participating in P2P energy trading.

Use of DLTs in P2P Energy Trading

The aim of P2P energy trading markets is to allow participants to engage in bilateral transactions, with as little involvement by a centralised third party as possible. Furthermore, energy transactions are usually characterised by small unit sizes. Current centralised market structures, i.e. traditional wholesale power markets, are not designed to handle such small quantities nor direct energy exchange between consumers (particularly those living in the same geographical area).

Distributed ledger technologies (DLTs) such as blockchain have been used extensively in P2P energy trading pilots (Soto et al. 2021). The distributed structure of DLTs allows households to sell energy directly with a high degree of autonomy. Recent technological advancements have made DLTs more energy efficient (IRENA 2019). Additionally, *smart contracts* (a key feature of DLTs) are crucial in enabling automatic financial transactions between P2P participants. However, existing regulatory frameworks are not keeping pace with developments around these technologies, or pre-date the emergence of DLTs. The resulting regulatory uncertainty has led to most DLT applications of P2P being piloted in behind-the-meter use cases or as part of regulatory sandboxes (IRENA 2019). Figure 2 below explains how P2P energy trading uses smart contracts.

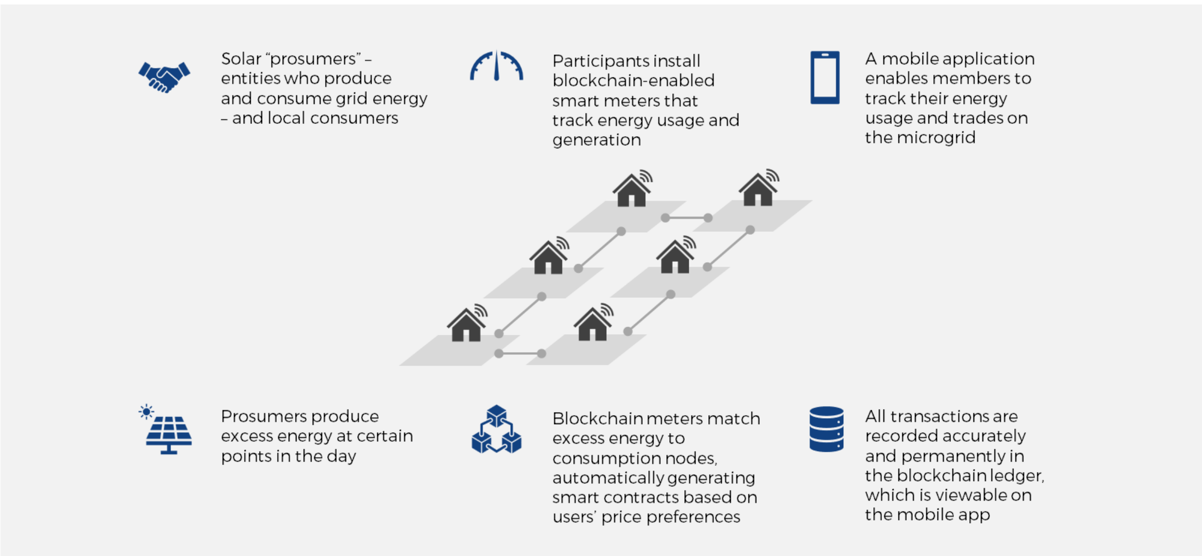

Figure 2 P2P energy trading using smart contracts (adapted from Henderson et al. (2018))

Role of Standards

DLTs potentially present risks to energy consumers' security due to gaps in regulation around the cybersecurity, data privacy and scalability aspects of these technologies. There is an added element of risk attached to deploying DLTs in the energy sector, since energy infrastructure is of systemic importance and needs to guarantee reliability, security, and continuous supply of electricity to consumers.

Due to these risks, most P2P energy pilots have taken place with small groups of consumers at a small scale, failing to investigate the consequences of more realistic scenarios involving a larger group of consumers (Capper et al. 2022).

A key challenge when integrating DLTs into the energy system is ensuring **interoperability** with new and legacy systems commonly used by network operators, retailers and utilities, as well as the different products, services and systems involved in delivering energy services (Snjum et al. 2017). The lack of standards around DLTs, including for technical protocols and smart contracts, can lead to incompatibility between different types of DLT and disregard for existing market standards and practices (Janssen et al. 2020). Interoperability also strongly relates to the topic of **scalability**. If the market is too fragmented, it becomes challenging to scale up DLTs and fully leverage their benefits (Peter et al. 2019). Scalability is also affected by aspects such as the speed at which transactions can occur and the costs associated with them (Janssen et al. 2020).

Another area where standards could play an important role is **data management**. An efficient and functional energy system relies on data being shared 'correctly, quickly and uniquely with the relevant actors within the system' (Peter et al. 2019). For example, having appropriate processes in place for processing large data streams from smart meters is a prerequisite for supporting the various DLT functions in P2P energy trading – including the settlement/matching of transactions, the monitoring of electricity delivery and processing of payments (Peter et al. 2019).

Third, standards could address issues related to the **governance** of P2P trading platforms. Decisions around DLT consensus mechanisms and underlying governance determine the extent to which different stakeholders can participate in the market, trust each other and reap the benefits of participation (Bokolo 2022). Guidelines in the form of standards would help ensure that governance decisions in DLTs are formulated in the interest of all those involved (Bokolo 2022).

Finally, there are some important considerations around **privacy** and **cybersecurity**. First, activities related to aggregation and trading usually involve the collection of large quantities of granular personal data. DLT-specific rules need to be developed to make sure that data collection and exchange as part of P2P transactions comply with data privacy regulation (e.g. General Data Protection Regulation, GDPR) (de Almeida et al. 2021). As for cybersecurity, many risks have been identified in the literature ranging from attacks on cryptography, denial of service, sybil attacks, selfish mining attacks, and unauthorised access to bugs in smart contracts (Bokolo 2022).

The Institute of Electrical and Electronics Engineers (IEEE) Blockchain Transactive Energy (BCTE) programme reflects the hierarchy of standardisation priorities in the field (see Figure 3) (Rahimi et al. 2021). Transactive energy (TE) – encompassing the concept of P2P energy trading – refers to the formation of an economic mechanism to incentivise the balancing of demand and supply in the electricity grid (GWAC 2015). The standardisation priorities of BCTE include (1) legacy power systems and energy standards widely adopted in the industry, (2) standards related to transactive energy methods and models (including P2P energy trading), (3) existing standards addressing DLTs more generically, and (4) standards that cover all other aspects related to data formats, cybersecurity, privacy and more (Rahimi et al. 2021).

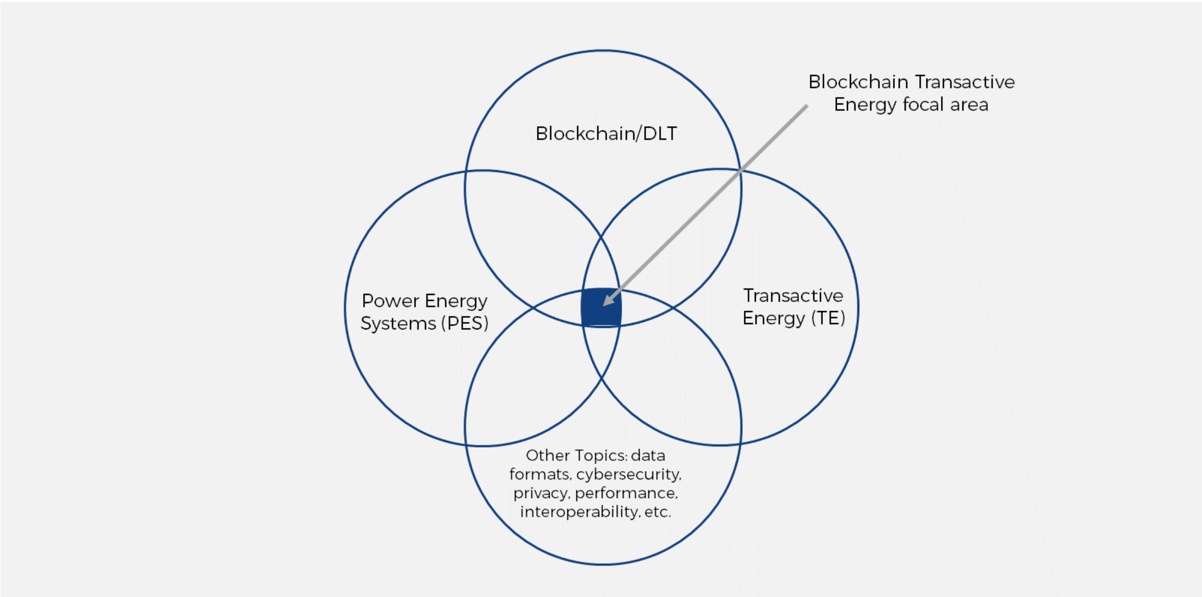

Figure 3 BCTE Intersection Areas (adapted from Rahimi et al. (2021))

When analysing current standardisation efforts in the field as part of this report, we observed how they do not reflect the structure and hierarchy above. Current standards either specifically focus on the application of DLTs in the energy sector or on the application of DLTs in general, independent of use case. However, the latter often focus on the financial sector. There is a gap in current standards relating to the second of the IEEE standardisation priorities, around transactive energy.

The integration of pilot projects as case studies in the development of standards plays a crucial role in providing a realistic perspective of how technologies are being used in practice. When analysing the status quo of standards in the field we found P2P energy trading examples to be scant. This report aims to fill this knowledge gap by providing information on how DLTs are used in P2P energy trading and identifying obstacles inhibiting pilot projects from engaging in standardisation efforts.

Aim of this Report

The aim of this report is to set out a realistic picture of P2P energy trading using DLTs, in the form of findings from interviews of pilot projects. Interviewees were asked about why they used DLTs, the challenges they encountered when using DLTs for energy trading, and whether they were involved in, or aware of, standardisation efforts in the field.

The findings in this report are crucial in how they show a less prominent role of DLTs in the trading of energy than is publicly advertised, and a lack of awareness of and support for standards by industry stakeholders. Based on these findings, this report aims to provide recommendations for those involved in standardisation efforts, to improve the standards applicable to the use of DLTs in energy trading – a largely unregulated activity which could potentially put consumers at risk.

The work was conducted as part of the Joint Task Force between the Global Observatory on Peer-to-Peer, Community Self-Consumption and Transactive Energy Models (GO-P2P) and the International Association for Trusted Blockchain Applications (INATBA). The Task Force ran from July 2020 until March 2022 and included 40 members of GO-P2P and INATBA from 12 countries, mostly representing industry and academia. The aim of the Task Force was to promote knowledge exchange between the two organisations.

GO-P2P, a Task of the User-Centred Energy Systems Technology Collaboration Programme (TCP) by the International Energy Agency (IEA), aims to collect data on case studies of P2P energy trading around the world. This also includes case studies using DLTs, due to their popularity in the field. INATBA is an organisation set up in 2019, bringing together industry, policymakers, civil society, and standards-setting bodies to support the scaling-up of DLT solutions in a range of economic sectors.

INATBA has a Standardisation Committee focusing on key themes, including:

1) Identity and privacy
2) Data management
3) Interoperability and scalability
4) Governance

These topics align with those focused on in this report, extracted from an analysis of current standards in the field, and will be further discussed in the section below.

Research Methods

To meet the aims set out above, the authors of this report relied on the analysis of three main sources of information: (1) draft documents from the main standardisation efforts in the field, (2) seven interviews with representatives of peer-to-peer energy trading pilots using DLTs, and (3) three interviews with senior experts in DLT standardisation.

As part of step 1, we reviewed the standards drafted by multiple standardisation bodies, and classified their work into the four key recurring themes outlined above. An important barrier to conducting analysis in this area is that most standardisation bodies follow a members-only access policy and therefore do not make their work publicly accessible during the developmental stage. This was a major obstacle to acquiring an accurate overview of the current situation. As such, we reviewed standardisation documents that are in the public domain or which we received exclusive one-time access to.

For step 2, interview participants were selected through purposive sampling to maximise technological and geographical variation, as well as to get an insight into different stages of the innovation chain. Most participants were active in the GO-P2P/INATBA Energy Trading Task Force. To allow for the collection of in-depth and novel information, the chosen interviewing style was semi-structured and open-ended. As such, participants were asked to discuss the four general themes drawn out from standards analysis, and then prompted to provide more details through follow-up questions.

For step 3, DLT standardisation experts were selected from GO-P2P and INATBA networks. Most of them were not active in energy-specific standardisation. The interviews with the DLT standardisation experts were carried out in order to reflect on the pilots' perspective on standards.

Participants were recruited via email and enrolled in compliance with UCL's ethics guidelines. Interviews took place between July and October 2021. As most interviewees opted for anonymity, instead of analysing findings based on single case studies, collected information was aggregated and analysed through thematic analysis. Findings from the interviews are set out in the next sections.

Overview of Pilot Projects

Aims and Objectives

Before we go into the standards-based thematic analysis, in this section we provide information on the reasons for, and ways in which, DLTs were used in the P2P energy pilots interviewed for this study.

Interviewees consisted of seven start-ups/organisations using DLTs for the purpose of P2P energy trading. Altogether, the companies are (or have been) engaged in a total of sixteen pilots in seven different countries, including the United Kingdom, the Netherlands, Ireland, Italy, India, France and the United States. The objectives of the pilots range from operational, to economic and social. These are summarised in Figure 4 and are discussed more extensively below.

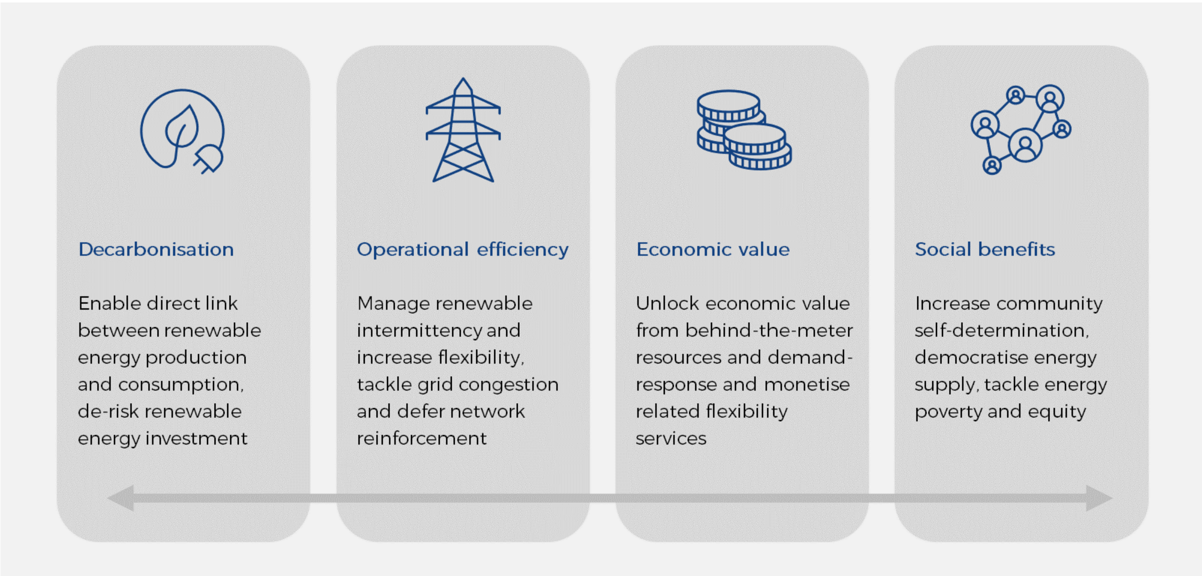

Figure 4 Objectives of interviewed P2P energy trading pilot projects

First, decarbonisation of energy supply seems to be a major driver. Specifically, this reflects a desire to directly link renewable energy production and consumption, de-risking renewable energy investment, removing its exposure to wholesale market (and policy) risk, and improving access to renewable energy for consumers.

The second main driver is managing renewable intermittency, as the growth in variable generation such as wind and solar can cause challenges on the energy grid related to system balancing. For example, a significant presence of intermittent generation in a certain area might lead to higher network congestion rates and costly grid reinforcements. Several participants identified tackling this issue as a key driver of their activities.

Another driver is to unlock flexibility from an often underutilised resource: behind-the-meter assets and demand-side response (e.g. industrial sites, residential appliances, electric vehicles). In doing so, pilots aim to explicitly monetise the value of flexibility services offered by distributed resources generating revenue streams and economic value for individuals and local communities. An important by-product of this, often identified as an explicit goal by participants, is to enable the decarbonisation of other sectors beyond energy such as smart mobility and industrial activities.

Some of the pilots aimed to leverage digital systems to contribute to a shift in the market from a centralised to a decentralised structure, and hence a process of democratisation of the power supply chain. In other words, the goal is to advance community self-determination and empowerment in the context of an industry historically dominated by large incumbent players.

Finally, there is another set of recurrent goals revolving around social issues such as tackling energy poverty, affordability, and equity. In fact, P2P energy trading models could enable communities to share energy and enable energy donation to less well-off segments of society.

Distributed Ledger Technologies

Interviewed stakeholders used a range of DLTs in their pilots. The types of DLTs used were: Ethereum, Hyperledger Fabric, Hyperledger Sawtooth, IOTA and Hedera Hashgraph. Descriptions of these technologies are provided in Figure 5. An important consideration explaining the variation in choice is scalability and affordability, i.e. the price of transactions.

More specifically, the main reasons identified by participants for using DLTs are related to their potential in enabling the following:

- The automation of transactions (through smart contracts);
- Preserving anonymity and protecting identity;
- Enabling traceability of information and devices;
- Boosting cybersecurity.

In terms of the specific functions DLTs were used for, these include:

- Optimisation of everyday matching and trading;
- Recording, certification and storage of transactions;
- Billing and settlement;
- Automation of supplier switching;
- Use of cryptocurrency for payments.

It is important to note that, with one exception, pilots used DLTs as an infrastructure technology supporting transactions, rather than to *enable* trading. In the words of one participant, “blockchain is used as a storage system [...] a traceability tool rather than for automating processes” Finally, there was some variation among the pilots in terms of the use of smart contracts.

Ethereum

- Since 2014
- Blockchain with proof-of-work consensus mechanism (at the time of writing)
- Public/private ledger
- Smart contracts are a fundamental building block of Ethereum

Hyperledger Fabric

- Since 2016
- Supports pluggable consensus protocols (i.e. Cash Fault Tolerance or Byzantine Fault Tolerance)
- Permissioned ledger developed for enterprise solutions
- Includes a smart contract model (chaincode)

Hyperledger Sawtooth

- Since 2016
- Supports a variety of consensus algorithms (i.e. Practical Byzantine Fault Tolerance and Proof of Elapsed Time)
- Permissioned ledger developed for enterprise solutions
- Includes smart contracts in a variety of languages

IOTA

- Since 2016
- Uses a Directed Acyclic Graph (DAG) called Tangle
- Public/permissioned ledger
- Built for the Internet of Things with no transaction fees and a variety of application areas

Hedera

- Since 2017
- Is a proof-of-stake network built on hashgraph distributed consensus algorithm
- Public/permissioned ledger
- Unique feature is its governing council which runs the consensus nodes that determine transaction ordering

Figure 5 DLTs used in P2P energy trading pilot projects

Figure 5, which shows the different types of DLTs used in pilots, makes a distinction between public, private and permissioned ledgers. Public ledgers, used in popular blockchains applications such as Ethereum, enable easy access/participation and low initial investment by users. However, they have important technical limitations such as the slow speed of transactions, as well as issues related to unrestricted access and lack of governance. On the other hand, in private ledgers access is managed by a central authority with the authority to define those who can execute the consensus mechanism. Private ledgers are characterised by high levels of efficiency and fast transaction timeframes. However, they present important trade-offs in terms of security, scalability and might require higher upfront investment. Finally, permissioned ledgers are a hybrid solution between public and private ledgers: participation and applications must be approved by the relevant consortium, but users have freedom to operate as they wish after approval (Peter et al. 2019; Hedera 2019).

The next sections will focus on the four themes drawn out from existing standards in the field, which formed the focus of the interviews.

Response to Four Standardisation Domains

The following sections summarise critical insights from the seven semi-structured interviews regarding the four main standardisation themes identified in standards analysis: 1) identity and privacy, 2) data management, 3) interoperability and scalability, and 4) governance.

1) Identity and Privacy

Any information needed to identify a subject generally falls under the category of identity. The interviewees distinguished between two types of identities: the identity of smart devices such as smart meters or sensors; and the identity of natural persons, in this case, the energy end-users. Data privacy was a key concern as regards the latter category, since existing data protection regulation (in the European context, this is the GDPR) is applicable to personal data.

In most interviewed pilot projects, all personal data[1] is stored off-chain to avoid any data privacy risk. Depending on the type of DLT, different approaches link the on- to the off-chain data. In the few cases where personal data is stored on-chain, it is in an encrypted format and can be decrypted using log-in credentials. Similarly, where personal data was needed for the execution of smart contracts, cryptographic approaches were applied to preserve the anonymity of participants. Finally, where the involvement of third parties was necessary, the data was authenticated using zero-knowledge proofs.

All interviewees agreed that processing personal data and ensuring compliance with the 'right to be forgotten'[2] in the GDPR are key factors influencing the choice of DLT for a project. Problems around compliance were attributed to the immutability of DLTs. Once data has been recorded on the ledger, it is necessary to make sure it is fully anonymised, since the immutability of DLTs makes it difficult to remove or amend data. According to the pilots interviewed, additions or amendments to the data would result in additional transactions, leading to unnecessary transaction fees and storage costs and should therefore be avoided. While immutability was generally seen as a unique and decisive feature for choosing DLTs, additional clarity from the regulatory side is needed to explore its potential and implications. The interviewees requested more certainty about compliance with GDPR.

In light of this, a combination of private and public DLTs (i.e. hybrid) was seen as a solution to capture most benefits whilst ensuring compliance with current regulations. One interviewee stressed that a critical benefit of widely used permissioned DLTs is that they are more committed to observing compliance with the GDPR. Using a permissioned DLT allows them to avoid making personal data publicly available.

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[1] "Personal data are any information which are related to an identified or identifiable natural person..." (Article 4(1) GDPR)

[2] "The data subject shall have the right to obtain from the controller the erasure of personal data concerning him or her without undue delay and the controller shall have the obligation to erase personal data..." (Article 17 GDPR)

It is therefore clear that data privacy is a major obstacle to the scaling up of P2P pilots using DLTs, due to concerns around complying with rights set out in regulation such as the GDPR. Standards could play an important role here as a bridge between the relevant (sector-agnostic) regulations and data privacy issues specific to the energy industry, such as the need to collect personal data from energy consumers to enable trading on DLT platforms. Nevertheless, until regulation in this area is further defined in this area, the problem is likely to persist.

2) Data Management

Data management in all pilot projects was influenced by challenges highlighted in the section above. How much a particular DLT is trusted and what information can be stored publicly or privately will determine what the DLT is used for. Most interviewees have stressed that in their current development stage, they use DLT as a 'proof of concept' rather than a fully functional and regulation-compliant solution.

In most pilots interviewed, DLTs were mainly used for their embedded infrastructure features rather than as a financial transaction tool. Key functionalities decisive for selecting DLTs included the automation of transactions through smart contracts, as well as tracking the identity and traceability of information and devices. Usage was often limited to the recording, certification and storage of transactions and devices.

The registration and identification of devices operating in the energy market, such as solar panels, energy meters and sensors, is a crucial feature of all energy trading markets. In many pilot projects, the DLT is directly embedded in the smart meter or linked through a middleware to avoid identity theft. Device identification is necessary to trace the energy's origin and ensure participants' accountability.

Therefore, the potential of data management for the first type of identity set out in the previous section, namely identity of smart devices, is recognised by most pilot projects. DLTs are used as a tracking and recording tool of non-personal data. This probably explains why DLTs are not commonly used as a financial transaction tool in pilots, i.e. technology enabling energy trading (which is what is publicly advertised for DLT use in P2P energy applications). Once further clarity is provided on GDPR implications for personal data stored on ledgers, particularly at a sector-specific level by standards, data management could move to becoming more transaction-related.

3) Interoperability and Scalability

Interoperability generally refers to a system's ability to communicate and exchange data with other systems. In the context of energy markets, interoperability is a vital prerequisite for the uptake of DLTs in the field. Interviewees highlighted that DLTs currently in use should be interoperable with existing industry-specific protocols and standards. Interviewees confirmed that their solutions comply with common data taxonomies and widely known industry-specific standards and protocols. Interoperability between DLTs was not ranked among the most urgent challenges, as all pilot projects used commercially available solutions and were not directly involved in the development of the DLTs themselves. However, a few interviewees mentioned that their teams closely monitored the standardisation developments around interoperability.

Scalability was a decisive factor for the selection of a type of DLT for a pilot as it determines the capacity of a system to change in size to scale. In the context of DLTs specifically, scalability can be restricted by DLT-specific features such as the number of transactions per second, the cost per transaction and the number of nodes or participants involved, often associated with the consensus mechanism. Those who opted for consensus mechanisms based on 'proof-of-work', i.e. Ethereum (at the time of writing), used a private blockchain instead of processing data on the public blockchain to keep transaction fees down (as well as meet GDPR requirements). Energy consumption of the DLT, determined by its consensus mechanism, also contributed to this decision. Alternative DLTs with more scalable consensus mechanisms and lower transaction fees like Hedera and IOTA were preferred by some interviewees.

More standardisation was requested by participants regarding the integration of local energy markets into the existing energy system. Specifically, standardisation of data flows and formats would ensure that legacy systems are interoperable with the design of local energy markets. Furthermore, interviewees highlighted that they remain technology-agnostic and would consider technology solutions other than DLTs in the future, indicating that DLT is not the definitive solution for P2P energy. Standards focusing on P2P energy trading should therefore aim to set guiding objectives rather than limit the technological solution.

4) Governance

Governance within the context of DLTs refers to how the technologies are operated and used by a group of users. The interviewees distinguished between two forms of governance: governance of the technology itself and governance of how the technology is used within a use case. While the former relates to the integration of norms, rules, or culture into the development of the technology, effectively the code, the latter describes how the functionality and constraints of the technology are operated within the unique environment of a use case.

Some DLTs used in the pilot projects, such as Hedera and IOTA, have built their technological solutions around governing councils. Their primary function is to ensure that the network is operational at a functional level and to keep the transaction costs low. Governing councils like Hedera's frequently change their members to avoid any abuse of power. For DLTs with a 'proof-of-work' consensus mechanism such as Ethereum, the governing structure is effectively defined by its miners. These could have an interest in keeping transaction costs high, which makes them a less attractive option for those planning commercial scalability of a pilot project. One interviewee highlighted that while the presence of a governing council might undermine the decentralised aspect many see as DLTs' main advantage, governance is necessary for the technology to be able to scale up in the future.

The consensus mechanism of the DLT also influences the governing structure of the use case. The choice of DLT was therefore influenced by whether it would provide an answer to some of the critical challenges innovators seek to address in the development of local energy markets. For instance, DLTs providing smart contract functionality were chosen by pilots since they enable automatic transactions and information exchange in the P2P market. Although they are programmable, one interviewee highlighted the lack of flexibility as a challenge when writing smart contracts on the Ethereum Blockchain. This could cause governance issues. A suggestion was to decouple smart contracts from the DLT.

The interviews demonstrated that standards around governance are needed in order to scale up DLT models. This is why DLTs with governing councils are gaining in popularity for P2P energy trading. However, these could undermine the decentralised nature of DLTs, popular with local energy markets, and the question is how standards could provide governance guidelines for different types of DLT used in the same use case.

Involvement in Standards Setting

Overall, participants' involvement in standards setting is limited to general exchange of information and know-how, such as the provision of case study data to standards bodies. While experts from two pilots were not involved in any standardisation efforts, others showed moderate to high interest, as well as involvement in multiple standards organisations. These included industry-agnostic DLT standardisation groups such as ISO TC 307, ETSI ISG PDL group, W3C and CEN-CENELEC. Others included industry specific DLT standardisation such as the IEEE P2418.5 working group on Blockchain in Energy or the Swiss DLT4Power initiative. Those who were actively involved highlighted that there is generally a high level of information exchange across the different institutions that work on the standardisation of DLTs.

Participants who do not use standards cited a lack of awareness and incentives to comply with existing standards. For them the disadvantages of engaging in standardisation efforts, in terms of additional work and costs, outweigh the advantages. Those who were actively contributing to standardisation work criticised current standards for being vague, with hypothetical and basic specifications. It was also mentioned that standards generally lag behind most recent developments in the industry, and there is thus little incentive to comply with them.

Some participants showed hesitation towards the standardisation of DLTs. DLT standardisation would contradict the core values of DLTs, such as decentralisation, deregulation, and leveraging technologies for disruptive change. Specifically, there is a concern that standardisation could restrict the technology's unique characteristics and limit future innovation. In addition, several participants highlighted that a consensus might start to emerge naturally on the use and operation of DLTs as these technologies become more widespread and integrated within the energy system.

However, all participants acknowledged that a certain degree of DLT standardisation and regulation in the energy industry would be necessary to incentivise the uptake of the technology, by creating trust in the sector. One participant also highlighted that they see a commercial benefit in complying with widely accepted standards, as they could act as a 'seal of approval'. This would allow companies to operate more transparently and gain their clients' trust by removing some of the stigmas of blockchain because of negative press around the cryptocurrency bitcoin.

The Future of DLT Standards

The responses of pilots regarding their involvement in standards development mirror those of standardisation experts interviewed for this report.

According to standardisation experts, standards aim to reach a consensus within the community. They result from a naturally formulated agreement, whether based on one solution having the first-mover advantage, an open-source solution, or a solution that has outcompeted other proposals. A significant benefit of complying with standards is that it ensures interoperability across solutions and technologies and enhances consumer trust.

However, contrary to a generally prevailing opinion amongst the pilot interviewees, standardisation experts highlighted that standards are not trying to dictate how something should be done by specifying a single correct approach. Instead, standards try to reach a set of defined objectives, while the mechanisms used to achieve those objectives can vary. This is important to avoid slowing down innovation. Standards' detail and technical focus will differ depending on the standard type.

The current market is dominated by a few permissioned enterprise solutions. When asked about which DLTs are likely to be predominantly represented in standards, the experts emphasised the unpredictability of technological innovation. Hence, standards should not focus on one type of technology but on creating the right environment for new, more advanced solutions to emerge.

However, a potential key reason as to why standards adoption by the community might have been slow is the temporal shift between the innovation happening and the progress in standardisation development. Experts highlight an essential trade-off in this context. While there is an opportunity to accelerate formal (mandatory) standards, at the same time, there is an opportunity for the industry to innovate and adopt voluntary standards. This shows how standardisation and innovation can happen in parallel, with standards being adopted gradually.

Beyond issues related to the objectives and form of standards, engagement in standardisation efforts emerged as a critical theme in expert interviews. While the standardisation process would benefit from wider early-stage involvement of industry, start-ups and non-profits, it is particularly challenging for these to engage. Most standardisation bodies operate behind closed doors. To access their work, it is necessary to become a member or to purchase documents against a fee, which are not publicly accessible during the development stages. Standardisation experts recommended more advertising of standardisation efforts and a more open approach to actively involving smaller actors in the field.

Discussion and Conclusion

Interviews have shown that peer-to-peer energy trading pilots use DLTs to find new ways to resolve energy sector issues, such as decarbonisation and operational efficiency of the grid, unlocking economic value from behind-the-meter assets, and social aims including the democratisation of energy supply. DLTs are used for their decentralised properties, enabling automation of transactions (through smart contracts) and the traceability of information and devices.

As opposed to what is publicly advertised around peer-to-peer energy trading, DLTs are presently not used for trading directly (i.e. automating processes), but rather to support it. They are used for instance to record transactions, keeping track of devices, and billing and settlement. This is due to several obstacles to scalability, linked to the properties of the technologies.

The first is immutability, which is one of its main selling points, enhancing trust between participants. Difficulties related to removing or amending information on a DLT pose problems for compliance to data privacy regulation, such as GDPR's 'right to be forgotten'. This meant that most pilots kept as much (personal) data as possible off chain. The second implication is that this led to most pilots using DLTs as tools to manage non-personal information, such as the recording, certification and storage of transactions and devices.

Data privacy and scalability concerns such as transaction costs and consensus mechanisms led most pilots to opt for private blockchains. Importantly, interviewees signalled that they were open to new technologies. They showed interest in alternatives to private blockchains, such as Hedera and IOTA. These two DLTs not only appealed to interviewees due to their lower transaction fees and potential for scalability, but also because of their governing councils. The latter would help scale pilots by increasing consumer trust.

There is a clear clash in our findings between the original aim of pilots to use the decentralising features of DLTs to help resolve energy sector issues, and the wish to scale up pilots in the face of obstacles presented by these very features. Even if regulators were to provide further clarity in new regulation, this would likely be technology agnostic, as it has been so far. Standards can play an important role in filling this gap and setting technology-specific requirements. This is particularly urgent in the use case of peer-to-peer energy trading, which requires granular (personal) data from consumers to enable peer-to-peer trading, and interoperability with legacy power systems.

Formulating standards on interoperability and data management could be useful to facilitate the current supporting (rather than enabling) role of DLTs in P2P energy trading. It is however questionable whether standards on data privacy would have any use without legal clarity on the application of GDPR to DLTs. Furthermore, standards on governance might be less effective, as DLT options differ in their governance views, and some already provide governance solutions. Guiding standards/principles on governance could be an alternative to mandatory standards.

However, most interviewed pilots had low awareness and engagement with standards. They did acknowledge that these were of importance to lead towards the commercialisation of pilots. The slowness of standards-setting (which could be argued as enabling innovation to develop in parallel), as well as inhibited access to standards bodies for smaller players, play a role here.

These findings raise several questions. First of all, are DLTs the right technologies for P2P energy trading, if aspects pertaining to their decentralisation present practical problems to those running pilots – ultimately hindering their scalability? Furthermore, there is the question of whether standards and regulation are suitable instruments for technologies that promote themselves as being disruptive, decentralised and ungovernable.

Lastly, many P2P energy trading pilots are being run by small actors such as start-ups and community energy groups. How do we ensure there is a seat for them at the standards formulation table? This raises questions as to whether standardisation efforts might be overlooking important technological developments happening within smaller organisations. While access fees are pivotal in supporting the work of standardisation bodies, more thinking could go into how to enable wider access and participation for smaller players, e.g. through progressive membership fees, more publicity or external engagement workshops. This would ensure that the whole industry is aligned, and that expertise is leveraged across a wide range of use cases.

Based on the interviews with pilots and standardisation experts, we have the following recommendations for stakeholders involved in standards setting, particularly around the use case of peer-to-peer energy trading using DLTs:

- Standardisation bodies should enable wide early-stage involvement of small actors such as start-ups and community energy groups, by creating alternative models to the member-only access policy and fees.
- Standards should not focus on one type of technology but on creating the right environment for new, more advanced solutions to emerge. They should aim to set guiding objectives rather than limit the technological solution for a use case.
- Standards could serve as a bridge between the relevant regulations and the energy industry by ensuring the energy industry's compliance with identity and privacy regulations. Nevertheless, until some regulatory aspects (e.g. privacy law) are further defined in this area, challenges are likely to persist.
- Prioritise the formulation of standards for the interoperability of DLTs with legacy power systems. This would help ensure that legacy systems are interoperable with the design of local energy markets.
- Continue collecting case study data to ensure standards reflect the evolving reality of peer-to-peer energy trading using DLTs.

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