ETLA Working Papers

No. 43

11 October 2016

Juri Mattila
Timo Seppälä
Catarina Naucler
Riitta Stahl
Marianne Tikkanen
Alexandra Bådenlid
Jane Seppälä

Industrial Blockchain Platforms: An Exercise in Use Case Development in the Energy Industry

Suggested citation: Mattila, Juri, Seppälä, Timo, Naucler, Catarina, Stahl, Riitta, Tikkanen, Marianne, Bådenlid, Alexandra & Seppälä, Jane (11.10.2016). "Industrial Blockchain Platforms: An Exercise in Use Case Development in the Energy Industry". ETLA Working Papers No 43. http://pub.etla.fi/ETLA-Working-Papers-43.pdf

ETLA ELINKEINOELÄMÄN TUTKIMUSLAITOS
THE RESEARCH INSTITUTE OF THE FINNISH ECONOMY

ISSN-L 2323–2420
ISSN 2323–2420 (print)
ISSN 2323–2439 (online)

Industrial Blockchain Platforms

An Exercise in Use Case Development in the Energy Industry

Juri Mattila*) – Timo Seppälä**) – Catarina Naucler***) – Riitta Stahl***) –

Marianne Tikkanen***) – Alexandra Bådenlid***) – Jane Seppälä****)

Abstract

To encourage public discourse on blockchain use case development, this paper provides a pragmatic view on how to develop and to describe blockchain use cases. We approach the issue by developing a tentative use case for autonomous machine-to-machine transactions of electricity in a housing society environment through an iterative process with stakeholders in the energy industry. We proceed by evaluating the outlined concept and its technical specifications against six criteria for a sensible blockchain use case, as identified by blockchain industry specialists. Finally, we conclude with observations and discussion on the use case development process, and its future steps.

Key words: digital platform, industrial platform, blockchain technology, autonomous marketplace, energy industry

*) The Research Institute of the Finnish Economy (ETLA), juri.mattila@etla.fi

**) The Research Institute of the Finnish Economy (ETLA), and Aalto University; timo.seppala@etla.fi

***) Fortum Oyj; firstname.lastname@fortum.com

****) Aalto University; jane.seppala@aalto.fi

Table of Contents

Introduction 1

1 Characterization of blockchain technology 2

2 Defining the target state: interoperability of different energy systems 4
- 2.1 The decentralizing energy system 4
- 2.2 Centralized and decentralized platform control 6

3 The conceptualization of the use case 7

4 Technical Specifications 10
- 4.1 The distributed marketplace 10
  - 4.1.1 Blockchain as the backbone 10
  - 4.1.2 The matching engine 10
  - 4.1.3 Searching and storing data 11
- 4.2 The smart devices 12
- 4.3 The communication protocols 13
- 4.4 The power transferring mechanism 13
- 4.5 Measurements 14
- 4.6 The market analytics 14

5 A checklist for blockchain use cases 15
- 5.1 A database shared by multiple parties 15
- 5.2 Enabling multiple concurrent writers 15
- 5.3 Maintaining consensus regarding the content of the database 15
- 5.4 Interacting modifications 16
- 5.5 The absence of trust 16
- 5.6 The undesirability of intermediation 16

6 Observations and discussion 17

References 19

Acknowledgements

The authors would like to express their special gratitudes to Heli Antila from Fortum for her extensive support to this research. The authors would also like to thank Klaus Känsälä from the VTT Technical Research Centre of Finland, Jero Ahola from Lappeenranta University of Technology, Antti Tahvanainen from the Research Institute of the Finnish Economy, Brian Fabian Crain and Rick Dudley from Monax, Bruce Pon from Ascribe, and Sam Warburton and Carsten Stoecker from RWE for their insightful comments regarding this research, as well as Ville Peltola from Technology Industries Finland for enabling this study in the first place.

This research is an ongoing collaboration of BRIE, the Berkeley Roundtable on the International Economy at the University of California at Berkeley, and ETLA, The Research Institute on the Finnish Economy. Timo Seppälä has received support for his work from the iPlate research project which considers integrating platform competences toward network effects, with funding from Tekes, the Finnish Funding Agency for Innovation.

Introduction

Today, sustainability and digital platforms[1] rank higher than ever on the global agenda of companies, and economic developers alike. In the last few years, driven by both regulatory initiatives and novel, technology-enabled business opportunities, this policy mandate is no longer based on a fad but an economic megatrend with considerable disruption momentum (Chander, 2014; Lauslahti et al., 2016). The implicit principle of resource efficiency facilitated by digital platforms, now coupled with enhanced financial returns, will become integrated in nearly every sector of the economy (Evans & Gawer, 2015).

Emergent digital platform ecosystems, such as smart grid and similar, are gradually starting to deliver on the much heralded promises of business potential, and sustainability – both environmental and social (for example see Rudkevich, 2016).[2] Striving to take advantage of the emerging digital platform opportunities, e.g. blockchain technology, companies across the conventional industry boundaries are now investing in efficiencies and value added services. In doing so, they are defying and disrupting conventional industry boundaries and building new value chain structures outside their familiar playgrounds.

In the process of developing digital platforms, business models are changing, allowing for scale and revenue growth, but also threatening the validity of businesses that refuse to adapt. Enabled by intelligent integration of hardware, software, sensors, data, analytics, and other technologies, the physical layer of conventional infrastructure of incumbent industries is becoming connected with the cloud; It is becoming part of the digital platform architectures, providing the capability to any third party to develop and roll out intelligent complementary innovations, goods and services (Kushida et al., 2011; Pon et al., 2014; Seppälä et al., 2015; van Alstyne et al. 2016).[3]

From the point of view of industrial and social digitalization, blockchain technology is an interesting concept in terms of developing a use case for a number of reasons[4]. Firstly, there are very few detailed conceptualizations publicly available for sharing opinions, thoughts, discussion and debate about the technology. Secondly, blockchain technology has been quickly adopted onto the technology radars of major industrial companies, e.g. Fortum Oyj and RWE, and

---

1 Digital platforms refer to information technology systems upon which different actors — that is, users, service providers and other stakeholders across organizational boundaries — can carry out valued-adding activities in a multi-sided market environment governed by agreed boundary resources. Typically these actors create, offer and maintain products and services that are complementary to one another. Platforms quintessentially lure and lock in various types of actors with their network effects and economic benefits thereof (Seppälä et al., 2015).

2 On the history of electrification in Western society, see e.g. David & Bunn, 1988; Hughes, 1993.

3 For example, see St. John, 2013.

4 For more information about the impact of blockchain technology, see Mattila, 2016.

society at large, e.g the Bank of England (Hirtenstein & Zha, 2016; Saarinen 2016). Thirdly, from the standpoint of digital platforms, blockchain-enabled distributed consensus architectures offer a number of interesting possibilities and unique technical features for the management of autonomous marketplaces, e.g. OpenBazaar[5].

The motivation for this paper has been to create a formatted template structure for the support of any future discourse on blockchain use case development. We approach the problem of how to describe blockchain use cases by developing a tentative use case for autonomous transactions of electricity in a housing society through an iterative process with stakeholders in the energy industry. Our rough-cut planning structure begins with the characterization of blockchain technology. On the basis of the outlined suitability of the technology, the next step is to define a target state and to conceptualize a preliminary use case which meets the criteria of a useful application of blockchain technology. Ideally, the concept should be such that it allows for future implementations in a larger scale, and involves a roadmap on how to achieve that scalability. Once the concept has been outlined, the structure of our protocol continues by the filling in of technical specifications and requirements to an adequate level. We then evaluate the technically specified use case in greater detail against the six requirements for a sensible use case identified by industry specialists.

Following our use case development structure, the paper continues as follows: First we provide a characterization of the blockchain technology and the target state. In the second chapter we construct a blockchain-technology-based conceptualization together with industry experts from Fortum Oyj. In the third chapter we provide technical descriptions of our use case concept. In the fourth chapter we evaluate the use case of a distributed marketplace against a checklist for a sensible blockchain use case. We end the paper with observations and discussion.

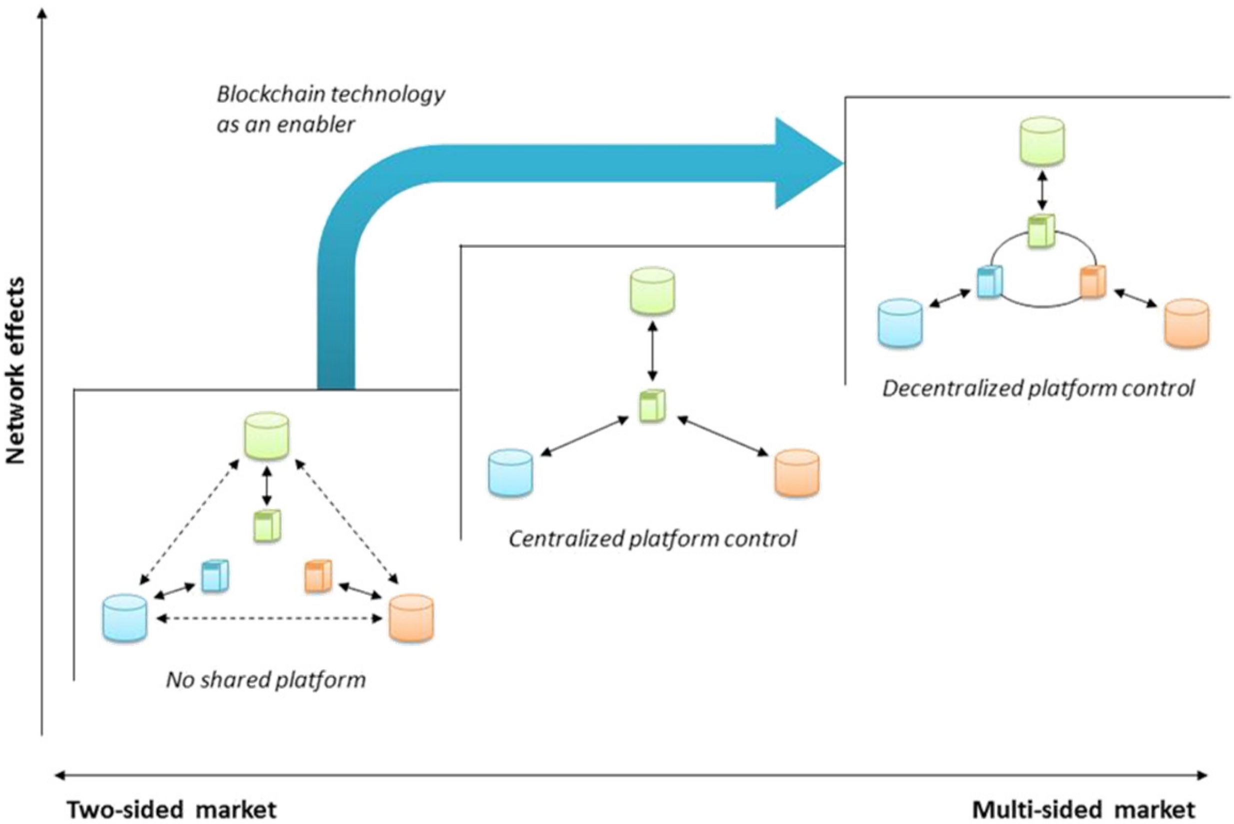
1 Characterization of blockchain technology

The definition of the term 'blockchain technology' is somewhat ambiguous. Systems with similar features are sometimes used for purposes not associated with distributed databases, and not all distributed databases make use of the kinds of consensus algorithms that are usually associated with blockchains. Most commonly, however, the term 'blockchain technology' is used in reference to 1) a certain cryptographically concatenated data structure, 2) the distributed digital consensus architectures which the data structure enables, and 3) the domain of applications built on top of such architectures (Mattila, 2016).

[5] <https://openbazaar.org/>

The essential disruptive element in blockchain technology is the ability to maintain consensus regarding the content of a database that is shared between equipotent and equally privileged nodes which are unknown to each other (see picture 1). Blockchain-based solutions are particularly well suited for databases where everyone can access all of the data but no one party can have total control over how and by whom the database can be modified. In industry discussions, such arrangements have been found useful at least for light-weight financial systems, provenance tracking, inter-organizational record-keeping and multi-party data aggregation (Greenspan, 2016).

In a wider scope, blockchain technology is disrupting society in two fronts. Firstly, by providing disintermediated, censorship-resistant and tamper-proof digital platforms of distributed trust, blockchain technology enables direct and reliable transactions of valuable and scarce assets over the internet between any two parties willing to do so (Mattila & Seppälä, 2015; Mattila, 2016). Due to this disintermediating effect, blockhain technology introduces new elements into the discussion on how is value created around platforms, who captures the value and who owns the platforms themselves (for comparison, see Gawer, 2009; Zysman & Kenney 2015, van Alstyne et al. 2016). Secondly, for enterprise- and industry-level systems, blockchain technology is providing efficiency gains on top of existing structures by removing the constant need for actively intermediated data-synchronization and concurrency control by a trusted third party, as in any typical supply chain, for example (Mattila, 2016; Mattila et al., 2016).



Picture 1. *Blockchain technology has enabled platforms in which platform control is decentralized (Mattila et al., 2016)*

Global high-level cross-industry collaboration schemes can also benefit from blockchain technology, as such co-operation requires seamless interoperability between devices and systems by different manufacturers. Blockchain technology can facilitate novel platform architectures with disintermediated control for societal and industrial platforms (Mattila & Seppälä, 2016).

2 Defining the target state: interoperability of different energy systems

2.1 The decentralizing energy system

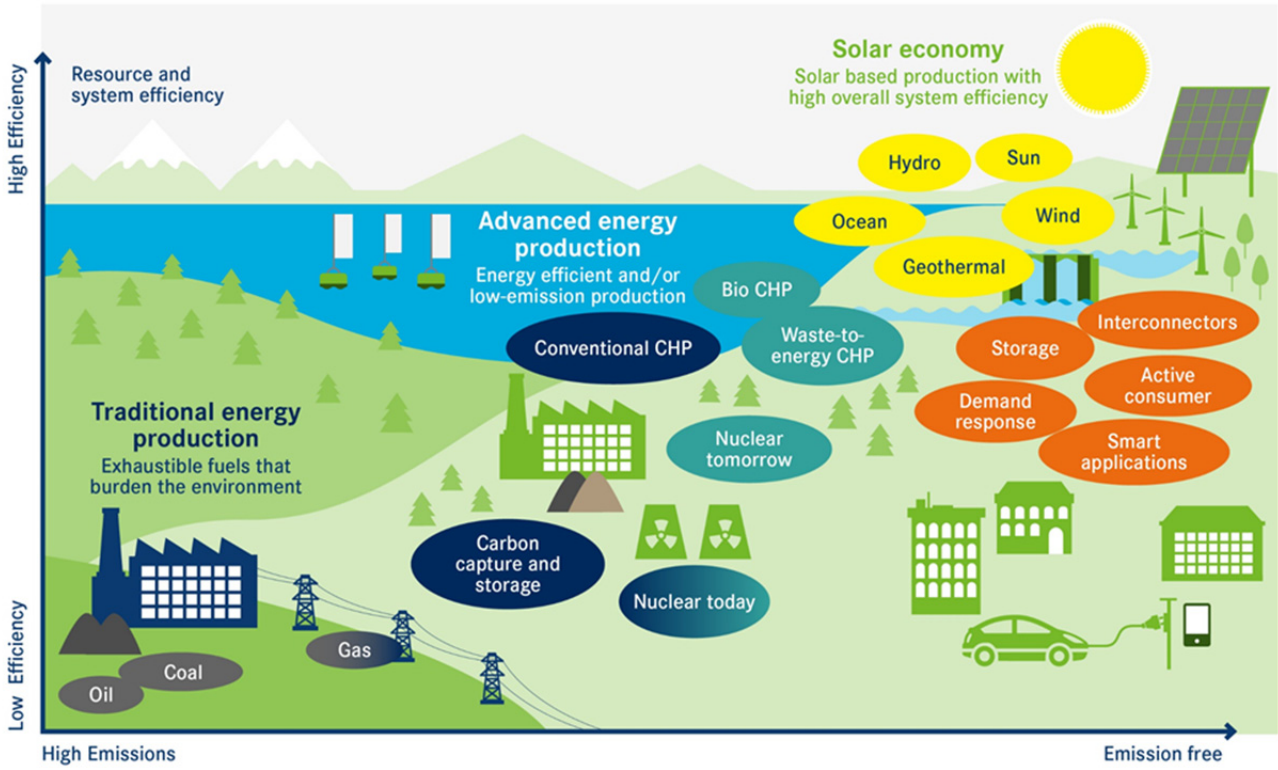
The transition towards more new renewable sources of energy means that energy production is becoming more dependent on the weather, and therefore more unpredictable and intermittent, requiring more alternatives for short-term and long-term demand-supply balancing (see picture 2). Respectively, average power prices will decline but price variation increases. At the same time energy system becomes more decentralized and versatile wind turbine parks and household solar panels are a growing trend in the generation of electricity and primary energy in general. This calls for a more flexible energy system: flexible production and consumption on a household level, as well as innovative energy storing solutions, such as home batteries and refrigeration batteries for commercial facilities[6].

In the future energy system there will be times when there is too much energy produced (a sunny and windy day) and periods when there is lack of energy (very cold day with no wind). The key question regarding the new energy system is how to secure for each time resolution that production and consumption of electricity are in balance. To be able to provide an answer, increased possibilities for flexibility in all energy resources is essential. In some areas the decentralized energy system could also mean a constraint for the local grid, with both electric vehicle (EV) and photo-voltaic (PV) as new local resources. Therefore, one objective is that entities could allocate electricity among themselves autonomously so that the allocation is efficient, self-sustained and not controlled by an external intermediator. Some earlier use case concepts have been drafted which focus on allocating distributed renewable energy resources between neighboring households using blockchain technology. Some of them have even been realized in practice[7]. The objective of this study, however, is to take these concepts one step further and to outline a tentative use case for device-to-device electricity transactions. The idea discussed in this paper is that by creating a distributed marketplace powered by employing a blockchain consensus

[6] For an example on a refrigeration energy storage, see <http://www.axiomexergy.com/>.

[7] For example, see <http://www.ccgrouppr.com/practical-applications-of-blockchain-technology/sectors/energy/>.

architecture, the smart devices can act as buyers or sellers of electricity, according to their own free determination.



Picture 2. *The new energy system called Solar economy, described by Fortum (Fortum Oyj, 2016).*

On a higher contextual level, this concept draws from the idea of servitization of everything. What this concept entails is that a customer could lease a refrigerator as a service, with the maintenance, the insurance, and the electricity, alongside with everything else the machine requires to operate, included in the price. To take this idea of servitization even further, a scenario could be envisioned where a solar panel producer offers to provide a private individual with a new solar-panel-mounted roof for their house free of any cost, but under the condition that the solar panel producer retains ownership over any electricity the panels produce during their lifetime, and that the solar panel producer can use the household grid infrastructure to convey and to sell that electricity either to the household devices, or into the national grid.

Effectively this means that the devices provided as a service would have to be able to operate using the same connection to the national grid and the same smart meter that the customer uses for his or her own devices. Therefore, for the concept to be feasible, it must be possible to distinguish the electricity used by the refrigerator from the rest of the electricity flowing through the household smart meter. Furthermore, it must be possible to measure and to document this data in a reliable way from both parties' point of view. To achieve this, we must go beyond smart meters on the level of households and examine transactions on the level of individual devices. By doing so, this paper endeavours to shed light on the question of what is the optimal level of transacting entities for such device transactions[8]. On the scale from households to individual devices, this use case can help visualize the latter extreme.

2.2 Centralized and decentralized platform control

Many proposed platforms exist today which could function as the basis of a ubiquitous network of systems. Most of them, however, are based on an architecture with centralized platform control (see picture 1). While such systems are easier and cheaper to construct, they may not be optimal for society from a network of systems perspective (Mattila & Seppälä, 2015).

In practice, companies are usually reluctant to submit into operating within technical frameworks which are controlled by other companies. While there may be a number of good reasons for companies in certain situations to deviate from this rule, as long as there are options, getting locked into someone else's platform is generally a bad idea, as it usually translates into becoming the underdog in value capture potential. As a result of this reluctance, companies would rather strive to build their own company-specific or consortium-based platforms (Seppälä & Mattila, 2016; Mattila, 2016).

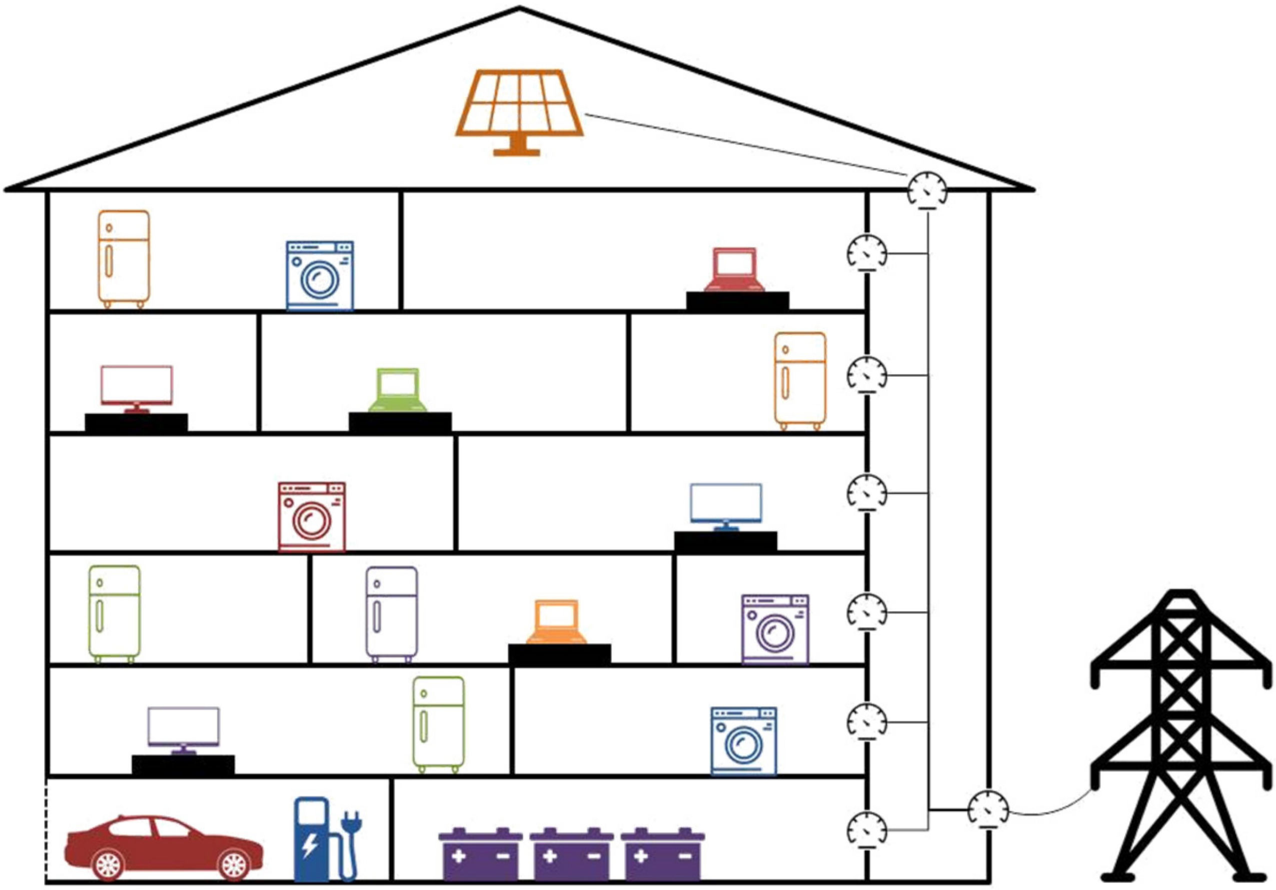
Supposing that the architecture of a ubiquitous network of systems would be based on a large number of such company- and consortium-level platforms, the interoperability between all the platforms bubbling into and out of existence would present a colossal challenge for seamless functionality. Conversely, if a small number of such centrally controlled platforms managed to become the dominant players in the market, they could easily be turned into vertical silos by their owners. In other words, the providers could reduce their platform's interoperability with other platforms on purpose in order to enforce a stronger customer lock-in to their own domains of products and services (Filament, 2015; Mattila, 2016).

So, in essence, building a platform for a ubiquitous network of systems is difficult because the interests of the platform participants are inherently conflicting with those of the platform provider. Blockchain technology could offer a way to circumvent this problem by providing a neutral ground where all the parties can operate on a shared platform, on completely equal footing. Instead of the platform provider being the dominant player to the power of whom all others must submit, blockchain technology could enable all the participants to produce a platform together in a distributed manner, without having to trust each other in almost any capacity (Seppälä & Mattila, 2016; Mattila, 2016).

[8] For further discussion, see e.g. Buchmann, 2016.

3 The conceptualization of the use case

To outline the use case described in this paper, let us consider a Swedish housing society ('bostadsrättsförening' in Swedish, see picture 3). The society owns an apartment building and the inhabitants of the building co-own the society in proportion to the sizes of their apartments. This means that a lot of things are shared in the building — the stairs, the elevator, the cellar etc.



Picture 3. *A housing society with one shared national grid access point and a second level of smart meters behind it. Icons courtesy of freepik.com.*

The electricity infrastructure of a housing society can involve two levels of smart meters. On the first level there is a single smart meter (or two smart meters for bi-directional measuring) shared by the entire housing society. The second level is populated by apartment-specific smart meters (submeters). One idea behind this arrangement is that since the electricity market in Sweden is unbundled (that is, the electricity fee and the grid fee are separated), the inhabitants can save money by reducing the number of the grid access points through which they operate. Another idea is to optimize the system on the whole housing society level to be as self-sufficient as possible and use the grid only when needed and to open up an local market were peers-to-peers can sell and buy electricity. This structure could also in the future open up for customers to have access to the market even if they do not have access directly to choose supplier to their own grid connected meter.

In our use case, the internal electricity allocation in a housing society consists of various independent energy transactions between individual smart devices within the housing society.

To conceptualize the use case in greater detail, some example transactions have been described below.

As the sun rises, a smart solar panel array installed on the roof of the housing society starts to generate electricity. The solar panels have been installed free of charge by an external company under the condition that the company retains the right to sell the electricity produced by the array. The networked computer chip integrated to the array connects to a distributed peer-to-peer marketplace equilaterally generated by various kinds of smart devices and powered by blockchain technology. The system scans the order book of the distributed marketplace for the highest bid for electricity. The array compares this bid with its investment and operating costs, as well as any price parameters predetermined by its owner. Based on said parameters, the smart array then either accepts the highest bid available or, issues a new sell order at a lower price point. As there are no bids currently in the market, the solar panel array issues a sell order at its lowest acceptable price.

An autonomous battery unit has been installed into the building's basement to function as a buffer for the distributed marketplace. The networked computer chip integrated into the battery unit scans the orderbook and the market transaction history to conduct autonomous trend analyses on the demand, the supply, and the market price of electricity. Based on its analysis on the current market situation, the battery system autonomously decides whether to purchase electricity to recharge itself, to sell its remaining charge back into the network, or to do nothing and to wait for the market situation to develop further. Since there are no bids in the orderbook from other devices at the given time, and hence no other device to which the solar panel can sell its electricity, the battery system offers to purchase the electricity from the solar panel at a minimal cost.[9]

A person in one of the housing society's households decides he needs to run his washing machine. The washing machine connects to the distributed marketplace and scans the order book for any open sell orders. It sees three entries in the order book: a sell order from the macro-grid at a spot price, a sell order from the solar panel array currently, and a purchase order from the battery unit. The last two are currently being mached at steady intervals by the matching engine of the distributed marketplace. The washing machine issues a new purchase order

[9] To cover some of its depreciations, it makes sense for the solar panel array to accept the battery system's offer, even if, in principle, the solar panel array is making a loss on the trade.

with a bidding price one unit higher than that between the solar panel and the battery. The solar panel sees the bid, terminates its arrangement with the battery and starts supplying the washing machine instead. The battery responds by raising its bid until it reaches its self-determined threshold of profitability. If the highest bid is still below the spot price offered by the macro-grid, the washing machine bids one unit higher than the battery's threshold, and thus the solar panel keeps allocating its electricity to the washing machine at a market equilibrium price.

The sun has set and the solar panel array has stopped producing electricity. Due to some heavy consumption in the evening, the battery unit has also been depleted. Another resident of the housing society parks her electric vehicle into the garage of the building and connects it to a charging station. The computer of the electric vehicle scans the order book and the transaction history of the distributed marketplace to conduct trend analyses to assess the current market situation for electricity in the housing society. The computer determines that the vehicle's batteries are still half full and that the battery has been charged at a lower price than the current sell orders in the market. Based on trend patterns, the computer also decides that the price of electricity will decrease in the morning, as the solar panels start producing electricity again. Therefore, the electric vehicle issues a sell order for the remaining energy left in the battery, at a lower price than the current market balance in the housing society.

There are several ways that the marketplace for exchanging electricity between households and individual smart devices could be built. On the level of individual housing societies, the simplest way to organize the marketplace would be to employ a centralized third party as the trusted marketmaker. However, in terms of trust, scalability and interoperability, there are benefits that a distributed system provides when expanding the concept from the level of individual housing societies — or systems of systems — to a much wider network of systems perspective. While a centralized solution might be more logical from the perspective of any single housing society, the purpose of utilizing a distributed solution in this small-scale proof of concept is to enable network-of systems-level integration between smart devices where a large number of housing societies and other parties can maintain a transaction market system together in a shared fashion.[10]

[10] The benefits and the problems of utilizing a distributed marketplace have been acknowledged in earlier research by Hoffner *et al.*, 2000, albeit from a slightly different perspective: *"By carefully separating certain virtual marketplace aspects and by physically distributing them, it is possible to derive a marketplace architecture that satisfies the important requirements of both customers and providers of such markets. However, it is important to bear in mind that centralisation has advantages, and that distribution does not come for free; there is a price to pay in terms of the overall complexity of such marketplaces. This complexity, however, is heavily outweighed by the advantages accrued by distribution. – – The distributed approach supports a scalable marketplace and also points towards a way of addressing providers' legacy problems. – – It is also possible to employ the distributed marketplace in another manner, by*

4 Technical Specifications

4.1 The distributed marketplace

4.1.1 Blockchain as the backbone

The distributed marketplace for electricity transactions can be created by utilizing a distributed consensus architecture, more colloquially referred to as a *blockchain.* It enables shared databases to be maintained on a distributed basis without any central authority exercising multiversion concurrency control over the database.[11] In other words, the equipotent nodes which maintain the blockchain are able to maintain consensus on the content of the database despite simultaneous modifications happening at different points of the network.

The marketplace can either be made private (e.g. only accessible to the participants of the housing society), or it can be made public and permissionless, so that all willing devices can freely connect to it, as long as it adheres to the designated protocols. In such a public configuration, any participant can issue purchase orders or sell orders, for example as smart contracts, all of which can be respectively accepted by any other device in the network.

The reconciliation between the local energy production and the main utility network can be executed so that the local distribution cabinet participates in the distributed marketplace as just another device amongst the others. It can provide the micro-grid with a steady supply of electricity from the main grid by holding out a permanent sell order at a spot price.

4.1.2 The matching engine

For any market where assets are traded, the purchase and sell orders must be somehow matched together. This is usually achieved by utilizing a matching engine. While some distributed matching engine concepts have been developed and patented, an easier half-way solution might be to integrate the simpler concept of a distributed search engine into the client software and to leave the order matching to individual participants on the basis of their search results. Multiversion concurrency control, in such a distributed solution, would be provided by blockchain technology.

---

allowing several dialogues to be conducted with multiple providers simultaneously. This, however, raises the problem of synchronising and managing these multiple dialogues, – – [which] may force the client side to deal with issues such as asynchronous dialogues, monitoring and audit trail provision, separation of client from provider, reliability, security etc."

[11] When two parties are unknowingly trying to edit the same piece of data in different ways at the same time, multiversion concurrency control is what prevents the database from becoming fragmented into multiple parallel versions. In essence, it is the protocol according to which it is decided what the true sequence of events has been and whose modifications are considered valid. In the discussed use case, if two parties are accepting an offer at the same time, multiversion concurrency control is needed to determine whose order is filled and whose is not.

Another possible way to achieve order matching would be to utilize a pre-existing blockchain application platform with an integrated virtual machine, such as Monax's smart contract application platform, or potentially Ethereum's Homestead. These platforms are specifically designed for independent, customizable blockchain applications, such as smart contracts, to be built on top of them.[12] On one hand, Ethereum utilizes a public blockchain and therefore may be more rigorous, but it may also be difficult to scale, somewhat expensive, and slower in block generation. Monax, on the other hand, employs a private blockchain solution for each use case which may be more useful for this purpose. Another potential way to get around Ethereum's scalability issue might be to use MultiChain's streams instead of Solidity-based smart contracts altogether. Other options also exist which may potentially be suitable.[13]

4.1.3 Searching and storing data

To function accordingly, a distributed marketplace would require data on the issuances and the acceptances of offers containing all the relevant price and product details, records on the executed transfers of electricity, and records on the completed payments for those transfers. As the discussed concept is based on a distributed architecture, the marketplace would also require information on where and how the market orders can be found in the peer-to-peer network.

Depending on the order matching approach, market orders could, for example, be issued (and accepted) as smart contracts, the metadata of which could be logged into a distributed hash table to make them more easily queryable. To ensure that the network scales in a linear fashion, any potential "blockchain bloat" could be circumvented by using a blockchain ledger in conjunction with a distributed database such as the BigchainDB and potentially a distributed file system such as the IPFS.

One open question regarding the data management and system architecture is that of the refresh rates regarding the market orders. A higher frequency of market updates sets the requirements higher for the system specifications, while a lower frequency may translate into lower matching accuracy. For practicality, the system parameters should be designed so that the refresh rate is no lower than once every minute.

---

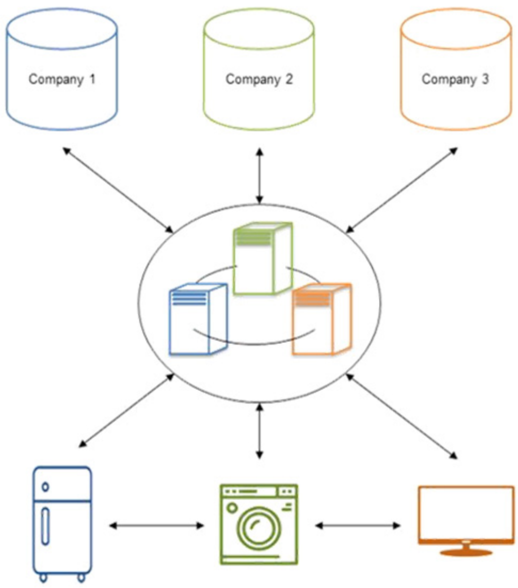
[12] The idea of smart contracts is that by formulating contractual arrangements between parties into computer code format and storing them into a blockchain, contracts can be made tamper-proof, self-executing and automatically enforceable (for further information, see Lauslahti et al., 2016).

[13] For example, one option would be to fork a modified version of some pre-existing distributed marketplace, such as OpenBazaar <https://openbazaar.org/>. However, this procedure would be quite heavy for the purpose, and the odds are that simply leveraging the existing smart contract libraries of Monax, for example, would be easier and more cost-effective.

4.2 The smart devices

Certain technical capabilities are required of the smart devices in the network in order to be able to participate accordingly. To operate the distributed marketplace, the devices need to be able to run a smart contract application client. They also need to be able to combine the distributed market data with sensory inputs on the traded flows of electricity. For these purposes, the smart devices will require basic computational functionality and networking abilities. While this could be realized in variable ways for different devices, one generic option would be to utilize an embedded platform such as a Raspberry Pi or something of a similar fashion. Networking abilities could also be established with products offered by Filament, namely Tap and Patch. The most sensible operation system to use for the described purpose would undoubtedly be Linux.

It should be noted that in all likelihood, no matter how the computational functionality were to be integrated into the devices, over time the storage capacity of those devices would not be sufficient to store an entire copy of the blockchain onto each device, even if it was used in conjunction with a distributed database and/or with a distributed file system.[14] For this purpose, a separate network of full nodes would be required, to and from which the smart devices could send and receive data as required (see picture 4). In a large-scale network-of-systems-level adaptation of this concept, full nodes could, for example, be maintained by housing societies, office buildings, and other entities of the same caliber.



Picture 4. *The relationship between smart devices, the blockchain architecture, and company IT systems.*

[14] For example, the Bitcoin blockchain currently requires about 90 gigabytes of storage space per each node of the network. <https://blockchain.info/charts/blocks-size>

4.3 The communication protocols

Direct power line communication (PLC) can be relatively expensive and inefficient over long distances. Therefore, from the perspective of scalability and longer data transfers, the best way for the smart devices to communicate would most likely be over the Internet. This, as mentioned, can be achieved with a simple Linux controller attached to each device, costing approximately a couple of euros per month per device.[15] The controller should also include a temporary data storage, so that if the network connection is lost, the data is saved locally and communicated forward as soon as the connection is re-established.

Communication between the nodes of the distributed marketplace can be achieved using the remote procedure call protocol JSON-RPC. The client programs for the distributed marketplace can communicate using practically any socket protocol desired. To ensure that messages are sent to the correct recipient, the devices can identify themselves to each other using public key cryptography. IP address whitelisting, firmware authenticity monitoring, and multi-element sensor environmental data authenticity monitoring are also possible to provide extra layers of security.[16]

4.4 The power transferring mechanism

In the electricity market, the physical and the commercial layer are detached in the sense that the buyer is not necessarily getting the same physical electrons as the seller is feeding into the network.

Some devices in homes are not as flexible as others. For example, when a person arrives home, the usual pattern of behavior is to switch on the lights immediately and not 20 minutes after the arrival. For many regular appliances and household devices, it would most likely be sufficient to aggregate the consumption levels of all the sub-meters in one household, and let that consumption be part of the total transaction towards a market. In such an arrangement, some devices, such as laptops, could still offer flexibility despite the lack of a bi-directional flow of electricity into and out of the devices. For example, a household freezer unit could cool itself to a lower temperature when energy is readily available. During the workday, when the residents are not home, the freezer unit could then "sell" the reserve back into the network by abstaining from cooling itself for a contracted period of time, thus releasing the occupied capacity for the contractual counterparty to use. Respectively, a laptop battery could abstain from recharging itself for an agreed period of time, and so on.

For devices which are capable of higher flexibility, such as electric vehicle batteries and other energy storage units, it would make more sense to steer the

15 The most expensive communication cost, however, is the initial programming work required to establish the system.

16 <http://www.chainofthings.com/cs1solar/>

physical transfer of electricity to and from the storage, as such devices could also potentially be used for distributed balancing and frequency control.

Looking at the scalability potential of this concept, any physical transfers between apartments, or transfers via the national infrastructure, such as between two housing societies for example, would need to be converted into AC in order to be fed into the grid. In such an arrangement, it would be vital to be able to determine in a distributed manner which of the three phases in the AC-grid to supply, since a severe imbalance between the phases can make the grid unstable.

Currently, most of the distributed local electricity production (e.g. solar panels, wind turbines, and batteries) is generated in direct current (DC) form. As most white goods and home electronics are designed for alternating current (AC), an inverter is required for the conversion. Too many inverters placed one after another are not necessarily always energy efficient or otherwise economically feasible, which may introduce criteria for the infrastructural design of the network.

4.5 Measurements

In order for a distributed marketplace for electricity transactions to function, it must be possible for the devices to measure flows of electricity and to communicate them into the system. The hardware required for facilitating such measurements and the communication thereof is readily available. There are several smart plugs in the market that also can connect to a WiFi system. To control more advanced devices, it might be necessary to have some kind of smart management device, such as a WiFi-based control system.

Depending on whether the distributed marketplace would be built around smart contract technology, one possibility for conveying the information into the transaction system would be to employ oracles — that is, smart contracts which are specifically designed to convey information from various APIs into a blockchain database. Oracles are required because any factors affecting the execution of smart contracts must be imported into a blockchain to ensure deterministic validation across the entire network of full nodes (Lauslahti et al. 2016).

4.6 The market analytics

The most likely scenario in the presented use case would be that the market analytics would be sold to the devices as a service, or provided in a centralized manner by their manufacturers themselves. While there is nothing preventing locally produced analytics per se, from a grid computing perspective, looking at the relationship of latency vs. local computing power, it is likely that the control mechanism would be situated outside the device, somewhere on a backend server. In a commercially offered solution, the performance of the predictions could then be impartially verified from the data in the blockchain, thus ensuring a fair prediction market.

5 A checklist for blockchain use cases

In industry discussions, certain conditions have been identified which need to be met before it makes sense to utilize blockchain technology for any particular purpose (Greenspan 2015; Greenspan 2016). In this chapter, we analyze the use case outlined in this paper against these criteria.

5.1 A database shared by multiple parties

The first requirement for the sensibility of a potential blockchain use case is that it entails an inherent need for a database to be shared between many parties. This is due to the fact that blockchain technology is based on a peer-to-peer network structure, and therefore it has no applicability whatsoever in a centralized database.

For the reasons explained earlier in this paper, in order to have a platform for a network of systems to which smart devices can freely connect and disconnect, and where devices can autonomously trade locally produced electricity, the use of a shared database is justified. A centrally controlled architecture would run the risk of interoperability issues and/or vertical silos in a larger scale.

5.2 Enabling multiple concurrent writers

In order for the application of blockchain technology to make sense, there must be a need for many parties to be able to make potentially overlapping modifications into the database at the same time. In essence, this is due to the fact that where such a need is not present, some more conventional database structures will be sufficient for the purpose.

In a distributed transaction system with a large number of devices, it is important that more than one party can make modifications to the shared database at the same time. If concurrency control was carried out by locking the entire database, or even one data input from all users but one at a time, the database would become less robust, and quite possibly too slow in its performance. As a result, the update frequency of the account balances of the smart devices would have to be lowered accordingly, potentially leading to a lower degree of allocation efficacy.

5.3 Maintaining consensus regarding the content of the database

For any system which involves maintaining a distributed consensus architecture, it is of vital importance that all participants agree on the content of the shared database. Otherwise, it is impossible to rely on the fact that one's counterparty agrees with one's view on the current state of the shared database. Needless to say, unacknowledged disagreements on contractual terms, for example, would later result in countless conflicts, essentially rendering such a fragmented system completely useless.

In the distributed marketplace we have conceptualized, the classical double-spending problem must be resolved, just as with any other system of financial book-keeping. The smart devices and the full nodes of the network must be able to maintain consensus on what offers and purchases are on the table in the mutually produced marketplace and which offers have already been accepted and by whom. Moreover, the devices must be able to agree on account balances and on which transactions have been paid for accordingly, and which ones are still waiting for payment.

5.4 Interacting modifications

A genuinely strong blockchain use case also requires that the modifications written into the shared database by all the concurrent writers somehow interact together. This means that even when the modifications do not directly overlap or contradict each other, they are still somehow interconnected.

In the use case described herein, a smart device's ability to enter a contract and to execute a transaction acutely depends on the acceptance of the open offers by other devices at a given time. An open offer accepted by one device in the shared marketplace can no longer be open for other devices to accept. Thus there is an inherent possibility that the database modifications by different writers overlap and conflict with each other if multiversion concurrency control is not applied.

5.5 The absence of trust

The key disruptive element in blockchain technology is its ability to maintain consensus on the content of a shared database between equipotent, equally privileged nodes that are unknown to each other. Therefore, it is exceptionally well suited for situations where the parties that have a need for a shared database do not trust each other in some capacity. The lack of trust can either stem from direct opposing interests and potentially dubious motives, or it can simply result from doubting the ability of all the parties involved to cope with the data synchronization due to the high volume of the flowing information, for example.

In order for a distributed electricity transaction system to be truly effective, it must be possible for anyone to participate by adding new devices into the network. The implication of this requirement is that the autonomous power allocation must remain possible even if the new devices are not fully trusted by all the pre-existing participants. Over time, as old devices are disconnected, and new ones joined into the system, the network may gradually morph into a completely different entity. Therefore, any trust that may have existed in the beginning would become diluted over time in any case.

5.6 The undesirability of intermediation

In most cases where all the aforementioned requirements are present, they can all be resolved by simply employing a trusted intermediating central authority who governs the database by maintaining its validity and guarding its authenticity. In order for blockchain technology to be a truly viable alternative for an intended purpose, a reason must exist why resorting to such an intermediary is non-optimal or otherwise undesirable. The reason could, for example, be that no suitable intermediary can be appointed, or the ones that exist are too expensive to use or cannot be trusted to behave honestly.

The reason why a centralized database is not a suitable option for this concept is that in order for a system with autonomous transactions of electricity to function efficiently, transactions must be made possible between any two devices in the network, whether the transactions between them have been premeditated or not. This, in turn, requires that devices from different manufactures, built for different IT-ecosystems must be able to tap into the same database and the same transaction system, without running into any vertical silos. By utilizing blockchain technology, companies can run their own dedicated servers which can also function as full nodes for an interoperable network of servers with different manufacturers, controlled in a distributed fashion.

6 Observations and discussion

We have approached the problem of how to develop and to describe blockchain use cases by placing ourselves in the position of R&D developers and developing a tentative use case for autonomous transactions of electricity in a housing society through an iterative process with stakeholders in the energy industry. We started by characterizing blockchain technology and defining a target state, and then proceeded to conceptualize a preliminary blockchain use case which we then iterated with industry experts to outline some of the technical specifications and system requirements. Finally, we evaluated the use case against criteria for a sensible application of blockchain technology as identified by industry specialists.

With disruptive innovations, such as blockchain technology, companies should always seek to insource the in-depth knowledge regarding those innovations as an integrated part of their technological competence. The strategic importance of this practice is significant, as failing to do so would equate to outsourcing the company's strategic decision-making capability regarding such disruptive innovations. In the light of this observation, the starting point and the motivation for this use case exercise has been to pinpoint and to understand the essential disruption and significance of blockchain technology in the energy industry. Other methods, such as industry hackathons, for example, provide only a narrow view on how to leverage new technologies to provide incremental solutions to existing problems. Therefore, they are inadequate on their own as a method for developing a strategic understanding regarding the full scale of possibilities enabled by disruptive innovations. For this reason, it is recommended that a strategic understanding is first built through a tentative use case which is drafted in close collaboration between industry experts and professional blockchain technology developers.

During this process, a few observations have become clear regarding the development of industry-specific use cases. Firstly, as the insourcing phase of the technological understanding has been quite extensive, developing an industry-specific blockchain use case seems to require a process of several months of intense R&D collaboration. We have observed that developing use cases not only requires that the technological know-how regarding blockchain technology is insourced into the company, but that know-how also has to be fused with the industry-specific insights regarding which problems to address with the new technology, and where the benefits of doing so can be found. This requires an incremental process which involves several rounds of iterative contributions from various collaborators.

Secondly, due to the fact that the maturity of blockchain technology is still relatively low, the technological know-how is still concentrated to a small group of blockchain industry experts, scattered around the globe. As the specifics of the outlined use case become more detailed through the iterative process, it becomes increasingly difficult to find technology developers that are able to understand the industry-specific aspects of the use case, and who are willing to provide further technological insight. Therefore, first and foremost, insourcing the technological know-how should be considered a strategic initiative to gain knowledge on the technology rather than just an operational resource for solving certain technology issues in product design. The purpose of such use case exercises is not to dismantle existing operational system architectures but rather to establish new modes of operation enabled by the new model adjacent to the pre-existing solutions.

It should be noted that for the use case concept outlined in this paper, the iterative development process is far from complete. Many technical aspects still remain to be addressed and the customer, social and business value of the outlined concept is yet to be analyzed in detail. As the next steps in the iterative use case development process, we intend to proceed by building a business case for a strategic initiative, by building scenarios for viable business models, and by establishing requirement specifications for further industry pilots.

References

van Alstyne, M., Parker, G. & Choudary, S. (2016), *Platform Revolution: How Networked Markets Are Transforming the Economy – And How to Make Them Work for You.* W. W. Norton & Company Ltd, New York.

Buchmann, M. (2016), *Information Management in Smart Grids – The Need for Decentralized Governance Approaches.* Bremen Energy Working Papers No. 25.

Chander, A. (2014), *How Law Made Silicon Valley.* Emory Law Journal 63(3), pp. 639-694.

David, P. & Bunn, J. (1988), *The Economics of Gateway Technologies and Network Evolution: Lessons from Electricity Supply History.* Information Economics and Policy 3(2), pp. 165-202.

Filament (2015), *A Declaration of Device Independence.* <https://medium.com/@FilamentHQ/a-declaration-of-device-independence-b6f83e8b6441#.flo8gr95x> Accessed 5th October 2016.

Greenspan, G. (2015), *Avoiding the pointless blockchain project.* <http://www.multichain.com/blog/2015/11/avoiding-pointless-blockchain-project/> Accessed 5th October 2016.

Greenspan, G. (2016), *Four genuine blockchain use cases.* <https://www.linkedin.com/pulse/four-genuine-blockchain-use-cases-gideon-greenspan> Accessed 5th October 2016.

Hirtenstein, A. & Zha, W. (2016), *Bitcoin Technology Harnessed to Push Electricity Revolution.* Bloomberg Technology. September 12, 2016. <https://www.bloomberg.com/news/articles/2016-09-12/bitcoin-technology-harnessed-to-push-electricity-revolution> Accessed 5th October 2016.

Hoffner, Y., Facciorusso, C., Field, S. & Schade, A. (2000), *Distribution Issues in the Design and Implementation of a Virtual Market Place.* Computer Networks 32(6), pp. 717-730.

Hughes, T. (1993), *Networks of Power: Electrification in Western Society, 1880–1930.* Johns Hopkins University Press.

Kenney, M. & Zysman, J. (2016), *The Rise of the Platform Economy.* Issues in Science and Technology, Spring 2016, pp. 61-69.

Kushida, K. E., Murray, J. & Zysman, J. (2011), *Diffusing the Cloud: Cloud Computing and Implications for Public Policy.* Journal of Industry, Competition and Trade 11(3), pp. 209-237.

Lauslahti, K, Mattila, J. & Seppälä, T. (2016), *Smart Contracts – How will Blockchain Technology Affect Contractual Practices?* ETLA Report No. 57. <https://www.etla.fi/julkaisut/alykas-sopimus-miten-blockchain-muuttaa-sopimuskaytantoja/> Accessed 5th October 2016.

Mattila, J. & Seppälä, T. (2015), *Blockchains as a Path to a Network of Systems: An Emerging New Trend of the Digital Platforms in Industry and Society.* ETLA Reports No. 45. <https://www.etla.fi/julkaisut/blockchains-as-a-path-to-a-network-of-systems-an-emerging-new-trend-of-the-digital-platforms-in-industry-and-society/> Accessed 5th October 2016.

Mattila, J. & Seppälä, T. (2016), *Platforms, Blockchains and Digital Trust.* In: Kilpi, E. (Ed.): Perspectives on New Work. Exploring Emerging Conceptualizations. Sitra Studies No 114, p. 99-100.

Mattila, J., Seppälä, T. & Holmström, J. (2016), *Product-centric Information Management – A Case Study of a Shared Platform with Blockchain Technology.* Conference Paper. Industry Studies Association Conference 2016. Minneapolis, Minnesota.

Mattila, J. (2016), *The Blockchain Phenomenon – The Disruptive Potential of Distributed Consensus Architectures.* ETLA Working Paper No. 38. <https://www.etla.fi/julkaisut/the-blockchain-phenomenon-the-disruptive-potential-of-distributed-consensus-architectures/> Accessed 5th October 2016.

Pon, B., Seppälä, T. & Kenney, M. (2014), *Android and the Demise of Operating System-Based Power: Firm Strategy and Platform Control in the Post-PC World.* Telecommunications Policy 38(11), pp. 979-991.

Rudkevich, T. (2016). *White Paper on Developing Competitive Electricity Markets and Pricing Structures.* New York State Energy Research and Development Authority (NYSERDA) and New York State Department of Public Service. NYSERDA Contract: 64271.

Saarinen, J. (2016), *Bank of England Settlement System to Support Blockchain.* iTnews. 19th September 2016. <http://www.itnews.com.au/news/bank-of-england-settlement-system-to-support-blockchain-437666> Accessed 5th October 2016.

Seppälä, T., Halén, M., Juhanko, J., Korhonen, H., Mattila, J., Parviainen, P., Talvitie, J., Ailisto, H., Hyytinen, K., Kääriäinen, J., Mäntylä, M. & Ruutu, S. (2015), *The Platform – History, Characteristics, and the Definition.* ETLA Reports No. 47. < https://www.etla.fi/julkaisut/platform-historiaa-ominaispiirteita-ja-maaritelma/> Accessed 5th October 2016.

Seppälä, T. & Mattila, J. (2016), Ubiquitous Network of Systems, Berkeley Roundtable of International Economy (BRIE) Research Note.

St. John, J. (2013), *Duke Energy: From Smart Grid Devices to Grid Computing Platform.* Greentech Media, October 2, 2013. <http://www.greentechmedia.com/articles/read/duke-energy-from-smart-grid-devices-to-grid-computing-platform> Accessed 5th October 2016.