Blockchain Solutions for the Energy Sector: SPARCS Feasibility Study

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Disclaimer

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

About SPARCS

Sustainable energy Positive & zero cARbon CommunitieS demonstrates and validates technically and socioeconomically viable and replicable, innovative solutions for rolling out smart, integrated positive energy systems for the transition to a citizen centred zero carbon & resource efficient economy. SPARCS facilitates the participation of buildings to the energy market enabling new services and a virtual power plant concept, creating VirtualPositiveEnergy communities as energy democratic playground (positive energy districts can exchange energy with energy entities located outside the district). Seven cities will demonstrate 100+ actions turning buildings, blocks, and districts into energy prosumers. Impacts span economic growth, improved quality of life, and environmental benefits towards the EC policy framework for climate and energy, the SET plan and UN Sustainable Development goals. SPARCS co-creation brings together citizens, companies, research organizations, city planning and decision making entities, transforming cities to carbon-free inclusive communities. Lighthouse cities Espoo (FI) and Leipzig (DE) implement large demonstrations. Fellow cities Reykjavik (IS), Maia (PT), Lviv (UA), Kifissia (EL) and Kladno (CZ) prepare replication with hands-on feasibility studies. SPARCS identifies bankable actions to accelerate market uptake, pioneers innovative, exploitable governance and business models boosting the transformation processes, joint procurement procedures and citizen engaging mechanisms in an overarching city planning instrument toward the bold City Vision 2050. SPARCS engages 30 partners from 8 EU Member States (FI, DE, PT, CY, EL, BE, CZ, IT) and 2 non-EU countries (UA, IS), representing key stakeholders within the value chain of urban challenges and smart, sustainable cities bringing together three distinct but also overlapping knowledge areas: (i) City Energy Systems, (ii) ICT and Interoperability, (iii) Business Innovation and Market Knowledge.

Partners

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1. INTRODUCTION

The story of blockchain began as a whitepaper released in the midst of the 2008 financial crisis by a person or persons working under the pseudonym Satoshi Nakamoto. This whitepaper explained the technologies behind Bitcoin, the first and most famous blockchain-based virtual currency, and the philosophy behind the release of this new decentralized competitor to traditional banking. Nakamoto was seeking to provide a solution to a problem within the current financial system, the over-reliance on trusted middlemen that handle financial ownership and payments. These middlemen provide services and tools such as bank accounts, credit cards and loans, and in turn charge fees for these services. For example, a credit card provider can take a monthly fee from the credit card user, and a transaction-by-transaction fee from the merchant for every payment made using the card. In addition, the provider charges interest for credit owned when certain predisposed restrictions are met (for example, if credit is not paid within a certain timeframe).

Using trusted centralized providers to provide services is a widely used solution within several sectors, as it provides advantages in safety, speed, fraud protection and ease-of-use. However, this solution also has its own problems, including the aforementioned fees, the access needed for citizens to take part in financial services, and new security issues connected to cybersecurity and misplaced trust. Currently, these problems are endured as the advantages provided by middlemen overweigh the problems with most users, as can be seen in the lack of cash use within Finland. For example, in 2020, almost 90% of consumer goods were bought via card payments. However, as the technical solutions within the blockchain sector expand, it is entirely possible that digital infrastructure can replace traditional central entities by providing trust in a way which is embedded to the solutions themselves.

Since 2008 and the invention of Bitcoin, blockchains have been one of the most rapidly growing ICT technologies with possible applications in several different fields, such as finance, logistics and energy. Within the SPARCS project and this paper, a focus will be set on possible blockchain solutions within the energy sector. In this sector, blockchains could be an especially useful technology in providing solutions for tracking, transferring, and collecting data in decentralized applications. When discussing smart city solutions within the energy field, blockchains could be a way to handle transactions securely within a decentralized energy community or aggregator service.

This report looks into the role that blockchains could play in the future of the energy transition, focusing on solutions within technological themes such as demand response, Virtual Power Plants (VPP) and bi-directional power grids. Pros and cons of different blockchain solutions will be analyzed in relation to how they can be used within these fields. In addition, use cases of blockchain solutions will be presented and the current legal and regulatory framework will be analyzed.

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2. Relevance of Blockchains in SPARCS

Within the SPARCS Grant Agreement, blockchains are addressed on several occasions:

Objective 2

> *"Interoperable digitalization solutions including big data optimization and adaptation of blockchain technology."*

Subtask 3.3.1 Virtual Power Plant for optimized RES energy use (SIE, VTT, ESP, KONE) [M1-M36]:

> *"Blockchain technology options for supporting demand response and virtual power plant in positive energy districts. Blockchain enabled business cases and control strategies will be studied, while possible policy and regulation related challenges will be identified. (ESP; Action E15-2)."*

Subtask 3.3.2 Smart energy services (ESP, SIE) [M1-M60]

> *"Blockchain technology as enabler. Enabling energy transfer and tracking in bi-directional power grids (electricity and heat) with the use of blockchain technology. (ESP; Action E12-3)."*

Specific Challenge Narrative (Page B-9)

> *"Plug & Play clean energy production technologies (EVs and positive energy buildings block) and energy storages, associated to holistic AI & Big Data management-based energy management solutions and harnessing emerging/disruptive technologies (such as user centric platform, blockchain and engaging people practices through gamification) for enabling novel business and financing models (peer to peer energy transaction, shared ownership and energy virtual communities, green bonds)."*

Regulation Addressing: (Page B-14)

> *"Blockchain enabled business cases and control strategies will be studied, policy and regulation related challenges will be identified. (E15-2)."*

Leipzig actions: L2-2.

> *"Research questions are aiming on: how blockchain enables prosumers to sell their surplus electricity on a Peer-to-Peer marketplace to con- and other prosumers, the coordinating role of blockchain in local market dynamics between generating plants and consumers."*

TRL increase from 6 to 8 (Page B-56)

> *"Blockchain enabled energy transactions: The VPP platform will be further enhanced with blockchain technology supported by ESP for ensuring transparent participation and objective remuneration of buildings/consumers in energy management services. Novel applications for energy transactions between citizens (peer-to-peer) will be developed and validated by LSW with the support of StromDAO."*

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3. Blockchain-Related Activities in SPARCS

With a unique opportunity of working with partners that have an interest in the business of blockchain technologies within the energy sector, SPARCS provides an opportunity for investigating blockchain as a solution for the energy sector both locally and internationally. To achieve this, SPARCS needs to substantiate any benefits that blockchains offer compared to business as usual within the selected themes of Virtual Power Plants (VPP's) and Demand Response (DR) within action E15-2, and bi-directional energy transfer within action E12-3. The sections below will show the detailed plan for these two actions in more detail.

3.1 E12-3: Blockchain technology as an enabler

This section will give a brief explanation on how this action within SPARCS (E12-3) was tackled. Figure 1 below will give an idea on the plan followed during the deliverables. In this action, the feasibility of blockchain solutions for enabling bi-directional energy transfer will be analyzed. This analysis will be composed of a literature review, SWOT analysis, proposals for possible solutions and models for the energy sector, an analysis on costs and benefits (reduced to analysis on pros and cons as the analysis focused on the role of blockchain as an enabler) and a legal analysis with an emphasis on Finland. As action E12-3 is heavily linked to action E15-2 (explained in the next section), a decision was made to prepare one larger document that encompasses both actions.

Action E12-3	**Blockchain technology as enabler. Enabling energy transfer and tracking in bi-directional power grids (electricity and heat) with the use of blockchain technology.**
Detailed plan	Conduct literature study and compile blockchain models globally Create SWOT table for blockchain utilization in Kera Propose blockchain model for electrical and thermal energy transactions and flexibility aggregation in Kera Estimate costs and benefits Investigate legal barriers Ref: Action E16-2 blockchains for city-wide DSM.
Targeted outcome	Cost-efficiency and uptake of distributed power and heat generation is enhanced if prosumer model is streamlined and automatic. Blockchains ensure prosumer model transparency and verification functionality.
Roles and responsibilities	ESP: Overall coordination. VTT and Siemens: technical support. Stakeholders
Schedule	M14 literature and models studied M18 SWOT table prepared M22 Blockchain model proposed M25 Costs, benefits and legal barriers investigated
New deviations into plan (as compared to D3.1)	M23 literature and models studied M24 SWOT table prepared M28 Blockchain model proposed M30 Costs, benefits and legal barriers investigated
Progress until M24	Literature review done within E15-2/E12-3, and study of different use cases within Kera ongoing. SWOT table prepared.

Figure 1: Detailed plan of action E12-3 as presented in Deliverable 3.2

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3.2 E15-2: Blockchain supporting energy solutions

This section will give a brief explanation on how this action within SPARCS (E15-2) was tackled. Figure 2 below will give an idea on the plan followed during the deliverables. In this action, the feasibility of blockchain solutions for demand response and VPP's will be analyzed. This will be composed of an analysis on advantages and disadvantages, promising applications, and legal framework with an emphasis on Finland. As action E15-2 is heavily linked to action E12-3 (explained in the previous section), a decision was made to prepare one larger document that encompasses both actions.

Action E15-2	**Blockchain technology options for supporting demand response and virtual power plant in positive energy districts. Blockchain enabled business cases and control strategies will be studied, while possible policy and regulation related challenges will be identified.**
Detailed plan	1. Assessment of pros and cons of blockchain solutions. 2. Identification of most promising applications for blockchain. 3. Assessment of legal framework. Ref Action E12-3 Blockchains for Kera energy transactions.
Targeted outcome	Blockchains may prove a cost-efficient and reliable platform for energy prosumer and demand side management transactions
Roles and responsibilities	ESP: Overall coordination VTT: Technical support on blockchain solutions SIE: Commercialized blockchain services
Schedule	M15: Blockchain pros and cons assessed M30: Applications identified and mapped, legal framework assessed
KPIs	to be defined

Figure 2: Detailed plan of action E15-2

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4. BACKGROUND ON BLOCKCHAINS

Blockchain, or Distributed Ledger Technology (DLT), is a technology that can be used to store information securely in a decentralized manner without the aid of trusted third parties. This is due to the information being simultaneously stored on many resources known as nodes, which can be computers, servers or other devices which connect to the network and store and transfer information. Thus, trust and verification are enabled via collectivized supervision and storage. Distributed storage ensures that the data remains unaltered even if a single compromised node of the network alters any information within the blockchain, and distributed supervision ensures that all decisions made between the participants are decided upon securely even when trust is not present. This is done mainly via different consensus methods, which are a key blockchain technology used for validation purposes. Depending on the consensus method used within the blockchain solution, falsifying information afterwards can be difficult or even impossible, so the different blockchain users don't have to know each other to have trust on the transactions that are made and saved on the chain. Consensus methods are explained further in section 5.2 of this report. More information on the structure of a typical blockchain is shown in Figure 3, where the procedure of making a blockchain transaction is explained.

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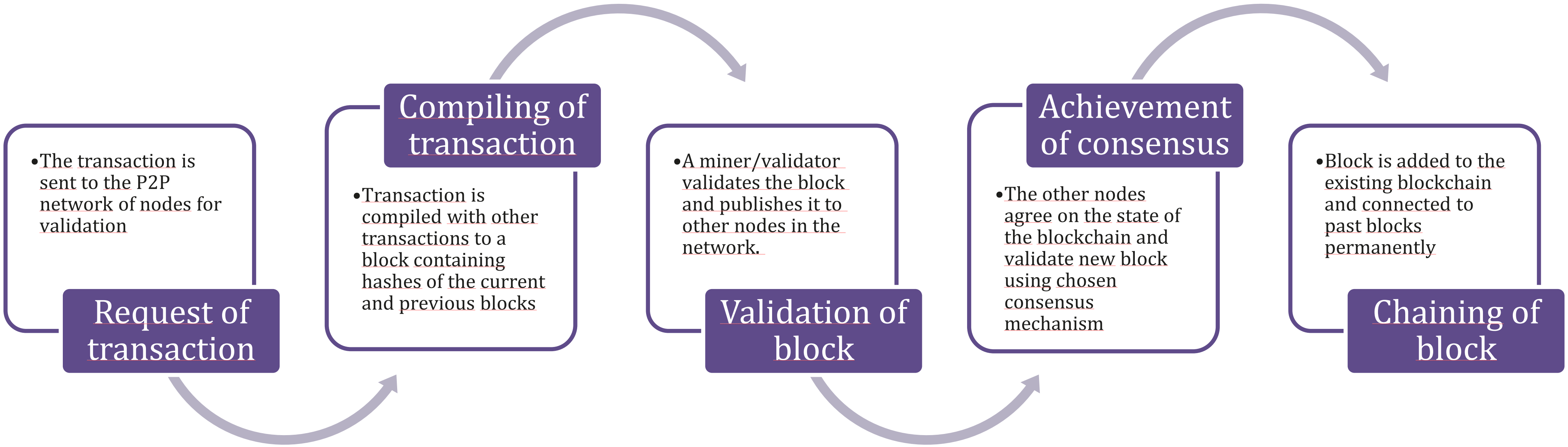

Figure 3: The structure of a blockchain transaction

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Blockchains have also implemented automated contracts known as smart contracts to automate the decision-making process between participants. A smart contract is a computer program that executes certain actions as given conditions are met [1], [2]. These conditions can be embedded in the blockchain, thus allowing the execution of a contract automatically. This could include automated transactions between users in an energy community, or automated sales between the community and the grid with proceeds divided between the users according to their capacity. Smart contracts are explained further in section 5.4 of this report.

Blockchains are evolving rapidly and are widely considered to bring fundamental changes to different service sectors, particularly peer-to-peer markets, financing, insurance, and logistics [3], in a similar way to the development of internet. While the mainstream discussion is still restricted to bitcoins, the real potential is just beginning to unfold. Recently, Ethereum has developed into the most widespread public blockchain platform for smart contracts [4], with version 2.0 underway [5]. However, scalability, transaction costs, energy consumption and privacy are issues that require further development.

A defining feature of securely creating new blocks within traditional public blockchains such as bitcoin, is the enormous heavy computation required within the process. This heavy computation needed has led to concerns regarding scalability, sustainability, and security [6]. These concerns have shifted the focus of major blockchain solutions from mining towards separate validator nodes and from proof-of-work towards proof-of-stake or proof-of-authority. In practice, this means that validating transactions within the blockchain would not require enormous energy input, but instead require a stake within the platform. Thus, the validity of the chain is protected by the risk of losing the chosen stake instead of exponentially growing hardware requirements.

As the global internet has demonstrated, decentralized technologies are more complex but can allow for more reliable, faster, cheaper, trustworthy, and automated ways to carry out virtual operations and transactions without intermediating parties. Micropayments, smart contracts with fully automated implementation and digital signatures can enable peer-to-peer (P2P) interaction without the need to verify identity, authority, or execution, to any third party that does not directly add value.

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5. THE BLOCKCHAIN ARCHITECTURE AND PLATFORMS

Before analyzing blockchain as a solution for the central SPARCS themes, a general analysis of the different layers of a blockchain model is needed. This section aims to achieve this by providing information on the main architectural pieces of blockchain. However, after a general literature review on the core blockchain technologies, no single way of dividing blockchain as a technology was identified. One article divides blockchain into three different architectural tiers, the PN-Tier (The Protocol and Network Tier), the S-Tier (The Scaling Tier) and the Federated Tier [7]. Another article divides the blockchain system architecture to nine interconnected parts, infrastructure, basic components, ledger, consensus, smart contracts, interfaces, applications, operations, operation & maintenance, and system management [8]. A third article devises blockchain solutions as follows [9]:

"Who has access?

Who can transact or mine?

Transactions or smart contracts?"

Blockchain solutions can also be divided by the key technologies they include, and the solutions that are implemented within these technologies. An example of this can be found in [10]. Even if different methods of dividing blockchain as a technology are presented in different articles, connected themes can be identified. These include the consensus mechanism used, permission rules of the chain, smart contract implementation, encryption methods and the operational environment of the chain.

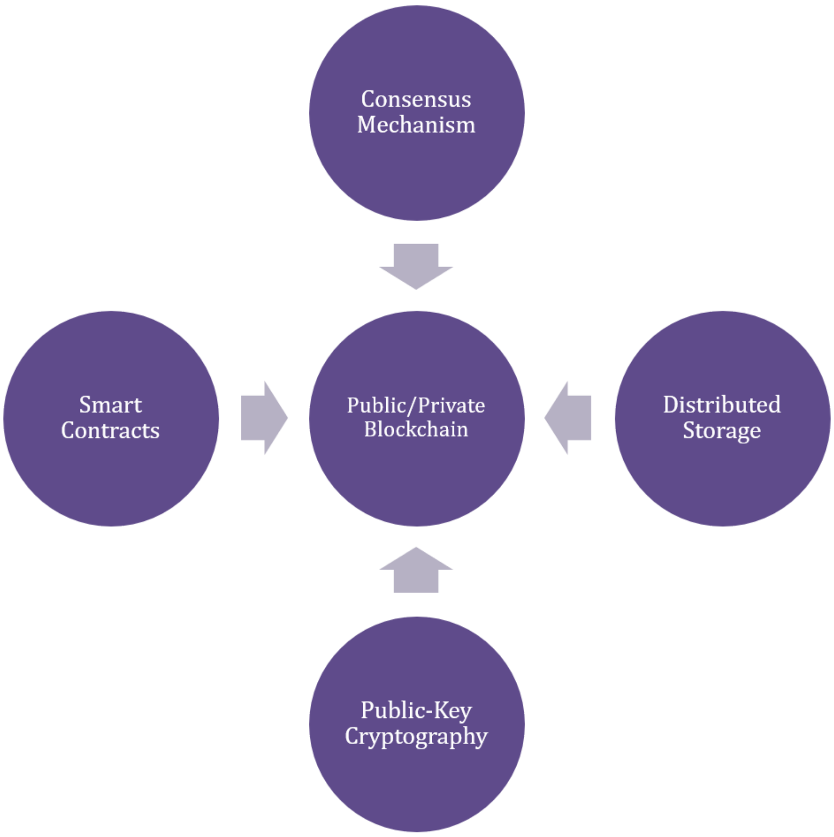

Figure 4: Key blockchain technologies as presented by [10]

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5.1 Privacy and Permissioning

The architecture of a blockchain solution will differ heavily depending on the privacy of the developed blockchain solution. Solutions are most often divided between public, private and consortium (otherwise known as alliance) chains [10], [8], or just between public and private (or permissioned) blockchains [2], [11], [12]. A public blockchain is always known as a fully permissionless chain, where anyone can join, transact, and validate. In turn, the definition of a private blockchain can differ between sources. Sometimes a private blockchain is defined as a chain with a singular owner. The owner can allow or disallow participants to join the chain freely. In some sources, private blockchain contains solutions with singular ownership and enterprise blockchains with divided ownership as long as joining the chain is permissioned. In this report the latter option is used. Still, it is important to note that both definitions of private chains are used in literature, and that fully private blockchain solutions can often be based on enterprise platforms. Private blockchains with singular ownership are most often used within a single organization, which controls the addition of data to the chain. An example of a private blockchain is the JPM Coin, that allows funds to be transferred between accounts within the J.P. Morgan Chase bank. Consortium, alliance, or enterprise blockchains refer to chains where management duties are divided between several participating organizations. Consortium blockchains can either be public or private, depending on the way that new users can view the chain. An example of a public consortium blockchain is the Energy Web Chain, which is an open-source chain, where only previously validated organizations can handle and alter the data within the chain.

Public blockchain

- Anyone can join, view data, transact and validate blocks
- Can provide anonymity to users while allowing transparency and verifiability of transactions. Offers low scalability and adaptibility to business solutions in the energy sector
- Example: Bitcoin, Ethereum

Permissioned blockchain

- Owner/owners allow right to access chain, view data and transact. Validation can be reserved to certain participants. Rights can be configured between participants, i.e. some participants might only have rights to view data
- Beneficial in business solutions, and provides faster decisionmaking, better scalability and governance while sacrificing a degree of decentralization compared to public chains.
- Example: Quorum, Ripple, Hyperledger, Enterprise Ethereum, Energy Web Chain

Figure 5: Public and private (permissioned) blockchains explained

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5.2 Consensus

The consensus mechanism, as the name implies, is the method used to achieve consensus within the decentralized blockchain system. This is essential for blockchain to function, as all of the distributed nodes within the system need to agree on the system state constantly to ensure the validity of the chain. Otherwise, the whole purpose of blockchain as a decentralized trust mechanism would be lost. In short, the consensus mechanism is an algorithm for choosing the node that is allowed to initiate a new proposal within the chain, and for the way that the other nodes will reach agreement on the development of the chain. Consensus algorithms can vary heavily between public and private blockchains, as decisions made between trusted and untrusted nodes need different mechanisms to reach consensus.

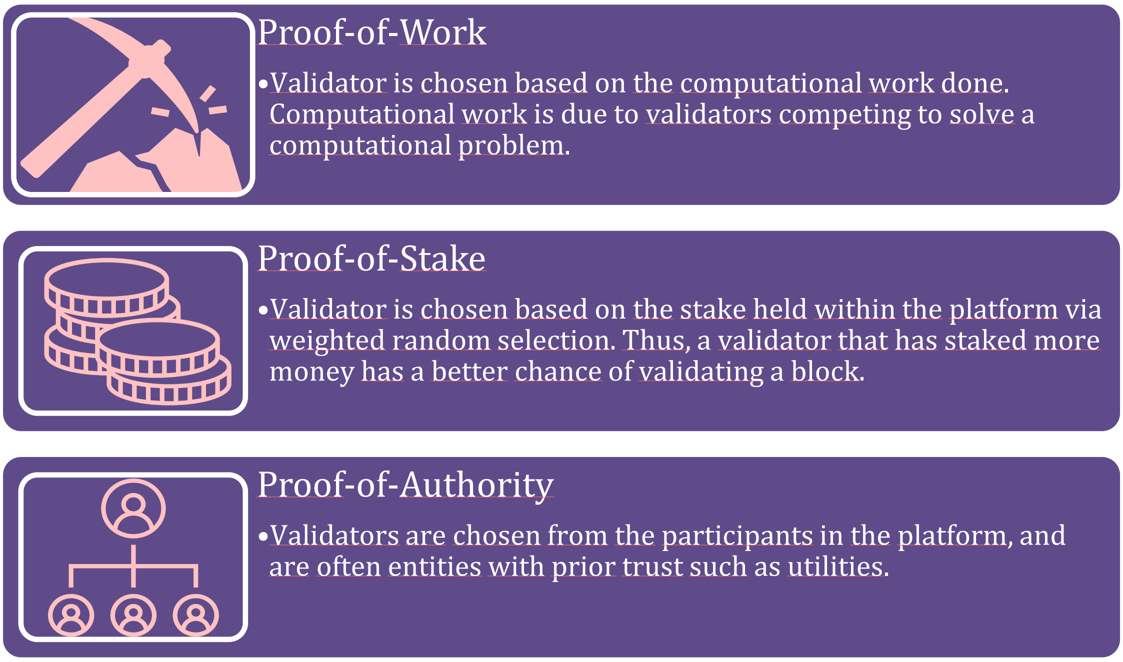

Figure 6: Further explanation of 3 consensus mechanisms

Figure 6 shows short descriptions of three key consensus methods identified within the literature review, which are Proof-of-Work (PoW), Proof-of-Stake (PoS) and Proof-of-Authority (PoA). These methods where chosen based on their prior use within energy-related blockchain applications. In the next paragraphs, these three consensus mechanisms will be explained further.

In the Proof-of-Work (PoW) consensus mechanism, the node that gets to insert a new block to the chain is chosen by the computational work done. In other words, the validator is the first node that succeeds in solving a computational problem linked to the hash of the block, and the rest of the nodes will reach consensus by checking the validity of the solution provided by the validator. This is a much easier process than solving the computational problem itself. PoW is based on the fact that anyone can join the chain and become a validator freely, and trust is built by the computational power needed, as committing fraud on the blockchain would need an unfeasible amount of computational resources compared to the value gained. The PoW method has been in wide use within the blockchain sector since its beginnings, as it was the consensus method piloted by

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Bitcoin, and has since been implemented in other popular blockchain platforms such as Ethereum.

Research towards blockchain solutions within the energy sector emphasizes the importance of moving forward from Proof-of-Work (PoW) due to its scalability-related issues [11], [12]. Proof-of-Stake (PoS) or Proof-of-Authority (PoA) are two solutions implemented within energy blockchain pilots [13], both of which have shown promise in alleviating the issues of PoW. In PoS, the next validator is chosen via weighted random selection based on the stake held by each validator. This reduces the computational power needed to validate new blocks, as validators compete with their financial investment instead of their physical hardware.

Proof-of-Authority (PoA) is a mechanism where the validators are decided on by their known reputation and are often known entities with prior trust. PoA is the solution implemented by Energy Web Foundation, an open-source ecosystem providing blockchain solutions to the energy sector, in their Energy Web Chain (EWC) [4]. As PoA utilizes previously trusted entities as validators, this consensus can be seen as a middle ground between fully decentralized and public blockchains and traditional solutions. In this way, enterprise-based solutions can scale up their solution in an easier manner while raking the benefits of decentralized communication and sharing of data. More information on the pros and cons of the current consensus mechanisms are explained in section 6 of this document.

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5.3 Encryption

Even though the consensus mechanism ensures that trust and consensus is achieved, and the blockchain itself is valid and secure, the blockchain architecture requires additional layers of security. As with traditional services, log in data for personal wallets needs to be secured, and users need to be ensured that transactions are received and sent from the parties they except. Within traditional services, these issues are solved via the trust placed between the users and the third party which handles the needed services. However, within a blockchain system, this trust needs to be placed between two parties without any trusted third parties in-between. This problem has been solved with a technology called public-key cryptography or asymmetric cryptography [10], [2].

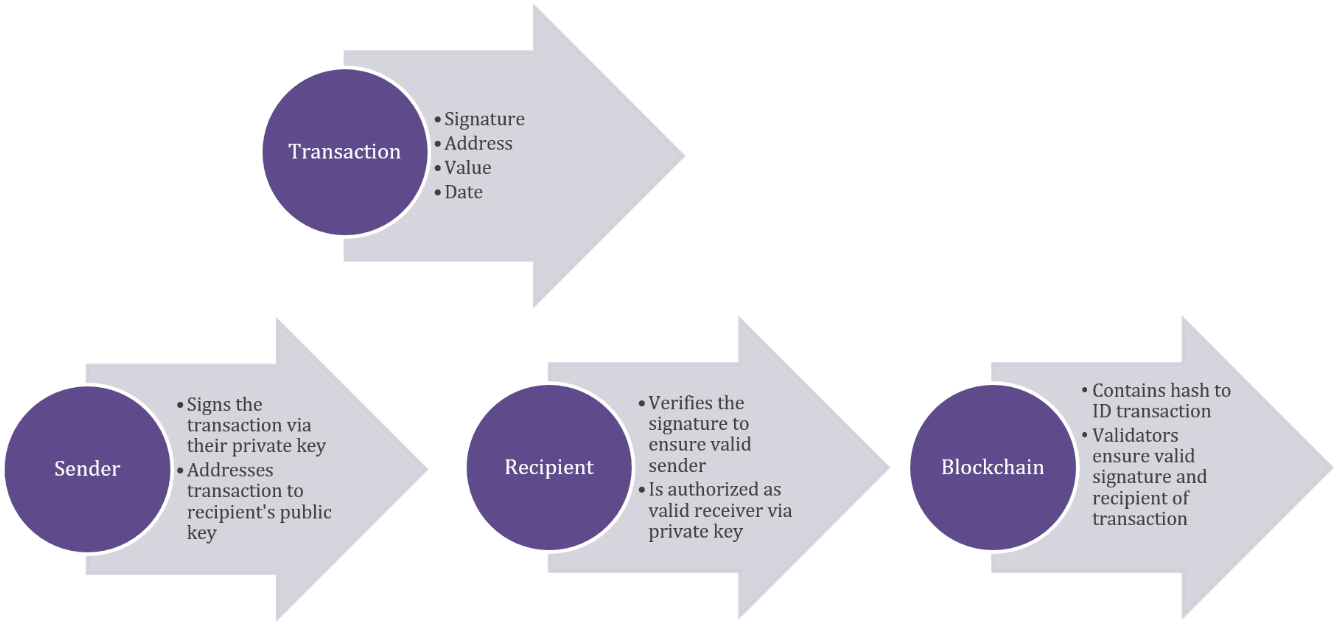

Figure 7: Public-Key Cryptography explained

Public-key cryptography uses an asymmetric protocol that can encrypt and decrypt interactions via public and private keys issued to each user. Each user is given a private key that only the user knows, and the public key is calculated from this private key via a one-way function, so that any personal data cannot be calculated from the outputted key. This function also ensures that all data encrypted via the other key can only be decrypted by its counterpart. Thus, the sender of the transaction can sign it via their private key, while marking the transaction using the recipient's public key. This whole formula ensures that every transaction is authenticated, and that every action is done by an authorized user.

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5.4 Smart Contracts

Smart contracts, a key technology of several blockchain platforms such as Ethereum, can be broadly defined as programs written to execute terms or agreements between blockchain participants [10], [2]. By making use of the encryption methods used within blockchain, smart contracts can lock certain actions behind certain private keys to ensure that participants cannot extend the rights given to them in an agreement. Using security keys or other identifiers to ensure allowance, smart contracts allow participants to complete actions using keywords given to the contract. For example, only one actor within the blockchain can be allowed to deposit or withdraw funds from the contract, but other actors can trade funds with the contract freely if it has funds to trade. Thus, the contract can be described as a separate actor within the blockchain that can be interacted with depending on your security status [6]. Thus, smart contracts are often defined as coded legal agreements, even though they are not necessarily always legally binding depending on the case [14]. More on the legality of smart contracts is explained in section 10.3.

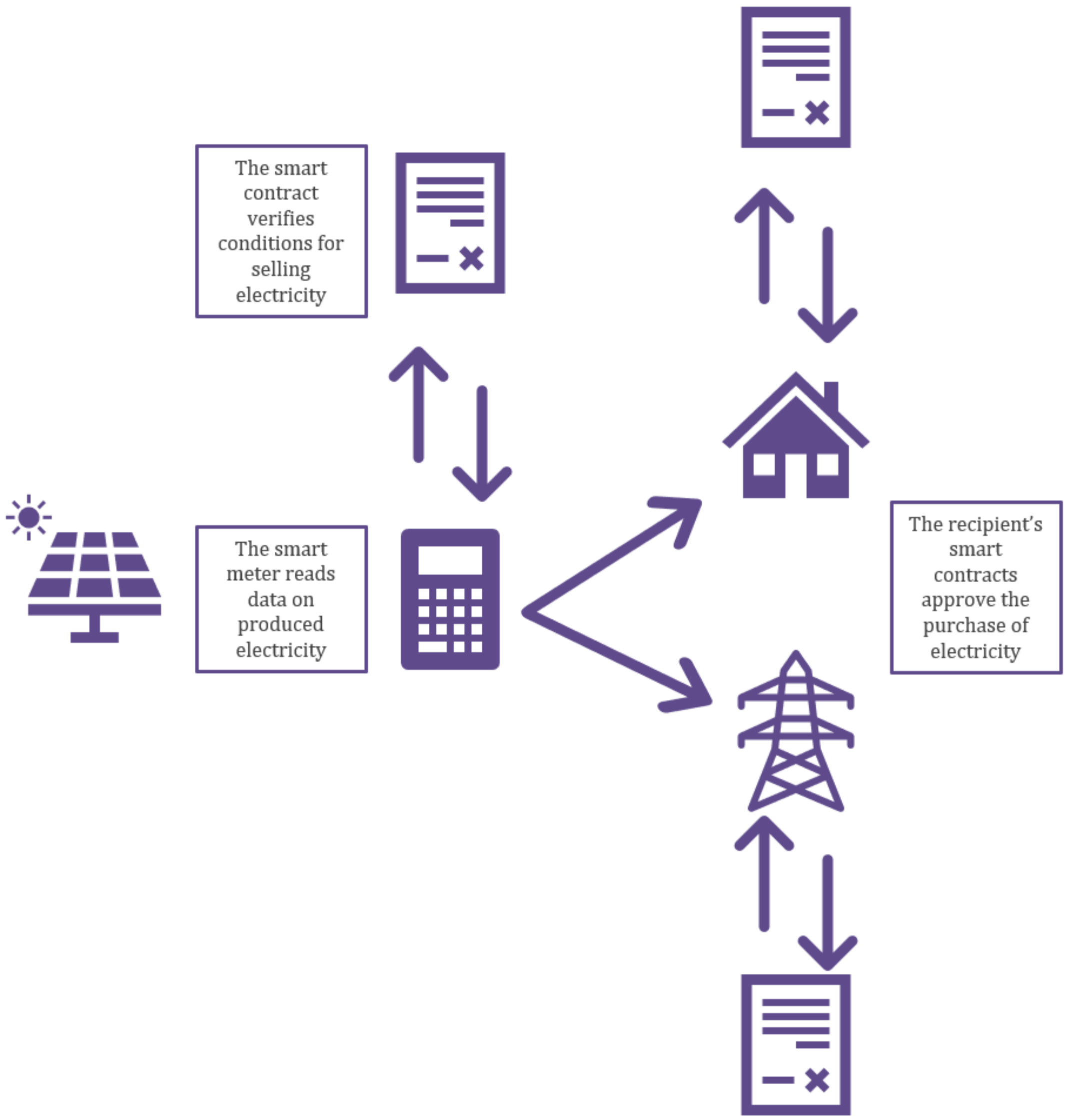

Figure 8: Example of a smart contract process for electricity trade [11]

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Within public blockchain solutions, smart contracts are also inherently transparent, as their code and interactions can be viewed by every participant of the chain. As smart contracts are verifiable and inspectable for every participant of the blockchain, the outcome of the contract can be inspected before a decision is made and every stakeholder can be certain of the outcome, thus creating trust in a situation where there is no trusted third party handling the transactions or linked agreements. However, for energy-sector solutions this can be unwanted depending on the secrecy of the agreement, thus leading to a need for privatizing these contracts.

As mentioned previously, the terms within the smart contract can be linked to the blockchain to automate the execution of an agreement, thus leading to reduced costs as less human work is needed. Due to blockchain solutions within the energy sector heavily focusing on P2P trading, renewable investment, and certificate trading, blockchain platforms using smart contracts can provide identifiable benefits when compared to other platforms. Traditionally, the price of energy is typically fixed or determined on a mechanism of demand and supply curves as in the Nordpool day-ahead markets. Smart contracts enable the use of more complex processes between a larger collection of actors. This could allow for a centralized marketplace for smaller-scale generators, where microtransactions can be linked to a smart contract between the different generators, aggregators, grid providers, and the energy market. Smart contracts can also be programmed to change their conditions depending on outside factors. This will be especially important for energy applications, as several factors outside the application can affect the energy prices within it.

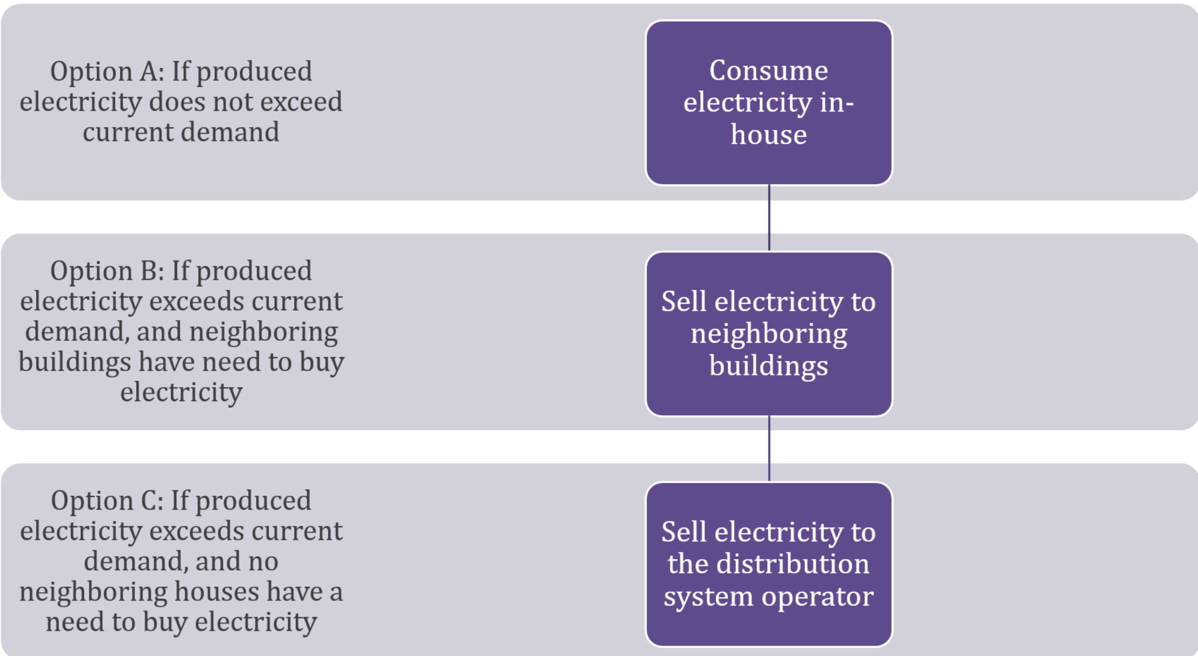

Figure 9: One example of smart contract prioritization within electricity transactions

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5.5 Blockchain platforms

Within previous sections, several examples of blockchain platforms were mentioned. These are development platforms for blockchain-based applications for different fields and use cases. They can be for public blockchain solutions, as in Ethereum, or for private solutions, as in Hyperledger or Enterprise Ethereum Alliance (EEA). Platforms can also be focused on certain fields, as in Quorum and Ripple, which are both blockchain platforms focused on the financial sector. These platforms offer the foundation needed to develop a new blockchain solution, and can also provide assisted or full development of the solution depending on the platform and the provider.

Blockchain Platform	Additional Information
Algorand	Proof-of-Stake consensus mechanism. Established as a carbon-neutral blockchain.
Avalanche	Open source blockchain with connection to Ethereum dApp production. Proof-of-Stake consensus mechanism.
Corda	Enterprise blockchain created by R3. Consensus mechanism completely unique, as it is divided into two parts: validity and uniqueness.
Energy Web Chain	Open source blockchain platform based on Ethereum and developed for the energy sector. Uses Proof-of-Authority consensus.
Ethereum	Open source blockchain focused on the creation of dApps (otherwise known as smart contracts). Currently uses Proof-of-Work but is switching to Proof-of-Stake.
Hyperledger	Enterprise blockchain platform developed by the Linux Foundation. Uses Crash Fault Tolerant Consensus based on Raft.
Quorum	Enterprise blockchain platform developed by ConsenSys. Supports Raft CFT and Istanbul BFT.
XRP Ledger (Ripple)	Uses Byzantine Fault Tolerant consensus protocol unique to platform.

Table 1: Blockchain platforms

As the building and operation of a blockchain model is a heavy and highly involved process which an actor completely new to the field might not be ready for, collaboration with Blockchain-as-a-Service (BaaS) providers might be needed to ensure that a developed blockchain model is according to industry standards. BaaS providers can provide services ranging anywhere from development consultation to full development

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of ready-to-use applications, depending on the abilities and wants of the client. To achieve this, BaaS providers often handle the establishment and operation of blockchain infrastructure on a blockchain platform. The blockchain infrastructure is handled on the cloud, enabling developers and users to create and run applications on the go with little own involvement on the underlying infrastructure. Examples of BaaS providers include AWS Amazon Managed Blockchain, IBM Blockchain Platform, Oracle Blockchain Platform and Quorum Blockchain Service.

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6. Blockchain and the Energy Sector: Pros and Cons

This section will investigate the pros and cons of blockchain solutions, focusing on the energy solutions mentioned within SPARCS actions. Firstly, a brief introduction on the central SPARCS themes within these actions will be provided. Next, the pros and cons of blockchain will be assessed. A look into the opportunities provided by blockchain, based on the identified pros and cons, is presented in sections 9.3.1 and 9.3.2. Table 2 in section 3.2 provides a brief overview on the identified benefits, including an analysis on the importance of each benefit for the energy sector, while section 6.3 will include the same in addition to an analysis on the possible solutions and their availability.

6.1 Blockchain and the SPARCS Themes: Demand Response, Virtual Power Plants and Bi-Directional Energy Transfer

Demand Response (DR), defined as the use of flexible consumption to change customer energy profiles upwards or downwards if needed, can be a very economically viable solution for balancing the energy grid, or even offering flexibility reserves in case of grid issues. DR services already exist on the Finnish energy market for heating and electricity, often focusing on large-scale customers. For example, the City of Espoo and Espoon Asunnot OY provide flexibility to the Espoo District Heating grid, while Sello, Lidl and VR (the Finnish national railway company) provide their flexibility to the Nordic reserve market. In Finland, this service is often known as a Virtual Power Plant. This definition of a VPP can differ from other European countries, where a VPP might focus more on local renewable generation and energy transfer. For example, Next Kraftwerke, one of the leading power aggregators in Europe, defines the objective of a VPP as follows [15]:

> *"In general, the objective is to network distributed energy resources in order to monitor, forecast, optimize and trade their power. This way, fluctuations in the generation of renewables can be balanced by ramping up and down power generation and power consumption of controllable units."*

and as follows [15]:

> *"But the VPP not only helps stabilizing the power grids. It also creates the preconditions for integrating renewable energies into the markets. Individual small plants can in general not provide balancing services or offer their flexibility on the power exchanges. This is because their generation profile varies too strongly, or they simply do not meet the minimum bid size of the markets. By aggregating the power of several units, a VPP can deliver the same service and redundancy and subsequently trade on the same markets as large central power plants or industrial consumers."*

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In addition, Toshiba defines a VPP as follows [16]:

> *"It is necessary to control many geographically spread power generation and storage facilities in real time, according to the ever-changing supply and demand situation. For that purpose, it is necessary to have excellent technology for remotely controlling dispersed devices and technology for more accurately predicting electricity demand and solar power generation. By adjusting the balance between supply and demand with VPP, renewable energy power can be used stably. VPP is expected to promote the introduction and expansion of renewable energy and contribute to a decarbonized society."*

Thus, a VPP can be seen as a virtual solution that combines energy supply and demand and optimizes them according to the needs of the VPP participants or the aggregator. Different VPP solution providers can choose to focus on different aspects of the solution to fit local market conditions. This can be seen in the Finnish VPP market, as the aggregation of flexible loads for the reserve market has clearly been seen as the viable solution by local aggregators within the Finnish market environment. Other international demand response providers can also see their solution as a VPP, which can be seen in the Enel X definition of demand response, which contains the following [17]:

> *"Demand response in its most traditional form turns energy users into virtual power plants by adjusting their energy consumption during specific times to relieve stress on the grid. Instead of turning on/up another traditional supply source like a peaking power plant, a utility or grid operator can use demand response to "turn off/down" electricity demand, thus negating the need for additional supply."*

In previous research done on blockchains and DR and VPP solutions, blockchains are seen as a solution for lowering the cost of participation for small scale participants by implementing decentralized solutions for management and control. In addition, the traceability, verifiability, and automated supervision of provided energy, flexibility and related settlements were seen as a positive of blockchain. [10] In addition, blockchain could enable the inclusion of several different energy solutions, such as DR, VPP's, grid control, energy storage management and crowdfunding of new projects into a single solution, thus streamlining a rapidly complexifying energy system. [13]

As VPP solutions aim to aggregate distributed energy resources to optimize consumption and production on a larger scale, the bi-directional transfer of energy between different participants can be seen as an integral part of the solution. This will enable the emergence of new actors in the energy field that both consume and produce energy with decentralized production resources, otherwise known as prosumers. VTT defines a prosumer as follows [18]:

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"Having increased agency over energy production and consumption turns consumers into prosumers. Prosumers are consumers that not only consume, but also produce energy. In the future, millions of us will become small-scale energy producers."

A traditional example of a prosumer would be a household that has invested in solar panels for local renewable energy production. However, prosumers can be different actors from different sectors of society. For example, Smart Energy Europe has defined 8 different prosumer models in its Smart Energy Prosumers -handbook. [19]

1. *"Grid-connected households with onsite PV, storage, and/or flexible load"*
2. *"Grid-connected households with offsite DERs"*
3. *"Off-grid Households"*
4. *"Commercial buildings with onsite DERs and flexible load"*
5. *"Industrial prosumers with onsite DERs and flexible load"*
6. *"Green Corporate Sourcing"*
7. *"Virtual Energy Communities"*
8. *"Virtual Communities based on grid proximity"*

Thus, prosumer models can differ wildly, and all prosumer models do not fall under VPP solutions. Instead, VPP's can be seen as a specific solution for enabling communication and energy transfer between different prosumers and other related actors, while optimizing the consumption and production of the whole connected system.

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6.2 Pros

This section will explain the different benefits achieved from implementing blockchain solutions within the energy field. A list of the key benefits identified through a literature review can be found below.

Table 2: Pros of blockchain solutions

Name	Explanation	Importance for energy
Transparency	All made transactions can be viewed by all participants, creating trust and verifiability without a central agency [3], [1], [12]	Can be important in decentralized energy solutions, where transactions are made between prosumers without a central operator
Multi-party consensus	Consensus on transactions can be achieved between participants without central authority [3], [20]	Can be important in decentralized energy solutions, where transactions are made between prosumers without a central operator
Fast settlement time	Settlement time between actors is faster due to removal of the “middle-man” that approves transactions [20]	Importance for energy quite low, as the clearance time is more important with the large volume of transactions
Verifiability	All transactions are logged in the blockchain, creating a verifiable string of transactions [12], [4]	Gives opportunities for both energy communities and for renewable certificates
Reduced costs	Reduced overhead and intermediary costs for transactions as well as reduced investment costs with easier division of assets through smart contracts [12], [20]	Can be important in decentralized energy solutions, where transactions are made between prosumers without a central operator
Automated	With the use of smart contracts, series of actions between actors can be automated [4], [12], [3], [1]	Provides opportunities to build services for energy communities and P2P trading
Security from manipulation	Because a transaction is approved by the whole blockchain community, the risk of tampering with old transactions is reduced [12]	Important, as a large risk within a sharing economy such as an energy community are the security risks involved

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Reduced geographical constraints	Through sharing of assets via blockchain, projects are not constrained by geographical boundaries [4]	Can be important in decentralized energy solutions, giving new options for investment
Security through decentralization	As the database is not situated under a single operator, security is provided through decentralization [1]	Can provide cybersecurity in decentralized energy solutions

As can be seen above, the key benefits of blockchain solutions are reduced costs, "chaining" of data for verifiability and tracking, decreased settlement time and greater security and trust without a third party. In addition to this, smart contracts can provide automation within p2p trading solutions. However, the pros and cons of blockchain depend heavily on the chosen model, as will be explained below.

The consensus mechanism, a key technology within blockchain, has a large role in providing trust between the participants of the chain. Via the chosen mechanism transactions can be cleared and validated securely and with a united consensus without a need for a central authority, such as a bank. However, the adequacy of blockchain for the energy field can very heavily depend on the chosen consensus mechanism, as several of the most used types have severe negative aspects as well [12], [4], [21], [3], [1]. Still, with the right consensus mechanism the positive aspects of blockchain solutions can be brought out while minimizing the negative "side-effects", such as energy consumption and slow clearance time [4]. More on the consensus mechanisms can be found below in the section "Cons" of the document.

The pros and cons of the blockchain solution also depend on the nature of the solution itself, i.e. whether the solution is a public or private blockchain. Public blockchains, Bitcoin being the most notable example, are probably the most famous type of blockchain. They, by definition, are not owned by any entity, are completely free to join by anyone, and are fully transparent between participants [20]. Public blockchains have many benefits but can be unbeneficial for the energy field due to their transparent and public nature conflicting with commercial secrecy and local regulation, and their scalability issues. In turn, private blockchains can fix several issues seen in public blockchains, such as the lack of privacy and scalability, to provide a more suitable solution. These blockchains are also known as consortium blockchains, where a chosen consortium can validate transactions, choose participants, and even change the rules of the blockchain if needed.

To sum up, blockchain has several benefits that are especially important for decentralized solutions. However, it must be remembered that blockchain is not a better solution compared to traditional databases in every situation, and thus the validity of blockchain as a solution needs to be assessed separately for each problem to avoid unnecessary work. Both the BOND project and WEC provide a list of conditions that a use case must meet to fit these criteria. The conditions presented in both are very similar [22], [20]:

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- *"Shared databases between multiple parties, where all need to view common information.*
- *Multiple parties need to record and change data in the database.*
- *All participants need trust in the recorded information.*
- *A third party as a central authority adds unnecessary costs and complexity.*
- *Reduced settlement times has a business benefit.*
- *Transactions interact between each other and depend on each other."*

The list above is the one provided in the WEC white paper [22]. The white paper notes that at least four of the above conditions need to be met for blockchain to be an approachable solution in the use case. The BOND project review collects these same six conditions but adds three more notes on how to prepare a blockchain use case depending on the situation. They are [20]:

- *"Set rules to check the legitimacy of each transaction.*
- *Pick how your validators are chosen depending on the use case.*
- *Choose who is the backer of the assets moved within the blockchain. In short, who is responsible?"*

This section has determined the positive aspects of blockchain solutions, and how to assess whether these positive aspects fit within a certain project. In turn, the next section will be looking into the negatives of blockchain, and the identified solutions for each negative aspect if available.

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6.3 Cons

In this section, the cons of blockchain solutions will be identified, in addition to their importance for the energy field and possible identified solutions.

Table 3: Cons of blockchain solutions

Name	Explanation	Importance for energy	Availability of solution
Irreversibility	Due to the nature of blockchain, its code and connected smart contracts might be rigid and resistant to change [2], [12], [13]	Transactions made on the energy market are irreversible in their nature. However, contracts made on the electricity market can be highly dependent on outside factors, and pilot solutions might need enhancements in design. Thus, it is important to ensure that aspects on the blockchain have a failsafe system on place in case of errors and changes	Errors and changes in design can lessen as implementation increases
Lack of privacy	Due to the inherent transparency of the blockchain system, privacy of transactions is rare in public blockchains [2], [11], [12], [4]	Important regarding regulation on user privacy and company requirements for commercial secrecy	Available, e.g. EWF has already prepared a privacy solution for its energy blockchain
Energy intensity	Depending on the consensus mechanism used the system can be energy intensive to handle [10], [11], [12], [13], [22]	Extremely important if the solutions usage increases substantially, as it effects the sustainability and cost of the solution	Available through new consensus mechanisms, e.g. proof-of-authority
Slow clearance time and transaction throughput	Due to the need for the whole decentralized blockchain to reach consensus, clearance time of transactions is	Important especially for electricity markets, as the amount of transactions to be cleared at a constant pace is large. Less	Available through new consensus mechanisms, e.g. proof-of-authority

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	slower [6], [10], [2], [11], [12], [13], [21], [4], [22]	important for smaller private energy communities	
The physical world of energy vs. the digital world of blockchain	As a digital solution historically used for non-physical value creation within finance, blockchain needs to transform towards a highly transformative physical energy system. In addition, the tokenization of energy transactions will need a physical value for users, utilities, and authorities, both in energy and in fiat currency. [10], [2], [21]	The blockchain solution will need to take into account the peculiarities of energy as a tradeable commodity to function	Available, as several blockchain solutions are emerging on the energy sector, thus proving compability
Lack of knowledge for development	Due to the technology being relatively new and rapidly evolving, energy regulators, developers and the energy sector are falling behind on knowledge [10], [21], [22]	As the energy field moves towards decentralization, more focus needs to be done on investing in IT experts with relevant information	Knowledge can increase as the implementation of digital solutions within the energy sector increases
Lack of knowledge creating distrust	A lack of knowledge on blockchain as a technology and its legitimacy can create distrust towards implementation and lower public perception of adoption. [11], [13], [21]	Important issue to face for each sector, as new digital solutions are investigated. In addition, energy has traditionally been led by a few utility companies, reducing the increase of knowledge caused by competition	Decentralization could naturally aid in solving this issue as competition within the field increases, simultaneously increasing public knowledge of solutions
User friendliness	Key management serves as an issue towards asset management and user friendliness,	The end user, either a prosumer or consumer, needs to be confident on their abilities to use the	

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	as a complex private key serves as a password to the system for users. [21], [11], [12]	solution efficiently for future scale-up	
Regulation challenges	Currently, the energy field is heavily regulated. Blockchain provides a new highly disruptive technology that needs to apply towards the regulative environment [10], [4], while this environment has to adapt towards the technology [13], [22] before it can be applied.	Important due to the heavy regulation connected to the sector	Organizations providing solutions for energy have already invented ways to include blockchain while considering regulation [21]
Investment needs	To apply blockchain solutions, current meters need to be upgraded accordingly, taking into account storage space [22], [4], [13],	Important for IoT solutions	For example, EWF has provided a light client version for IoT devices [4]
Cybersecurity	As a relatively new technology, blockchain can still have unforeseen issues in relation to cybersecurity. [2], [10], [12], [13], [22]	As the energy sector is a critical piece of infrastructure, all additional cyber-security issues create additional risk	Solutions, such as the EWF chain, have taken actions in increasing the security of their solutions
Lack of standardization	The lack of standardization between different solutions serves as a hindrance for regulation, interoperability, and trust. [10], [13], [22]	For further scale-up, standardized solutions are needed	No clear standard yet identified

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As presented in the previous section, blockchain provides opportunities especially for decentralized or p2p energy solutions. However, several key problems have slowed down the large-scale implementation of blockchain within the energy sector. The World Energy Council has determined current technical constraints, regulation, and lack of knowledge within the energy field as the key challenges in the implementation of blockchain within the energy field [22], [23].

The key technological challenge to overcome in relation to the energy field is the scalability of the blockchain solution. With scalability we mean the speed of reaching consensus within the system, which is linked to the slow transaction clearance times within current blockchain solutions, as well as the energy and computational intensity of the solution. The proposed solutions for these issues are new consensus mechanisms to replace the current state-of-the-art proof-of-work solution, new decentralized blockchains divided to different levels to reduce the computation needed or a mix of both [24]. For example, the Ethereum blockchain network is developing an upgrade to Ethereum 2.0, which includes a change to a proof-of-stake consensus mechanism [25]. This change should lead to an increase in scalability of the solution due to less computational power needed, and an ability of developing a network with several chains connecting to a central chain. In turn, the Energy Web Foundation (EWF) blockchain relies on proof-of-authority, where known organizations act as the validators of new transactions [4].

The second key challenge determined for blockchain solutions, regulatory issues, stems from the need to comply with a heavily regulated energy market while considering regulatory differences between geographical areas. In addition to this, the EU data privacy laws and confidentiality requirements of participating companies must be accounted for. The regulation of cryptocurrencies within the Finnish law also must be considered. More on the regulatory issues can be found in the following parts of this report. The privacy issue is important for other aspects in addition to regulation as well, as companies can be reluctant to reveal transaction information to competitors. However, solutions for private transactions have already been implemented in blockchains such as the previously mentioned EWF-developed blockchain [4]. The EWF blockchain has the capacity to differentiate between nodes to provide different permissions as well, to increase regulatory compliance and privacy [4].

The third issue, lack of knowledge, is relevant both for the industry itself and for the customer base [22], [23]. Within the WEC white paper, 60% of interviewees from within the energy sector identify lack of expertise on blockchain development as a major concern for implementation [22]. In addition, the interviewees identify lack of customer engagement as a possible barrier for adoption, as a majority of residential customers might be unwilling to engage in new responsibilities in relation to their energy usage [23]. Solutions for these problems have been investigated, but no sure-fire solution for this problem has been identified as of yet.

In the case of distributed ledgers within IoT, the compliance of physical hardware with the solution needs to be considered. The IoT infrastructure, connections to users and employees, and updated company processes all need to be considered for blockchain implementation. As the implementation of blockchain will require an upgrade to current

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metering procedures and hardware, the needed investment costs can be substantial [24]. Per the literature reviewed, blockchain needs to integrate with the current existing alternative solutions instead of fully replacing them, to ensure low investment costs [22]. This requires solutions in interfaces between these systems, as companies need to identify ways of integrating blockchain within their existing architecture. This can conflict with the lack of knowledge identified within the companies themselves, thus creating a barrier for large-scale adoption.

As was mentioned in the previous section of the report, blockchain is not a save-all solution for any sector. Instead, blockchain is a technology that can provide unique opportunities to different applications within the energy section while not being suitable to others [26]. The use of blockchain within these applications has several hurdles to overcome. However, projects such as the Energy Web Chain have already provided solutions for several of these challenges. This means that blockchain is a fully pilotable solution within the energy sector, if the project is planned and defined appropriately to meet the key strengths of the solution.

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7. SWOT Analysis

Figures 11 to 14 show the SWOT analysis produced within the SPARCS project, as detailed in the plan of action E12-3. This analysis aims to provide a look at the possibility of utilizing blockchain within Espoo. The different parts of the SWOT analysis are explained in more detail below.

STRENGTHS

- Automation for more streamlined processes
- Consensus on transactions and system state without central authority
- Tracking and verification of data
- Transparency of data if needed
- Reduced operating costs
- Security from manipulation and outer attacks on integrity

Figure 11: SWOT table -strengths

WEAKNESSES

- Scalability and energy use of current most-used solutions
- Technology still in early development especially for the energy sector
- May require physical changes to devices, incurring costs
- Energy intensivity
- Lack of knowledge within the energy field currently
- Heavily focused on decentralized systems

Figure 10: SWOT table -weaknesses

Beginning from the strengths, blockchain can provide transparent, automated, non-intermediated and decentralized digital solutions for the energy sector. In addition, blockchain can provide a platform for increased and streamlined data use, sharing and analysis. The streamlined use of data is especially important within Kera, as the district has been a testbed for novel digital smart city infrastructure. This smart city infrastructure currently consists of 19 5G smart poles, two smart bus stops and 250 IoT devices connected to a data platform and marketplace still under development [27]. The piloted data platform already uses blockchain-based smart contract functions for secure data trading [28], giving opportunities to link this data platform with local energy stakeholders.

However, blockchain is still a technology in its early development phases, with several competing providers with a lack of standardization causing possible confusion in choosing the best provider. The scalability of blockchain is still an issue with current solutions, due to storage capacity and energy use needed and the slow clearance time of transactions depending on different issues, such as the consensus mechanism used and the privacy of the chosen blockchain solution. The adoption of blockchain will also require investments both in software and in hardware if smart meters are used to log and utilize data automatically.

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OPPORTUNITIES

- Enables increased local and decentralized solutions
- Increase energy citizenship by data services for citizens, and local collaboration
- Boost local investments on renewables
- Provide verified and certified renewable energy
- Increase security of data
- Automation of contracts between stakeholders
- Enables discussions on the energy from a different, more customer-centric viewpoint

Figure 13: SWOT table -opportunities

THREATS

- Problems with accommodation to local regulation
- Reduced employment and community engagement due to automation
- Competing solutions taking ground faster than blockchain, especially as current solutions could provide same services
- Solutions for challenges changing the inherent nature of the technology
- Distrust from consumers and workers within the field due to lack of knowledge
- Lack of knowledge could lead to unnecessary expectations and unnecessary projects

Figure 12: SWOT table -threats

In terms of opportunities and threats related to blockchain, the former largely follows the aspects brought out in several previous sections. Blockchain can enable increased investment into decentralized energy production, provide increased information on sustainability of energy production and use to the city, private organizations, and citizens, and increase development of new services within the energy sector that can provide a new viewpoint to a sector generally dominated by centralized utilities. Going into the threats of blockchain, adopting blockchain could lead to reduced employment in relevant sectors due to the automation that the technology provides. The increased automation of blockchain could also reduce the amount of personal interaction between companies and their customers, thus having an opposite effect to the added community engagement that Espoo as a city is aiming for from studying blockchain implementation. In addition, accommodating blockchain to fit into the current regulatory environment and organizational requirements could result in blockchain losing its strengths compared to current solutions. This could lead to a situation, where implementing blockchain would not provide the massive changes that are expected, such as removing intermediaries from the process and adding transparency. A lack of knowledge on blockchain could also lead to several threats related to being both overly cautious and overly enthusiastic on the technology.

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8. Case Examples

In this section, three use case examples for blockchain solutions within the energy sector were identified and analyzed. These examples were the Brooklyn Microgrid (BMG) project in Brooklyn, NY, the Energy Web Decentralized Operating System (EW-DOS) by the Energy Web Foundation (EWF) and Powerledger, a provider of blockchain solutions for the energy sector based in Australia.

8.1 Brooklyn Microgrid (BMG)

The Brooklyn Microgrid (BMG) project established a microgrid energy market within three distribution grid networks in Brooklyn, New York. The idea of this local energy market between residents was presented after hurricane Sandy to reduce grid issues due to severe weather effects in the outdated Brooklyn distribution network. In addition, the BMG project provides a P2P marketplace where residents can trade generated energy with each other locally. The project implemented two components, a virtual energy market platform using private blockchain solutions, and a physical microgrid to work alongside the existing grid as a back-up island grid. It must be noted that the microgrid only applies to a single housing block within the project, and mostly the traditional grid infrastructure is still used. The microgrid is only used to decouple from the physical grid in power outages or other emergency situations. [29]

Figure 14: Solar rooftop panels in Brooklyn [30]

The virtual energy market provides a solution to transfer data between prosumers and consumers within a P2P marketplace. This is done by logging the consumption and generation data recorded on the smart meters of participating homes on their respective blockchain accounts. The energy management trading system (EMTS) creates orders to buy and sell electricity according to this data, and the sales themselves are handled within the market mechanism using a smart contract. The participants themselves can advise the trading system in issues such as the preferred source of purchased energy and price limits. Once the transactions are completed, they will be logged in the chain itself. The topology of the BMG project can be seen in figure 15. [29]

The structure of the blockchain system envisioned within the BMG project is in line with the information found on the literature review so far, as it has incorporated a private blockchain solution with a proof-of-stake validation mechanism. Participants within the microgrid can stake tokens to enter themselves to the electricity marketplace, and this stake can be linked to an IoT device that controls operation of the physical layer according to market signals from the virtual marketplace layer. The envisioned system would also incorporate clustering of nodes to ensure scalability with multiple marketplaces globally. [31], [29]

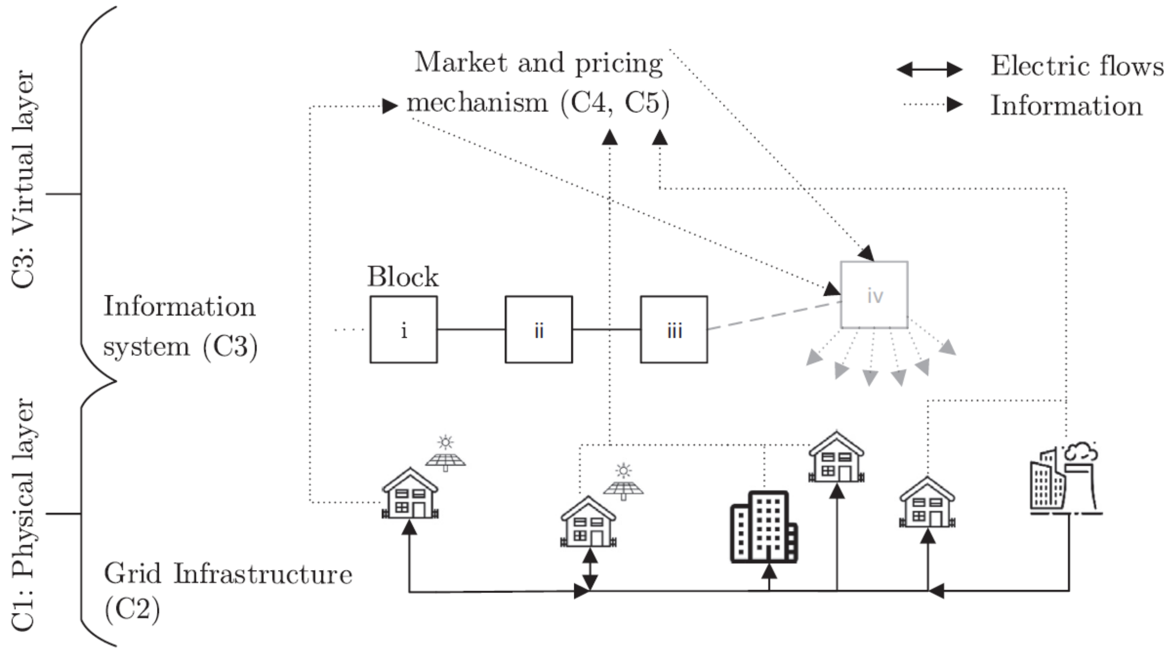

Figure 15: Topology of the BMG project [29]

The BMG project aimed to provide several benefits to local communities. It provides means for prosumers to sell their surplus electricity locally, while providing job opportunities for local companies providing the construction and operation of the renewable generation and P2P trading devices. These two aspects aid in keeping profits from the surplus electricity trade within the local community. This, in turn, provides social benefits for the community to aid local support in constructing additional microgrid projects. [29]

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8.2 The Energy Web Decentralized Operating System (EW-DOS)

The renewable energy market is constantly growing, with 2021 being a new record year for global renewable investment. Renewables are expected to account for almost 95% of the increase in global electricity generation between 2021 and 2026. [32] This can be interpreted to mean that renewables have created a totally new emerging market in the energy sphere, which will also mean a greater influence of smaller investors, including actors that have previously only been able to join the market as customers. The integration of this increased number of smaller producers to the electricity market is an integral part of facilitating the increased renewable investment. The Energy Web Foundation (EWF) is an open-source energy ecosystem that aims to create an open and public technology stack to facilitate this change. This ecosystem contains partners such as EDF (Electricite de France), Elia Group, E.ON, General Electric, Hitachi, Shell, Siemens, Vestas, Vodafone and Volkswagen. The technology stack created by EWF, known as the Energy Web Decentralized Operating System or EW-DOS, is built as a technology that provides an open-source solution that can connect customers and physical & digital assets to energy markets and applications. The technology consists of three layers:

- *The trust layer, containing the Energy Web Chain, Energy Web Token, validators, and the block explorer interface. The objective of this layer is to provide the trust and consensus that is needed for a decentralized operating system.*
- *The utility layer, containing tools such as the API solutions, a watchtower ecosystem and connective applications to e.g. the Ethereum mainnet and key providers. The aim of this utility layer is to simplify the experience of using the technology stack.*
- *The toolkit layer, with an aim of providing open-source templates for easier creation of applications.*

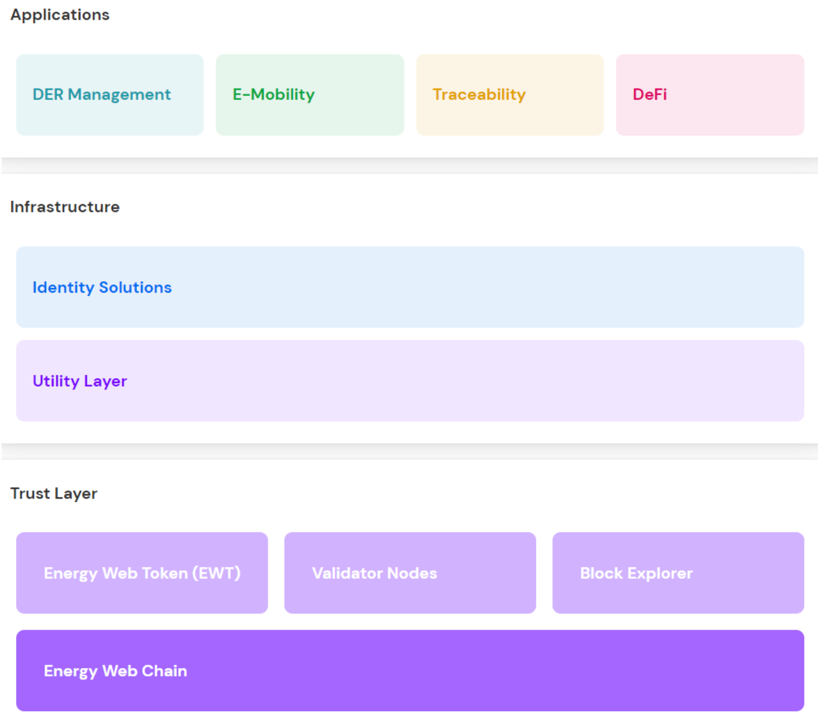

Figure 16: The EW-DOS technology stack [33]

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As this report focuses on the feasibility of blockchain, the added value provided by the blockchain solutions that are embedded to the previously mentioned three layers will be the focus of this use case example. The main part of this is the Energy Web Chain (EWC), an open-source Proof-of-Authority (PoA) blockchain for the energy sector. The EWC is based on Ethereum, which means that it already has a well-established basis for its technological solutions.

The first question to ask when analyzing a blockchain use case such as this is, why was blockchain chosen as a technology? EWF also analyzes this question in their EW-DOS whitepaper, where they note that blockchain, as a technology, is not a replacement for current technologies. They also remark that there is no inherent advantage of just adding blockchain to a use case. Taking full advantage of this new technology needs a combination of correct use of blockchain, augmentation of current processes to facilitate the change and augmenting blockchain to work in collaboration with current technologies for maximal impact [26]. EWF also mentions that blockchain is best suited for providing multi-party consensus, trust, and certification to decentralized energy solutions. [26] Thus, EWF has decided that the problem stated above, connecting customers, assets, the market, and digital applications with an open-source solution, is perfectly suited for blockchain. This is based on digital identities (DID), that serve as identification of the different assets that join the blockchain, enabling the monitoring of the system itself.

The EW-DOS itself is more of an infrastructure that enables use cases, instead of a use case. EWF established two main use case opportunities for the technology stack back in 2020. These are traceability and flexibility solutions. [26] However, several real use cases have been tested since then. Some of these are explained below:

- *Project EDGE (Energy Demand and Generation Exchange), which enables an Australian distribution system operator (DSO) Aemo to interact with customer assets via the digital identities that are saved to the blockchain. in turn, the assets that are added to the exchange can participate in the wholesale market more fluently.* [34]
- *Elia e-mobility dashboard, which aims to integrate the currently siloed eV market via the digital identities provided by EW-DOS. This provides verifiable and trusted data that can be used between eV charging market participants, aiming for more cost efficiency within the market. The project also enables the eV market participants in joining the flexibility market by providing balancing to the grid.* [35]
- *EW ZERO, a project that aims to increase renewable investment by tokenizing renewable energy facilities, thus providing decentralized renewable energy certificates that can be bought by individuals or corporations. So, in short, EW Zero is a marketplace integrator, providing a central interface for renewable procurement.* [36]

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8.3 Powerledger

Powerledger is a provider of different blockchain solutions within the energy sector, starting as a P2P trading system for surplus solar power, founded in Perth, Australia. Powerledger uses an in-house blockchain platform developed by Ledger Assets, called Ecochain. The platform can be used in other solutions in addition to P2P trading, including wholesale markets, asset management, electric vehicles and more. Within P2P trading, Powerledger tracks the ownership of produced electricity and manages sales between the producers and consumers. Prosumers gain additional value from working with the blockchain solution provider through a higher sale price when compared to selling electricity straight to the utility company. In turn, the consumers pay a slightly lower purchase price when compared to purchasing electricity straight from the grid.

Powerledger launched within 80 homes in central Perth in 2017. Since then, the solutions have expanded to over 30 client companies across the globe, such as ekWateur in France, Energie Steiermark in Austria and Silicon Valley Power in the US. These different client applications include:

- *ekWateur, France - The French renewable energy supplier uses Powerledger to track & trace the power supplied through the company. This allows a better knowledge of the power mix provided for the consumers and allows real-time customization of each customers energy mix.*
- *Sustainable Housing for Artists and Creatives (SHAC) cooperative, Western Australian Government - The housing collective purchases solar electricity from their housing provider, Access Housing, at reduced rates using the Powerledger platform.*
- *Silicon Valley Power, United States - The US utility uses Powerledger to track production and consumption of electricity at a parking garage and provides automatic credits to the utility by tracking the EV's that are charged in this garage.*

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9. OPPORTUNITIES PROVIDED BY BLOCKCHAIN

After the pros and cons of blockchain solutions for the energy sector have been identified, the focus of this report will move onwards to the key opportunities identified for blockchain solutions based on these pros and cons. To provide more of an Espoo context for the identified blockchain solutions, a decision was made to link these actions to the Espoo city strategy and the Kera district, which is a demonstration area within SPARCS. Kera is also linked to action E12-3 within the SPARCS Grant Agreement. To begin, a brief explanation of the city and Kera contexts are given.

9.1 The City Context

Espoo, a lighthouse city within the SPARCS project together with Leipzig, is the second largest city in Finland after its close neighbor Helsinki. Espoo comprises the capital region area of Finland together with the aforementioned Helsinki, Vantaa and Kauniainen. Espoo does not have a single city center. Instead, Espoo consists of five area centers: Leppävaara, Tapiola, Matinkylä-Olari, Espoonlahti and Espoon keskus. The demonstration areas of SPARCS, Sello, Kera and Lippulaiva are contained within two of these area centers, Leppävaara and Espoonlahti.

Figure 17: The Sello shopping center within Leppävaara

Figure 18: The Espoonlahti area before the construction of the new Lippulaiva shopping mall began

The Espoo city strategy, also known as the Espoo story, sets the city vision for four-year increments at a time. The newest Espoo story was accepted in October of 2021 and will run until 2025. To ensure that implementing blockchain solutions provides quantifiable benefits to the city, careful consideration of the links between the blockchain solutions and the strategy is needed. Some of the connected themes within the story are mentioned below [37]:

- *Espoo is resident- and customer-oriented:*
  - *"Active involvement of residents in the development of Espoo services and our comprehensive cooperation with partners ensures effective services that meet the needs of the residents."*

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- *Espoo is a responsible pioneer:*
    - *"Being a pioneer involves utilizing research and international experience, organizing experiments and knowing how to deal with possible failures. We develop Espoo in an economically, environmentally, socially and culturally sustainable manner."*
- *Espoo provides services together with the entire Espoo community:*
    - *"The development of services will be characterized by creative enthusiasm, the breaking of various boundaries and the strengthening of vitality, also with the help of technological development, art, top-level sports and business cooperation."*
    - *"We will develop management based on information, data analysis and effectiveness. Espoo and its partners will actively utilise digitalisation, robotics, artificial intelligence and other technologies throughout the operating processes. We will promote social innovations, resident-, customer- and partnership-based activities, effective service provision, improved productivity as well as cost savings. With the help of digitalisation, we will increase the openness of our activities, develop new platform solutions and speed up service processes. We will also take into account those who are unable to use digital services."*
- *Espoo is an internationally attractive capital of entrepreneurship and innovation:*
    - *"Espoo will strengthen its position as the internationally most interesting and attractive centre of innovation in Northern Europe in relation to competence, science, art and economy. Our partners – Aalto University, VTT Technical Research Centre of Finland and businesses in particular – will play a key role in this. Espoo will be known as the best Nordic city for start-ups and growth companies, and to support this, we will develop a growth company campus together with our partners."*
- *Espoo is an attractive city close to nature and a safe place to live:*
    - *"Sustainable and intelligent urban solutions will make daily life and mobility smoother. All Espoo residents will have good opportunities to make sustainable choices in their daily lives and make a difference in their local environment."*
- *Espoo will achieve carbon neutrality by 2030:*
    - *"Espoo will actively combat climate change, strengthen biodiversity and achieve carbon neutrality by 2030. Espoo will adapt to the impacts of climate change. Cooperation with universities, research organisations, innovation activities and businesses will generate solutions with a significant carbon handprint that will help tackle the global climate challenge. Espoo will promote new solutions for local energy production and examine the possibility of placing a small nuclear power plant in the city's area. A roadmap for combating climate change will be drawn up for the city to describe the City of Espoo's own activities and the cooperation with partners and residents to achieve the goal of carbon neutrality."*

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9.2 The Kera Context

The SPARCS demonstration site of Kera currently houses industrial buildings due to be demolished and replaced by residential and mixed-use buildings for about 14.000 residents. The current property owners include established companies such as S Group and Nokia, with significant involvement in renewable energy generation [38], [39] and ICT. The site will undergo a city planning process, new zoning, purchase by real estate developers and subsequently emerging as a modern and vibrant district with excellent train connections to other Espoo districts and neighboring Kauniainen, Helsinki and Kirkkonummi.

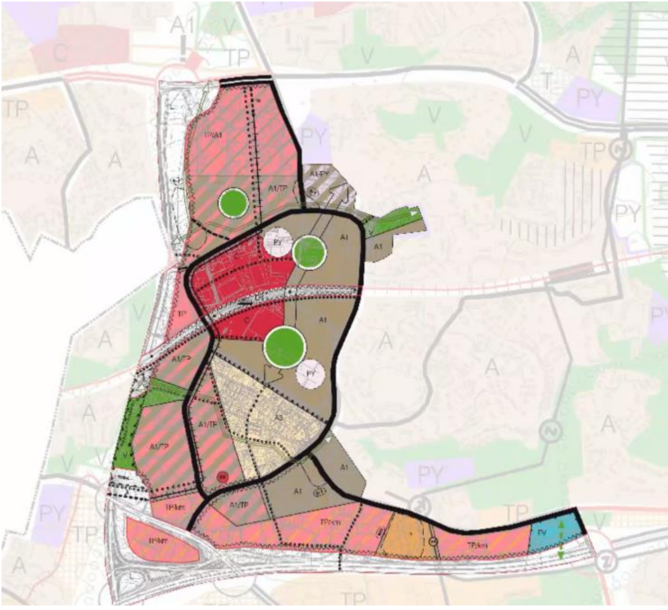

Figure 19: Zoning of Kera

The city council has set a target for Kera to serve as a front runner on smart ICT solutions and circular economy, and there are several co-creation projects to engage stakeholders in this development. In latest developments towards a more sustainable Kera, a Kera sustainability commitment agreement was accepted as an addition to the Kera land use agreement. The aim of this agreement is to ensure that the actors joining the Kera development process will adhere to the city goals related to sustainable development.

The largest plot, owned by S Group, is located on the south side of the railway, and it is expected that these properties will be sold. Nokia owns properties on the north side, close to the Nokia Headquarters area north of Kera. The company still has an incentive of involvement in Kera, as it could serve as housing for staff, and a showcase of smart city infrastructure like 5G smart poles.

In its current form, the Kera district is a deprived industrial and logistical site with relatively large plot sizes. Particularly the former Inex Partners logistical complex, owned by S Group, is located on a large plot, easily encompassing several prospective residential buildings, shops and perhaps even a school or kindergarten. As such, it thus could provide the ground for a Positive Energy District with a local microgrid for sharing any self-generated electricity. However, it is likely that the city zoning process will lead to smaller plot sizes, leaving only a small number of buildings to collectively produce and share

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electricity. Smaller scale increases the risk of grid feed-in, which reduces the financial attractiveness of self-generation.

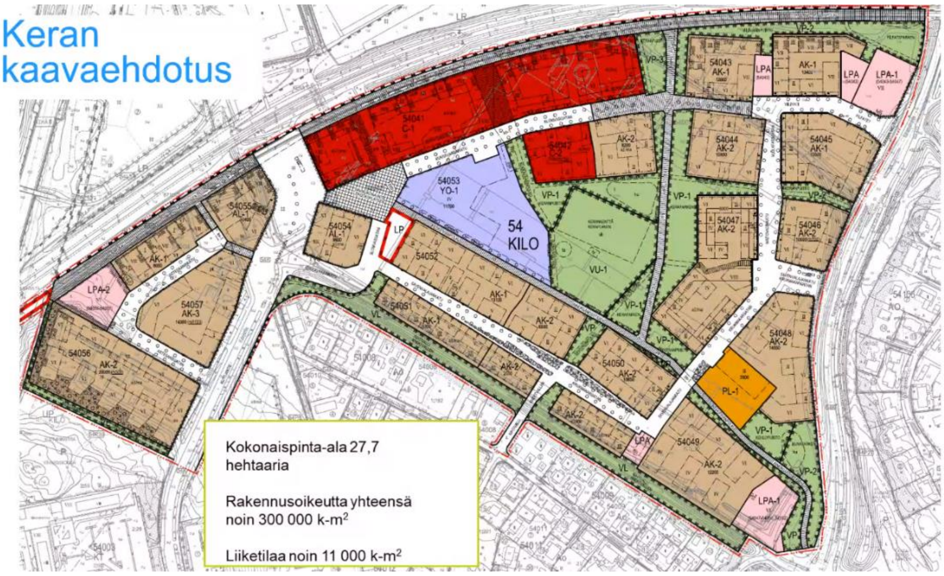

Figure 20: The proposed zoning of the south side of Kera

The proposed zoning of the south side of the railway includes medium or high-rise buildings. Higher density improves the feasibility of energy community synergies, as distribution distances remain low. However, solar energy availability is dependent on geographical area, and high population density reduces the chances of onsite energy ratio exceeding one. Under current legislation, energy communities are unable to share electricity over property borders, and therefore the site would need to host a number of smaller communities, each within one plot. This reduces the opportunity to avoid curtailment with prosumer transactions. For example, residents with an electric vehicle parked on a neighboring plot will be unable to charge their vehicles with residential solar energy.

The district heating infrastructure in Kera will be developed by Fortum Power and Heat. Their proposed solution for Kera is an air-source heat pump serving a water-based distribution system at about 70°C. The power demand for the heat pump and circulation pump is procured from renewable sources, making the heating system emission-free. While the temperature is lower than in traditional district heating systems, it is still sufficient to provide domestic hot water without heat pumps. However, most waste heat sources like data centers, chiller units, exhaust air heat exchangers and wastewater are unable to provide heat at the required temperature. Fortum will publish a tariff table for purchasing excess heat from customers, with price depending on outside temperature and distinguishing between heat injected into the hot or cold loop of the network. This enables two-directional heat transfer, but the economic returns for prosumer customers could be insufficient to cover connection fees and any heat pumps needed to prime the waste heat to required temperature levels.

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9.2.1 Smart and Clean Kera

Kera has been developed with an aim to become a global example of a smart and sustainable city district. The Smart and Clean Kera project was launched to aid in this development. Within the theme of smart infrastructure, this project investigated sustainable solutions for energy generation, transfer and consumption, and energy system optimization with digital solutions. These served as a central theme during the Kera development process, and the development of the Kera energy system continues. To analyze the most efficient energy solutions for Kera, the project team procured a report to identify the foundations of a local energy ecosystem aiming towards a Positive Energy District (PED). [40] Table 4 below shows the prioritized concepts found on page 51 of this report and prioritizes them based on their connections to blockchain technology based on the literature review process (bolded). These prioritized concepts are taken from a longer list, that considers the value chain needed for a PED area. This list is then prioritized based on the Kera characteristics.

Local Energy Production	Energy distribution and measurement	Energy recovery and storage	Services	Use	Overarching Themes
Solar electricity	**Smart Grid**	**Local electricity storages/batteries**	**Energy-as-a-service**	**Demand Side Management**	Reserve Power
Ground-source heat pumps (300m)	**Smart meters (15 min intervals)**	Waste heat	**Demand Side Management**	**Smart Infrastructure and IoT**	Net-Zero Energy Buildings
Water-to-air heat pumps	District Cooling Network	Power-to-X solutions	**Virtual Power Plants**	**Apartment-based circumstantial control**	**Energy simulation/Digital Twin/Optimization**
Deep wells (2km)	**Microgrids**		**Local trading of energy**	**A district energy market**	**5G sensors and data platform**
Geothermal heat (7km)	**Separated Kera electricity grid**				**Building energy management systems**
					KeraHUB/Other Kera development platform

Table 4: Key energy solutions identified within Smart and Clean Kera

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9.3 The Opportunities

This section provides a compilation of the different opportunities identified between blockchain and energy, and their applicability to Kera and the city strategy. General information of the different opportunities and their links to Kera and the City strategy is provided in Table 5 below. Sections 9.3.1 and 9.3.2 provide an extended analysis on how these opportunities are linked to actions E15-2 and E12-3, and what solutions have been researched and developed so far.

Opportunity	Applicable for Kera	Applicable for city strategy	The city's role in development
P2P digital transaction platform	**Direct** (District energy market, local energy trading)	**Indirect** (Digitalization, local energy production)	**Pilot platform**
Renewable certifications for energy use in public/private premises	**Indirect** (Solar electricity, local trading of energy)	**Direct** (Openness of services, digitalization, and data analysis**)**	**Central role as procurer of development project and future user**
Automated provision of information towards regulatory or contractual compliance	**Indirect** (District energy market, local energy trading)	**Indirect** (Sped up services)	**Central role to no/small role**
Enhanced IoT devices, to provide benefits in tracking and tracing of data	**Direct** (Smart infrastructure and IoT, 5G sensors and data platform)	**Direct** (Digitalization, data analysis, openness of services)	**Pilot platform and future user**
Real-time energy data platform to local consumers and producers	**Indirect** (Demand Side Management, Virtual Power Plants)	**Indirect** (Digitalization, data analysis, resident-oriented Espoo)	**Pilot platform**
Crowdfunding schemes for renewable investment	**Indirect** (Solar electricity)	**Indirect** (Promotion of resident and partnership-based activities, local energy production)	**No/small role**

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Support platform for small-scale producer aggregation and energy market entry	**Direct** (Virtual Power Plants)	**Indirect** (Digitalization, data analysis)	**Pilot platform and future user**

Table 5: Blockchain opportunities for Kera and the City of Espoo

Within Table 5, each identified opportunity is analyzed based on its links to the current city strategy, applicability to the Kera area based on prior district-level reports, and the City's role within development of the solution. The analysis on the applicability of each opportunity to Kera was based on their links to the Kera energy ecosystem analysis (see Table 4). In turn, the analysis on the applicability of each opportunity to the city strategy was based on their links to the strategy's central goals (see section 9.1). Links were divided between three different categories:

- *Direct, if a direct link to themes within the aforementioned reports was identified or if the opportunity was deemed to have a central role in the achievability or implementation of the identified themes.*
- *Indirect, if no direct link was identified but the opportunity could provide additional benefits to themes identified within the aforementioned reports or if the opportunity was deemed to have a non-central but nonetheless beneficial role in the achievability of the identified themes.*
- *No applicability if no links or role was identified.*

Next to each note on applicability, examples of the identified links are given. However, other links might also apply. Further explanation for how the decisions on these categories were made are presented in Tables 6 and 7 below. Within Table 6, the explanations for each opportunity's applicability in Kera are given. All of the identified opportunities have at least an indirect link to the central themes identified within a future Kera energy ecosystem, aiming for an energy positive Kera. In addition, three opportunities were deemed to have a direct link to the prioritized themes. These directly linked themes were focused on a local district energy market, Smart Infrastructure and IoT, and Virtual Power Plants. Thus, it is advised to focus possible blockchain development projects within Kera on these opportunities, and on the identified themes. Some of the local development projects have already begun blockchain implementation and testing, as the Kera Luxturrim5G Smart pole, IoT, and data platform pilot network already uses blockchain to provide benefits, such as automated smart contracts for data trading, within the data platform and marketplace [28].

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Opportunity	**Identified applicability for Kera**	**Explanation**
P2P digital transaction platform	**Direct** (District energy market, local energy trading)	A local transaction platform, possibly utilizing blockchain technology, was deemed directly beneficial for the implementation of local energy trading within a district energy market.
Renewable certifications for energy use in public/private premises	**Indirect** (Solar electricity, local trading of energy)	Blockchain-based renewable certifications can provide additional reasons to renewable investments locally, and the sale or purchase of locally produced energy, as the energy can be directly tracked to each stakeholder using blockchain. However, investments in local renewables and local energy trade can still be achieved without these services.
Automated provision of information towards regulatory or contractual compliance	**Indirect** (District energy market, local energy trading)	Streamlining regulatory compliance could aid small-scale producers in achieving regulatory requirements, such as tax payments, cost-efficiently, thus aiding the formation of local energy markets. However, this opportunity was not deemed a requirement in forming these local markets.
Enhanced IoT devices, to provide benefits in tracking and tracing of data	**Direct** (Smart infrastructure and IoT, 5G sensors and data platform)	IoT was mentioned as a key future solution within Kera reports, and the district is already home to a smart city pilot connecting 19 smart poles with over 250 IoT devices. In addition, blockchain is already in use within the data platform linked to this smart city pilot, thus providing possible incentives in testing the further implementation of blockchain within this theme.
Real-time energy data platform to local consumers and producers	**Indirect** (Demand Side Management, Virtual Power Plants)	Consumer-centric data platforms could provide additional services for the users of DSM and VPP solutions, such as real-time data analysis, visualization, customization and rewards. However, this platform can be an added service to these solutions, and is not a direct requirement for their implementation.
Crowdfunding schemes for renewable investment	**Indirect** (Solar electricity)	Crowdfunding could provide means for additional investment into local renewable generation.

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Support platform for small-scale producer aggregation and energy market entry	**Direct** (Virtual Power Plants)	Aggregators are a central actor within VPP's currently, and thus enhancing their operation can be central for aiding the scaling up of VPP services within Kera.

Table 6: The applicability of each opportunity to Kera with explanation

Within Table 7, the applicability of each solution to the Espoo strategy is analyzed, in addition to the city's role in development. The applicability is analyzed according to the rules given previously in this section. The city's role is given as an open-ended answer, which aims to explain the role that the city should take in a possible future development project. In addition, the answer notes if the city can gain value from the project as a future user. Keywords in the answers can be explained as follows:

- Central role: The city can be a responsible partner in the development project, as it gains value from tailoring the solution to its needs for future use. However, this does not necessarily mean that the city should develop the solution. Instead, the solution can be procured from a more knowledgeable party.
- Pilot platform: The city can provide a pilot platform through means such as the public building stock. However, the responsibility of the development project and the pilot itself should be with a third party that gains value from developing their services. The city can still be a possible future user of the developed service.
- No/small role: The city has no role in development or a small role through for example communicative activities.

Opportunity	**Applicable for city strategy**	**The city's role in development**	**Explanation**
P2P digital transaction platform	**Indirect** (Digitalization, local energy production)	**Pilot platform**	Espoo aims to aid local energy production, and new digital solutions. However, the strategy does not differentiate between the means of ownership for local production, or whether locally produced energy will be connected to the grid or traded via P2P channels. Espoo could participate as a pilot platform for new P2P solutions, but cannot have a central role in development, as the city does not currently participate in the sale of

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			energy. Energy is produced locally on city-owned properties, but any P2P sales done from these properties would most probably be done via third-party services.
Renewable certifications for energy use in public/private premises	**Direct** (Openness of services, digitalization, and data analysis**)**	**Central role as procurer of development project and future user**	Espoo aims to increase the openness of its services, while also aiding the development of new digital solutions. A more open renewable certification process was deemed directly beneficial on both aspects, as the city could directly specify the source of procured energy. The city was deemed to have a central role on possible future development projects within this opportunity, as the renewable certificates produce direct benefits to the city. The certification service would most probably be procured from third-party sources.
Automated provision of information towards regulatory or contractual compliance	**Indirect** (Sped up services)	**Central role to no/small role**	Espoo aims to speed up the city service processes, a fact that blockchain can provide benefits to. However, the provision of information to the city or by the city can also be developed without blockchain. The role of the city heavily depends on the development projects. Within the field of energy, information might be processed by the City, private companies such as the local DSO or DH operator, or other authorities such as Fingrid or HSY. Thus, the role of the city must be determined during planning phases.

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Enhanced IoT devices, to provide benefits in tracking and tracing of data	**Direct** (Digitalization, data analysis, openness of services)	**Pilot platform and future user**	Espoo aims to aid the development of new digital solutions, and enhance data analysis. Smart meters are integral in this development, and blockchain has been deemed to have measurable benefits for the track & trace abilities of data collected by these devices. In addition, these abilities would enhance the openness of city services via open data. Even as blockchain is directly beneficial to the strategy, the city would still only be a possible pilot platform and future user of the enhanced devices. The development project itself would be led by the company that installs and maintains the smart devices, and provides the collected information, analysis and visualization as a service to customers. In turn, they will gain value by enhancing their own services.
Real-time energy data platform to local consumers and producers	**Indirect** (Digitalization, data analysis, resident-oriented Espoo)	**Pilot platform**	Espoo aims to aid the active involvement of local residents in city development, and every resident's ability in aiding their own sustainable lifestyle. Additional services provided by blockchain solutions could aid in these endeavors. Espoo could provide users for a possible pilot project in this opportunity. However, the service itself, and the project responsibility, should be with the service provider.
Crowdfunding schemes for renewable investment	**Indirect** (Promotion of resident and partnership-	**No/small role**	Espoo aims to aid resident-based activities, local energy production and sustainable lifestyles. Crowdfunding could

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	based activities, local energy production)		provide opportunities for further investment into renewables by local residents. In a possible development project, Espoo should aim to be a partner with a small role in communicative activities. Much like other crowdfunding options like Kickstarter, the type of investment, the funding options, construction, and the provided value after project completion should be the responsibility of a third party.
Support platform for small-scale producer aggregation and energy market entry	**Indirect** (Digitalization, data analysis)	**Pilot platform and future user**	Espoo aims to aid new digital solutions and local energy production, which the aggregator business heavily focuses on. However, developing new solutions for aggregator business is not directly mentioned within the Espoo strategy. Within a related development project, Espoo public buildings could be a possible pilot platform. In addition, Espoo could gain value from future solutions as a user of aggregator services. However, the responsibility of implementation and operation should be with the aggregator.

Table 7: The applicability of each opportunity to the city strategy and the city's role in development

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9.3.1 E12-3: Energy Transfer and Bi-Directional Grids

To provide the information needed for action E12-3, Table 5 was analyzed further with a focus on which opportunities can enable the further development of solutions for energy transfer within bi-directional grids. The chosen opportunities were decided upon based on the benefits that they can provide for these services currently, and the additional features that they could enable for the future. This analysis was based on a combination of a literature review and the experience of the energy specialists employed at the City of Espoo.

From the different opportunities identified in Table 5 within section 9.3, all can provide additional value to the themes mentioned in action E12-3. This is because energy transfer within bi-directional smart grids is such a broad concept within the energy sector. Prosumers, as mentioned in section 6.1, can be different actors that participate within the energy sector in several different ways depending on their particular situation. These actors may include corporations sourcing green energy, off-grid households, industrial sites with local renewable production and flexible consumption, and more. In addition, the action aims to identify enabling blockchain solutions for energy transfer and tracking within bi-directional grids. This means that the solutions are not required to be directly linked to the transfer or tracking process, and processes like renewable certification can be included as they enable further process within local prosumer activities.

To provide additional information of the current landscape for these blockchain opportunities, a literature review was conducted to identify examples of implemented or researched solutions. Several of these can be overarching with the opportunities identified within Table 5 or might be more small-scale solutions that fall under the ones mentioned earlier. The opportunities identified within Table 5 are shortly explained in the following paragraphs, while identified solution examples are marked with a dot below each opportunity. Some of the solutions might be overarching with section 9.3.2, as bi-directional energy transfer is a very broad concept that can include themes such as prosumers, VPP's and DSM.

P2P digital transaction platforms can be a key solution for streamlining energy trading in the future, depending on future changes to Finnish regulation. Blockchain can provide opportunities for local prosumers to trade energy directly with local consumers. This is the key opportunity for blockchain on the energy sector and thus a focus for identified solutions from the literature review as well. The research examples below show several different energy trading solutions using blockchains, including energy generation within smart grids and EV charging/discharging.

Research:

- A blockchain solution to facilitate secure and private trading of energy between mobile EV's and connected buildings in a smart grid. [41]
- A blockchain solution for energy trading of EV's connected to a smart grid [42]
- A blockchain solution to provide a P2P trading network for prosumers and consumers on top of a DR scheme. [43]
- Blockchain solutions for P2P energy trading within smart grids. [44], [45]
- Blockchain-based energy management platform to facilitate energy transactions within a VPP. [46]

- Blockchain solution for secure and private energy transactions within a smart grid [47], [48]
- Blockchain-based solution for distributed coalition formation algorithms, to streamline energy trade within migrogrids. [49]

On-market solutions:

- Powerledger provides solutions for P2P trading for industrial, commercial and residential actors. This is applied with two platforms. Electricity retailers can allow their customers to trade electricity between each other via xGrid, and energy tracking and trade within microgrids can be done via μGrid. Currently, xGrid is deployed within projects in Australia, India, the United States, Thailand, Japan, Malaysia and Austria, and μGrid is deployed in Australia and Thailand. [50]
- Greeneum is an Israel-based company providing a solution that combines P2P trade of energy, renewable certificates and other aspects such as optimization and prediction services. The solution is heavily focused on developing markets in Latin America, Africa, India and Southeast Asia. [51]
- Mitsubishi Electric Corporation has commenced the development of a P2P energy trading solution together with the Tokyo Institute of Technology. [52]

Renewable certifications for energy use in public/private premises can be a key enabler for increased local trade of energy, if a streamlined process of providing authentication of local renewable energy is provided. Within Finnish regulation, every seller must certify the origin of procured or marketed renewable energy. In addition, producers and users that market their renewable energy must provide proof of the marketed proportion of renewable energy. This guarantee of origin registry is the responsibility of local TSO Fingrid and is handled by their subsidiary Finextra OY. However, this Renewable Energy Certificate (REC) system does not ensure that all consumed energy on the premises is renewable, as REC's can be traded between sellers and buyers within the EU. Instead, the current REC system only ensures that enterprises offset their consumption from renewable sources according to marketed values. In addition, these renewable energy certificates (REC) are handled monthly on 1 MWh bundles. Small scale producers can only handle their guarantees of origin via an aggregator service, as the service can otherwise be costly for smaller stakeholders. As blockchain tracks transactions and the origin of energy, blockchain solutions can automatically provide certifications of renewable generation if needed. Examples of blockchain-based REC solutions are given below:

- IBM is working on enerT, a solution intended to tokenize renewable energy certificates. [53]
- FlexiDAO provides two solutions for corporations aiming to procure renewable energy. Respring provides a tool for tracking data of procured energy certificates, and related emissions. Respring also provides an advanced solution where energy supply can be traced directly from the selected plants. CFEscore provides a tool for 24/7 tracking of the emissions from consumed electricity. [54]

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- The Energy Origin (TEO) tool provided by Engie is a device that is connected to production and consumption sites. The device then signs the data and registers it within the blockchain model. Thus, data of renewable production and consumption can be tracked in real time for certification.
- PowerLedger has piloted several REC marketplaces in the US with M-RETS, in Thailand with BCPG and in Japan with KEPCO. [55]

The current energy regulation within Finland does not allow the sale of electricity between properties. However, as this regulation changes to meet current EU directives on energy communities, regulatory compliance can still be required. This regulatory compliance is related to the Finnish electricity market act, the REC reporting requirements, the requirements of the local electricity market if electricity is traded, the requirements of the local DSO if electricity is fed to the grid and the Finnish financial regulation. All of this regulation requires reporting from different stakeholders within the energy sector, often provided to a central authority that is trusted with overseeing compliance of every participant. Several sources provide blockchain as a solution for streamlining the reporting process and providing automated solutions for all actors. For example, PWC has stated that blockchain could provide means for customers to trade energy between themselves while automatically providing verifiable records of renewable production for REC reporting, while transmission and distribution system operators can automatically divide energy between market participants for balancing settlements. [56] Within Finland, local authorities have already implemented or participated in several pilots on blockchain as a solution for streamlining regulatory compliance. These include research pilots on the use of blockchain within taxation and a digital solution for handling purchase of property. More information on these pilots will be given in section 10.

Blockchain can also provide solutions for Internet-of-Things (IoT) services within the energy sector. Blockchain can provide a platform for automated M2M communication and aid in the tracking of device data. According to a report by Deloitte, blockchain can aid in the tracing of device shipments, proof of device authenticity, proving device lineage in secondary markets, enabling P2P trade via crypto-enhanced smart meters, predictive maintenance, and virtualizing ID management. [57] In addition, IBM identifies applications for blockchain within IoT solutions in freight transport, component tracking and maintenance. The solutions within these sectors are very similar to the Deloitte report, as they contain tracing of shipments, proof of provenance and preventive maintenance. [58] Within the themes of action E12-3, using smart devices within P2P trade is the most obvious link between these reports. To facilitate energy transfer, smart contracts between participants can set the rules for trading, and smart devices can automatically decide upon the best course of action as energy is traded according to these rules and outside conditions. In addition, tracing of trades between devices, proof of smart device authenticity and predictive maintenance have a key enabling factor for energy transfer and tracking within bi-directional smart grids.

As smart devices collect data to facilitate the exchange of funds for energy, the data can be provided to the producers and consumers through digital platforms that provide knowledge in real time. These digital platforms can also provide means for users to make changes to their preferences for energy. Thus, blockchains can enable further investment into local renewable generation by providing local citizens with digital platforms that

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visualize living conditions, personal emissions, source of energy, local energy producers available for connection and more. In addition, these platforms can reward users based on their sustainable lifestyle choices in energy use or otherwise. Examples of blockchain-enhanced data platforms include the following.

- LO3 Pando, a digital solution aiming to empower local renewable production. This solution includes data visualizations and analytics for commercial users and a mobile app including visualizations, analytics and customization options for end users [59].
- AYR, a Portuguese-based sustainability platform that uses blockchain. Rewards carbon-neutral behavior by providing users with green credits that can be exchanged for services. In turn, local companies can use these tokens to offset carbon emissions [60].

As blockchain has been seen as a key solution for situations where diversified participants lack trust between each other but need to collaborate, blockchain could be a perfect solution for facilitating investments in renewable energy. This can be an especially good solution for facilitating energy communities or other decentralized energy solutions, as the frontal investment needs are a key barrier in participation. Thus, blockchain-infused crowdfunding schemes can be an enabler for local renewable investment. Examples of crowdfunding schemes within the energy sector enabled by blockchain include the following.

- A decentralized finance -based crowdfunding platform developed by Engie Energy Access and Energy Web. The platform focuses on supporting renewable energy projects in Africa. [61]
- Sydney-based start-up ASTRN energy provides Waves blockchain, a solution for crowdfunding renewable projects. The first funded project went live in May of 2021 [62].

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9.3.2 E15-2: Demand Response and Virtual Power Plants

To provide the information needed for action E15-2, Table 5 was analyzed further with a focus on which opportunities can enable the further development of DR and VPP solutions. The chosen opportunities were decided based on the functions that they can provide for current DR and VPP services, and the additional features that they could enable for the future. This analysis was based on a combination of a literature review and the experience of the energy specialists employed at the City of Espoo.

From the different opportunities identified in Table 5 within section 9.3, closely related to Demand Response (DR) and Virtual Power Plants (VPP's) are the opportunities explained in the following sections. A literature review was conducted to identify implemented or researched solutions. Several of these can be overarching with the solutions identified within section 9.3.1. The opportunities identified from Table 5 are explained below, while the identified solutions are marked with a dot below each opportunity.

P2P digital transaction platforms could provide additional services to VPP and DR solutions and aid in connecting current users to each other and the reserve market, depending on future changes to Finnish regulation. VPP solutions could be expanded to facilitate the transfer of electricity and heat between several participants, or the transfer of funds received from the reserve market.

- Trackable and unchangeable DR-related flexibility validation and transaction process within decentralized smart grids. Flexibility is transacted via a blockchain-based P2P marketplace, while the electricity grid is still operated by a central operator, such as a DSO. [63]
- A blockchain solution to facilitate secure and private trading of energy between mobile EV's and connected buildings in a smart grid. [41]
- A blockchain solution to provide a P2P trading network for prosumers and consumers on top of a DR scheme. [43]
- Blockchain solution for tracking and validating response provided, share data securely between stakeholders and settle related transactions via smart contracts. [64]
- A blockchain-based flexibility marketplace controlled by smart contracts that reward prosumers as flexibility is provided. [65]
- Blockchain solution for P2P energy trading within a VPP. [44]
- Blockchain-based energy management platform to facilitate energy transactions within a VPP. [46]

Blockchain can provide a platform for streamlining automated M2M communication and tracking of device data within VPP and DR solutions. This could assist in automating DR and VPP processes even further, while also tracking device data and using smart contracts to automate agreements between participants.

- A blockchain-based solution to store consumption data and implement the rules of the DR scheme. Aggregators provide the smart contracts with the rate of flexibility needed, thus requesting shifts in prosumer demand

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according to the related smart contract. Blockchain solution implements Zero-Knowledge proofs to ensure privacy of energy data. [66]
  - A blockchain solution to automate monitoring and billing for a cluster of up to 100 smart homes that collaborate in a DR scheme without a central aggregator. Smart homes decide upon a day-ahead power profile in collaboration with each other, while the blockchain solution ensures that the profile is met daily. [67]
  - Blockchain solution for tracking and validating response provided, share data securely between stakeholders and settle related transactions via smart contracts. [64]
  - Blockchain solution to optimize charging of energy storage units in a smart grid. [68]

Blockchain could enable the further development of visual platforms that utilize real time energy data to provide information to local actors. The collected data and related information can be used to provide information to the participants in the DR scheme or VPP. Thus, these participants can gain knowledge on their own energy use, and how their participation has affected their emissions or enhanced sustainable living in other methods. The visual platforms can also enable users to change their personal preferences to alter the flexibility or energy provided.

  - A blockchain solution to provide rewards for consumers if they reduce consumption on peak hours, connected to a blockchain P2P market. [69]

Blockchain could provide a support platform for aggregators. This could ease the entry to the energy market for smaller stakeholders. Blockchain can provide opportunities for new completely P2P aggregator solutions or streamline existing aggregator services.

  - A blockchain-based solution for aggregators and suppliers involved in a DR scheme, to ensure secure and automated integration of customers. Utilizes clustered nodes of several customers (similar to a VPP) to enable more efficient inclusion of small-scale demand to current DR business. Smart contracts are implemented to provide rules for flexibility response, associated incentives, and rules for balancing the demand of different node participants. [70]
  - A blockchain-based solution to store consumption data and implement the rules of the DR scheme. Aggregators provide the smart contracts with the rate of flexibility needed, thus requesting shifts in prosumer demand according to the related smart contract. Blockchain solution implements Zero-Knowledge proofs to ensure privacy of energy data. [66]

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10. THE LEGAL FRAMEWORK

This section provides information and analysis on the regulatory framework surrounding blockchain solutions and cryptocurrencies, including a dive on the energy-related regulation within Finland. Within Finland, local authorities have already implemented several pilots on blockchain as a solution for streamlining regulatory compliance. These pilots, according to [3], are given below.

- The opportunities of blockchain in taxing of salaries by the Finnish government was a research study aiming to conceptualize the opportunities of blockchain in Finnish taxation. Within its conclusion, the research team states that the expectations of blockchain have become disproportionate from its original intention as a solution for decentralized P2P networks. The opportunities of blockchain within taxation were seen to be somewhat questionable even if the technology was deemed a possible alternative for current processes, as the blockchain technology provided its own limitations. The research team also observed that the costs of a blockchain-based solution for taxation would surpass current solutions by a large margin. However, the research team saw consortium blockchain solutions, which they call distributed ledgers (DLT), more viable for taxation purposes. [71]
- The Finnish Tax Authority participated in a proof-of-concept pilot which the implementation of the SEED-system on a Hyperledger platform.
- Finnish authorities and private companies implemented a fully digital solution for the sale of stocks within a housing collective.
- The Finnish Ministry of Finance, together with 40 different organizations, implemented AuroraAI, a decentralized platform for interaction between different public and private service providers for better use of resources and better communication and interoperability between services.
- A blockchain based tool for the digitalization of the control and trading of unlisted shares and shareholder registries.

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10.1 Financial regulation

Finland has so far been slow in catching up to the train of regulation changes that several other EU countries have made towards the ease of use of virtual currencies and blockchain. For example, Estonia has been one of the first countries in the EU to draft a regulatory system for cryptocurrencies. In Estonia cryptocurrencies are divided into four different classes depending on their usage, and the regulation differs depending on the class that the virtual currency falls under. The different classes are as follows [3]:

- Security tokens, which give rights of partial ownership within a company, rights to stock-based revenue or rights to vote for company issues.
- Payment tokens, if the token can be used as a virtual currency beyond a single platform. Includes virtual wallet services used to store virtual currencies.
- Charity tokens, if tokens are only used for charitable funds without any provided benefit to the sender from the recipient.
- Utility tokens, if the token provides access to a product or platform.

Finnish regulation does not make this division between different cryptocurrencies, as the Finnish law on the providers of virtual currencies defines these currencies only as [3]:

- "Value provided in a digital form, not supplied by the central bank or other authority, which is not a form of legal tender but can be used as a means of payment and that can transferred, saved and transacted electronically."

This quite broad definition of cryptocurrencies, combined with the quite strict registration and security requirements leads to a situation where very different systems must abide by the one-size-fits-all regulation structure. The tight regulation increases trust on the providers of cryptocurrency services but causes requirements that might be difficult or even impossible for them to meet. Even more confusion is caused because of the quite broad definition of a cryptocurrency in Finnish legislation. This could lead to a situation where blockchain systems used just for transactions within one community, such as an energy collective, would have to register with the Finnish authorities and even calculate a euro-based rate for their tokens. The same problem is seen with taxation, as the Finnish tax authority has in their report on the instructions on virtual currency taxation defined the change in value within virtual currencies to be taxable in the following situations [72]:

- "Virtual currencies are changed to any fiat currency. Whether the funds stay with a broker or is transferred to the taxpayer is not relevant."
- "The virtual currency is transferred to a second party for any commodities or services."
- "The virtual currency is traded to another virtual currency."

The Finnish tax authority also notes that each use, sale or transfer of a virtual currency within the aforementioned situations is deemed as a separate taxable activity. In addition, the creation of new tokens within a virtual currency, often known as mining, is deemed as taxable income. The instructions provided by the tax authorities note the mining activities seen in virtual currencies such as bitcoin, and staking within Proof-of-Stake-based blockchains. Thus, also staking previously owned tokens to gain access to validate further transactions providing further tokens to the validator is deemed as taxable income. The electricity used within the mining of virtual currency and the acquirement of mining

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equipment can be reduced from the taxable income. However, proof of all these expenses has to be provided, including the exact amount of electricity used for the mining activities.

In addition to the current regulation on virtual currencies, the Finnish regulation on money laundering also provides challenges that blockchain solutions need to meet if funds are transacted or investments are made through their platform. Under the Finnish law on the prevention of money laundering and funding of terrorism [73], defined actors are required to gather information on their customers and report any suspicious activity to the authorities. The defined actors include traditional institutions such as banks, credit unions, gambling institutions, insurers, and lawyers, but also includes providers of crowdfunding and virtual currencies. Under the money laundering act, all defined actors must store the following information on each customer:

- Name, date of birth, social security number and address
- Representative's name, date of birth and social security number
- A body corporates line of business, full name, register number, date of registration, registered authority, address of home and business and rules of conduct. Names, dates of birth and nationalities of each person within the decision-making body of the body corporate.
- Name, date of birth, social security number and nationality of every beneficial owner.
- The method of authentication of identity, and related documents.
- Information on all activities of each client, their field and extent of business, financial status, their grounds of use and knowledge on the origin of all funds, with additional information needed if client is deemed politically important.
- Bank account number, name of account holder and people with access and date of opening and closing of account
- Deposit box: Information of owner as deemed in previous bullet points

If the defined actor cannot gather the information presented above, they cannot start a provider-client relationship with this entity and must sewer any prior relationship if it exists. In addition, the defined actor must report all activities of this entity to authorities if their business is deemed suspicious. This also includes occasional clients, if the conducted business exceeds 10 000 €, or 1 000 € if the defined actor is a provider of a virtual currency.

As financial solutions designed for pseudonymity, decentralization, and automation, most blockchain solutions do not conform to local money laundering laws. Instead, due to the low barrier of entry and possibilities for pseudonymity, virtual currencies have been popular between actors aiming to avoid the grasp of the law, such as terrorist organizations and criminal marketplaces. In addition, new tools, such as mixing services and fully anonymous virtual currencies utilizing zero-knowledge proofs, emerge at a constant pace with an aim to provide even more anonymity to users. Mixing services are pools that serve as an intermediary for a large amount of bitcoin transactions and shuffle this pool to sever the connection between sender and recipient. Thus, further anonymity is possible for bitcoin users that utilize this service, making the tracking of transactions between actors even more difficult. In turn, anonymous virtual currencies utilizing solutions such as zero-knowledge proofs, obscure every facet of every transaction by design [14]. This change can be seen as a necessary future to fully remove currencies from the centralized control of the current banking system. In this case, change in regulation

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can be seen as an equally necessary future for a more decentralized and people-centric banking system. From the opposing viewpoint, this future can be seen as a form of financial anarchism, where all financial flows are uncontrollable and out of the reach of central supervision that ensures the safety of the financial system.

It must be noted that most virtual currencies are pseudonymous, not anonymous. This is since blockchains have traditionally been fully transparent, with every transaction viewable by every participant. Even as transactions are handled by pseudonymous entities, a knowledgeable actor can discern identities from the information provided on the chain. This can provide an issue for the current data privacy and GDPR laws. Thus, blockchain can simultaneously be too anonymous and too transparent for current regulation. In addition, the transparency of blockchain solutions can provide new means for financial surveillance and censorship. As each public and private key can be seen as a form of digital fingerprint connected to a certain entity, transactions to and from certain keys could possibly be blocked by third parties if technology so allows [14].

In short, blockchains have the possibility to demolish the current banking system from the ground up, if the adoption of blockchain becomes widespread. Even if this scenario for the future is not met, virtual currencies will stay as a part of the financial system as long as there is demand for a decentralized virtual payment solution. Thus, the current regulation needs to evolve so that privacy of data can be attained within virtual currencies, while the requirements of national money laundering laws are fulfilled. In the meantime, the providers of virtual currencies need to show volition in collaborating with financial regulation, to fix the partly tainted reputation of virtual currencies within the larger masses. Currently, cryptocurrencies are fully banned in 9 jurisdictions, and implicitly banned in 42 more via strict regulation [74]. China, the second-largest economy in the world and leader in cryptocurrency mining, banned cryptocurrencies in 2021 due to issues with fraud and money laundering. The United States, the largest economy in the world, has not stated interest in banning these currencies outright, but aims for stricter regulation per Gary Gensler, the chair of the Securities and Exchange Commission [75]. With an unresponsive blockchain field, regulation will only grow stricter within most major economical areas.

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10.2 Regulation Within the Energy Field

As blockchains and cryptocurrencies are both remarkably different from our current ownership and transaction structures, they provide new issues to solve for our current regulation as well. This is especially a problem in the energy sector, which has traditionally been a very centralized system where locally situated utility companies provide the needed services for customers. In addition, these utility companies have a natural monopoly, as it is not economically feasible to construct competing electricity or district heating infrastructures within the same area. This has led to heavy regulation within the field to simulate competition. With a move towards more of a sharing economy using decentralized generation and blockchain technologies, a lot of new questions on the regulation of the energy business must be asked. Who is responsible when something goes wrong e.g., during a security breach, problem in a smart contract, or another unspecified problem? If the energy system is rapidly decentralized, who will be responsible for the electrification of rural areas with less population? Will the energy system switch to self-sufficient consumers in these areas with no grid connection? In this case, how will the energy system react to power outages in these areas? As can be seen, the change to blockchain-based technologies and decentralized energy communities leads to several questions, many of which don't have a solution as of now.

In this section, a brief explanation on the Finnish energy market will be conducted. This will provide a foundation for the legal analysis of blockchain for the energy sector. in this explanatory section, the energy market will be divided between two sectors, electricity, and heating. These two sectors will be explained in the sections below.

10.2.1 Electricity market

The Finnish electricity market structure is explained in Figure 21 below. Fingrid, the local TSO, divides the market into 5 sections, 4 of which occur before delivery of electricity and 1 occurring after delivery. Futures and options, traded within the financial market, focus on wholesale customers that can buy their base consumption for a longer future timeframe based on prior analysis. This base consumption can be bought for years at a time to ensure lower prices from producers. On the next-day market, electricity is traded on an hourly basis for the coming day. The market functions as an auction where producers and consumers/suppliers decide upon the final hourly rate based on consumption and production forecasts. The next day market aims to meet future demand as closely as possible. However, changes in consumption, weather or operational issues can always affect the production and demand of electricity after the next-day market has closed. The intra-day market provides an option to fix these issues by altering hourly rates up to 30 minutes before the start of the hour. The reserve markets (FCR-N and FCR-D for frequency control and aFRR for frequency restoration) and manual Frequency Restoration Reserve (mFRR) aim to keep up the balance of the electricity consumption and production constantly to control and restore frequency. Thus, these markets provide the security needed to keep up electricity transmission in case of infrequencies in supply.

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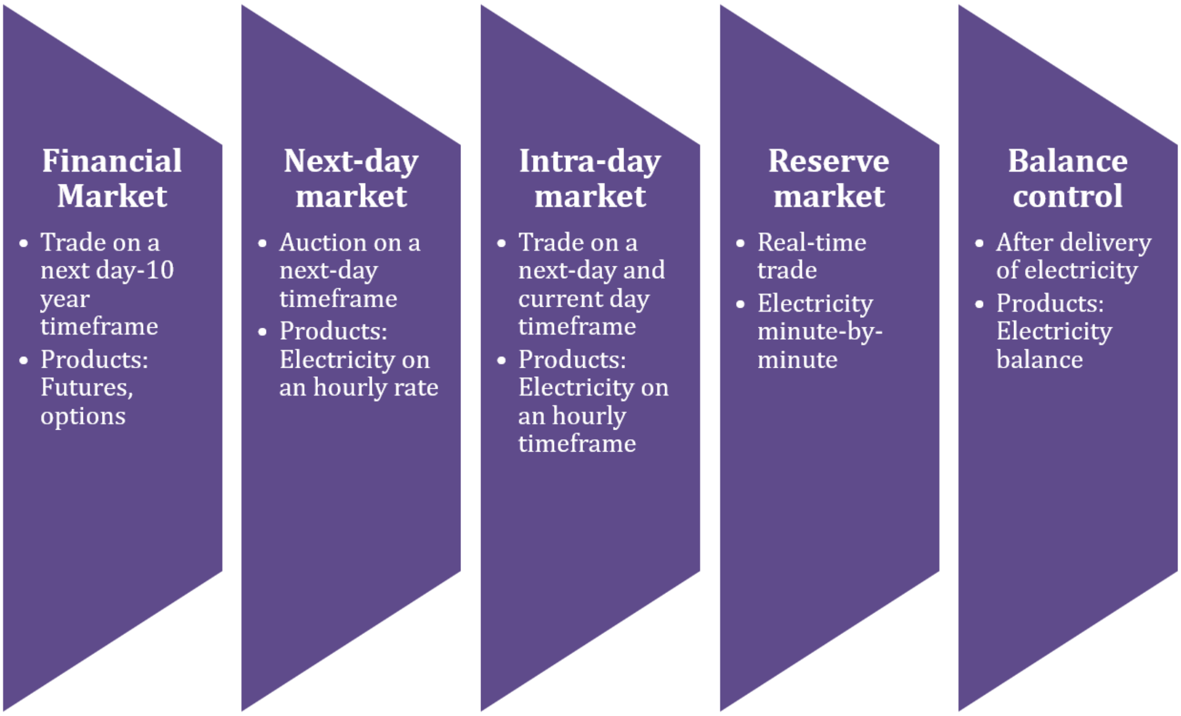

Figure 21: The Finnish electricity market

After the delivery of electricity, the balance control calculation phase aims to identify the market actors that have caused issues in market balance due to differences in traded and final supply or demand. In this way, the costs of miscalculated electricity can be billed to the correct market participants.

From the viewpoint of the general Finnish consumer, the Finnish electricity market is partly a regulated natural monopoly, and partly a competitive market. Every Finnish consumer can freely choose the supplier of their electricity, who in turn procures the electricity sold to the consumer from their own production portfolio or the Nordic market. In turn, the electricity distributor is a single provider depending on the geographical area of the consumer. This distributor charges a distribution fee from the consumer, which is separated from the consumption fee. Even though the Finnish regulation states that connection requirements must be non-discriminatory, the grid operator can still set technical requirements for connecting local generation to the grid.

In addition to the electricity market, Fingrid also handles and maintains the registry for guarantees of origin for all electricity traded within Finland, to comply with the European Energy Certificate System (EECS). All suppliers of electricity must provide information of the origin of electricity that they procure to their customers. Handling this registry is legally required from Fingrid and the handling of this requirement is overseen by the Finnish Energy Authority. These guarantees can also be traded between countries via a registry handled by the Association of Issuing Bodies (AIB).

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10.2.2 Energy communities

In addition to the current Finnish electricity market, a look into the current energy community regulation is needed for a full regulatory picture. This is especially important as slow but constant changes are happening in enabling energy prosumers and energy communities via regulation, which are a key opportunity for blockchain solutions in the future. As interest rises in implementing peer-to-peer platforms like Uber or AirBnB in the energy industry to facilitate solutions such as VPP's and energy communities, the slowly changing energy community regulation comes forward as a significant barrier in implementation. This also affects the adoption of blockchain within the energy field, as the technology has mostly been pioneered in decentralized peer-to-peer applications due to its nature. These barriers differ on the country in question, a problem also seen with the other peer-to-peer platforms, AirBnB and Uber, mentioned previously.

In Finland, a major ongoing change is the easing of regulation in relation to electricity distribution between consumers within one housing association (HOA). An amended Government decree on the determination of electricity supply and metering, enacted in January of 2021, has defined energy communities, active consumer groups and new service models for electricity net-metering within Finnish law. This allows for the generated electricity to be distributed between all the residents within one housing association. Before this amendment, housing associations could only use locally generated electricity for the electricity consumption of the association itself (i.e., elevators and stairwell lighting), while all extra electricity had to be sold to the grid. Thus, all solar electricity systems could only be optimized for HOA use as selling electricity was deemed unfeasible due to distribution fees and taxes exceeding the value of sold electricity. However, as of yet, it is not possible to distribute any extra electricity generated between properties without connecting via the local grid operator, with one exception. This exception, as defined by the Finnish regulation, allows for one production unit to connect to one consumer via a direct line between the two. This disallows connecting another consumer to the original consumer and connecting two prosumers via bi-directional power lines. Figure 22 below shows a representation of the old (on the left) and new (on the right) possibilities of local electricity production under Finnish legislation.

Figure 22: Explanation of the Finnish local electricity production legislation before and after changes

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10.2.3 Heating

Differing from the Finnish electricity market, the heating market is a more competed market where consumers can choose local heat production or the use of on-site excess heat instead of joining the district heating system. Within the district heating market, different areas are usually served by different heating/cooling providers. However, this is more due to the infrastructure costs of implementing a competing network within the area than any district heating regulation. Thus, consumers are also not required to connect themselves to the local provider and can choose to implement any heating/cooling solution that they deem beneficial. In addition, all customers can disconnect themselves from the local network without paying any additional fees.

In addition to the registry for guarantees of renewable electricity, the REC system will be expanded to gas, hydrogen, heating, and cooling, according to the new certificate of origin act that came into effect on 3.12.2021 [76]. The Finnish Energy Authority will handle the registry for renewable heating and cooling, and all needed actions will be handled via a registry application to be released on 1.4.2022 [77]. This registry system will divide heating and cooling between renewably produced and excess heat -based heating and cooling. According to the new government decree on guarantees of origin, the certificate should include the following information [78]:

- Name, location, type, capacity, and date of operation of the energy production facility.
- Specification on whether the certificate concerns heating or cooling, and whether the energy is produced via renewable energy or excess heat.
- Energy source of produced energy.
- A mention if the production facility has received support for investment and the type of funding.
- Date and country of origin for the certificate.

As with renewable electricity, the obligation to provide proof of origin can concern the seller, user and producer of energy, when energy is sold or marketed as renewable, or when produced energy is notified to be renewable [77].

As with electricity, the current district heating market is heavily expanding towards a more decentralized distribution of generation resources. Current technological innovations focus on lower-temperature loops, geothermal energy, increased use of excess heat within the DH system, industrial-scale heat pumps and DSM. The effect of this development to the current district heating market structure remains to be seen.

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10.2.4 Analysis on the legal framework

The energy field provides a unique issue for blockchain, as the field has traditionally been dominated by centralized utilities, providing electricity and heating to residents via a transmission system from centralized generation. This is especially true for Finnish cities such as Espoo, where district heating has been the go-to choice for heating in densely populated areas. Currently, approximately 50% of all new construction is heated via district heating [79]. In the electricity transmission sector, the Finnish electricity market act notes that transmission and distribution is reserved to permissioned operators, unless the distribution happens within a single building or between a small-scale generation system and building via a single power line. In addition, the Finnish energy authority will provide a geographical area of responsibility for the distribution operator, where the operator is also the sole distribution provider for consumers. The electricity market act provides an option for a closed distribution grid, but notes that this grid is only appliable for geographically limited industrial or commercial areas, where electricity is not transferred to consumers. As the DSO is the sole provider of electricity in a certain area, the act also includes certain obligations. These include obligations on non-discriminatory provision of electricity, requirements for the development of the grid and limits in the raise of distribution pricing. These requirements aim to ensure the development of the grid and healthy competition within a system that is essentially a natural monopoly due to regulation, geographical and infrastructural constraints.

Within the energy sector, blockchain has most often been seen as a technology that enables the expansion of P2P trading of energy without a central operator. Thus, major questions arise on how to regulate a technology that is remarkably different from the current system. Questions on responsibility of supply, data security, contracting and possible monetary compensation need to be addressed as the operational system of the distribution grid changes. Within a sparsely populated country such as Finland, the security of supply across the country is also an issue to be cleared. If regulation is changed, how can we ensure that rural customers have the same rights to supply as urban customers? Who is responsible for transmission at all times to areas with little population, and thus little interest from market players? These areas could produce energy on-site, but the security of supply should still be ensured in the case of a loss of power.

In addition to the energy-related regulation, blockchain solutions should also abide with other Finnish regulation. Issues such as the blockchain technology, virtual currencies, virtual identities, and smart contracts are still new and innovative, and thus are not heavily identified in current regulation. Regulation needs to provide trust to a very new and currently untrusted financial form, while accommodating to the different forms that it can form as. As can be seen from regulation in other nations such as Estonia, the regulation of virtual currencies should heavily depend on the type of the currency itself. In addition, taxation of funds gained via blockchain enhanced services should be harmonized, considering the opportunities that virtual currencies can provide. Currently, virtual currencies are taxed according to their value in euros. Thus, the value of tokens is tracked in euros even if the token is solely traded within a single platform.

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10.3 Smart Contracts

As smart contracts are a key technology of blockchain solutions, with possible large-scale implications to current contractual law, a short section on smart contracts is necessary within the legal framework analysis. When compared to traditional contractual arrangements, smart contracts can provide new benefits and new challenges. On one hand, smart contracts are automated and dynamic. The code will rigidly ensure compliancy by contractual rules, that can change dynamically by pre-set conditions without the need for outside interference, while code can be added or removed with ease if an agreement is made to change the contract. However, smart contracts are also transparent within most current blockchain solutions, leading to a lack of privacy, while contracts written by code might not be the most legible system for a large portion of the current population, even if compared to the current legal prose. In addition, as transactions made within blockchain solutions are difficult to alter after completion, and the decentralized blockchain system makes it difficult to halt a contract after its implementation, mistakes made within smart contract code or a missing self-halting mechanism for the contract can be costly for the participating actors.

From the regulatory standpoint, smart contracts are not inherently different from traditional contractual arrangements. In both cases, two or several partners reach an agreement, which is then recorded in a written form. In the case of a smart contract, this written form is in code which automatically handles the contract, while in traditional contracts this is often a written and signed agreement, which is then interpreted by the different partners within their activities. Thus, these both types of contracts can also complement each other, as the more rigid smart contract can automate certain parts of a written contract, such as the change of goods and value, while written contracts can be utilized where they work the best, being the less rigid, more contextual agreements within a contractual relationship that does not easily fit the rigid format of code. In prior research, it has been noted that a certain vagueness within contracts can lead to more efficiency, as future obligations and responsibilities can be stated via flexible denotations that leave space for a later decision of best course of action [80]. Thus, hybrid contracts that combine these two options into a cohesive package could be the best option in implementing smart contracts on a large scale.

Within the U.S. the partners of a contract can freely decide upon the form of the contract, and a contract is binding if it can be proven that the partners have set a contractual arrangement [14]. This same principle is the basis of Finnish contractual law. Known as the freedom of contract, Finnish law notes that all people have the right to choose whether they enter a contract or not, and they have the right to choose the type of contract, its content and format [81]. This contract can be written or spoken but spoken contracts can lead to disagreements that become a word-against-word argument [81]. By this account, smart contracts can also be seen as binding contracts, if all partners have made the decision on entering a contractual arrangement, and a smart contract has been decided upon as the type of contract for this arrangement. However, if a disagreement is reached on the contract and its validity, a court will decide if all parties have obliged to the arrangement. The fact that a contract is written in code instead of text should not be a factor in this discussion.

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11. Conclusion

According to the literature review made within the SPARCS project, blockchain can provide several valuable benefits to the energy sector. However, blockchain still has weaknesses that need to be addressed to ensure future development and new services. Identified benefits and weaknesses include the following:

Benefit	Weakness
Transparency	Irreversibility
Multi-party consensus	Lack of privacy
Fast settlement time	Energy intensity
Verifiability	Slow clearance time
Reduced costs	Digital blockchain in a physical energy sector
Automated	Lack of knowledge for development
Security from manipulation	Lack of knowledge creating distrust
Reduced geographical constraints	User friendliness
Security through decentralization	Regulational challenges
	Investment needs
	Cybersecurity
	Lack of standardization

Table 8: Blockchain benefits and weaknesses (see section 6)

However, it must be noted that blockchain is a tailored solution for certain use cases and is not necessarily a good upgrade for every situation. Thankfully there are projects, studies and reports that have aimed to identify different use cases that are deemed useful for blockchain solutions. Conditions for a good use case have been identified, and include the following:

- Shared databases between multiple parties, where all need to view common information.
- Multiple parties need to record and change data in the database.
- All participants need trust in the recorded information.
- A third party as a central authority adds unnecessary costs and complexity.
- Reduced settlement times has a business benefit.
- Transactions interact between each other and depend on each other.

In short, blockchain heavily focuses on solutions where several different parties need to track and change data without a central authority, while needing trust in the state of the system. Within use cases that fall under this spectrum, blockchain can provide direct benefits to stakeholders. In addition, the chosen blockchain architecture can have influence in the suitability of blockchain for the chosen use case as well. Public blockchains, including the most famous examples such as Bitcoin and Ethereum, have been deemed unbeneficial for solutions within the energy sector due to issues with scalability, energy use and privacy. However, consortium or enterprise blockchains with differing consensus mechanisms, such as PoA and PoS, could provide a good basis for

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blockchain-based solutions. These solutions can also provide more privacy as access to other users' transactions can be limited.

These weaknesses can be divided between three broad categories: technical, regulatory, and knowledge-based constraints. The key technical challenges for blockchain revolve around the scalability of the solution for large-scale implementation within the energy sector. Issues within scalability include slow transaction times due to divided consensus, the energy intensity of current solutions, and the computational power needed for PoW solutions. However, technical solutions have taken a large leap in recent years, and several solutions for these issues have been identified. Still, implementing blockchain within the energy sector will need large investments within physical hardware such as smart meters, while also interfacing with current solutions as blockchain is implemented in parallel. These can still provide technical and economic issues as the scalability issues are solved.

The regulatory issues focus on the need of blockchain solutions to fit in with the current financial, data privacy and energy-related regulation within Finland, the EU, and internationally, which has been deemed difficult due to the inner philosophy of blockchain as a service. Knowledge-based issues were identified for the energy industry itself and the users of energy services. Even as new pilots are implanted and new companies show interest in blockchain solutions, several stakeholders still identify a lack of knowledge within the sector. As the knowledge of other actors increases, customers, the key users of developed solutions, can still have a lack of interest due to a lack of knowledge. This issue, combined with the increased amount of customer responsibilities within these solutions, can lead to a lack of traction when pilots are scaled up to marketed services.

Based on this analysis on the benefits and weaknesses of blockchain, a SWOT analysis was developed. The identified Strengths, Weaknesses, Opportunities and Threats are given in the table below.

Strengths	**Weaknesses**	**Opportunities**	**Threats**
Automation for more streamlined processes	Scalability and energy use of current most-used solutions	Enables increased local and decentralized solutions	Problems with accommodation to local regulation
Consensus on transactions and system state without a central authority	Technology still in early development especially for the energy sector	Increase energy citizenship by data services for citizens, and local collaboration	Reduced employment and community engagement due to automation
Tracking and verification of data	May require physical changes to devices, incurring costs	Boost local investments on renewables	Competing solutions taking ground faster than blockchain
Transparency of data if needed	Energy intensity	Provide verified and certified renewable energy	Solutions for challenges changing the inherent nature of the technology

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Reduced operating costs	Lack of knowledge within the energy field currently	Increase security of data	Distrust from consumers and workers within the field due to lack of knowledge
Security from manipulation and outer attacks on integrity	Heavily focused on decentralized systems	Automation of contracts between stakeholders	Lack of knowledge could lead to unnecessary expectations and projects
		Enables discussions on the energy sector from a different, more customer-centric viewpoint	

Table 9: Blockchain SWOT analysis (see section 7)

By combining the SWOT analysis made based on the analysis on positive and negative aspects of blockchain and an accompanying literature review, opportunities of blockchain within the applied themes could be investigated. The aggregated table of all opportunities and their links to the City and Kera contexts, as seen in section 9.3, is given below for quick access.

Opportunity	**Applicable for Kera**	**Applicable for city strategy**	**The city's role in development**
P2P digital transaction platform	**Direct** (District energy market, local energy trading)	**Indirect** (Digitalization, local energy production)	**Pilot platform**
Renewable certifications for energy use in public/private premises	**Indirect** (Solar electricity, local trading of energy)	**Direct** (Openness of services, digitalization, and data analysis**)**	**Central role as procurer of development project and future user**
Automated provision of information towards regulatory or contractual compliance	**Indirect** (District energy market, local energy trading)	**Indirect** (Sped up services)	**Central role to no/small role**

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Enhanced IoT devices, to provide benefits in tracking and tracing of data	**Direct** (Smart infrastructure and IoT, 5G sensors and data platform)	**Direct** (Digitalization, data analysis, openness of services)	**Pilot platform and future user**
Real-time energy data platform to local consumers and producers	**Indirect** (Demand Side Management, Virtual Power Plants)	**Indirect** (Digitalization, data analysis, resident-oriented Espoo)	**Pilot platform**
Crowdfunding schemes for renewable investment	**Indirect** (Solar electricity)	**Indirect** (Promotion of resident and partnership-based activities, local energy production)	**No/small role**
Support platform for small-scale producer aggregation and energy market entry	**Direct** (Virtual Power Plants)	**Indirect** (Digitalization, data analysis)	**Pilot platform and future user**

Table 10: Blockchain opportunities for Kera and the City of Espoo (see section 9.3)

The analysis on the blockchain opportunities has provided three options with direct links to the goals of the Kera district development process, P2P transaction platforms, enhanced IoT devices and aggregator support platforms. The analysis also provided two opportunities with direct links to the Espoo city strategy, renewable certifications and IoT devices for the streamlined use of data. The city's role was deemed to differ heavily between opportunities and projects. However, a central role was perceived to be possible in renewable certifications and regulatory compliance, while the city can serve as a pilot platform for several other opportunities as well.

Finally, an analysis of the legal and regulatory framework around blockchain was provided. In short, the Finnish regulatory system is still in its infancy in accounting for blockchain, which can be a hindrance when combined with the quite strict regulation around energy especially in the power sector. Still, blockchain could have possible use in energy sectors such as heating, aggregator business and renewable certification while the main opportunity, P2P trading of energy, becomes available via Finnish regulation.

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