ELECTRICITY AND BLOCKCHAIN: HOW ADVANCED TECHNOLOGIES ARE ACTIVATING PEER-TO-PEER ENERGY MARKETS

by

NOLAN MAYFIELD

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Approved: *Alex Murray, Ph.D.*
Primary Thesis Advisor

Blockchain technology has been at the forefront of technological innovation for several years and presents a fascinating emerging technology to assess. Due to its cost savings, security, and reduced transaction times the technology has the potential for substantial disruption. The energy industry happens to be ripe for disruption, as an industry that has undergone a distinct lack of innovation over the last several decades. The goal of this research piece is to produce a technical snapshot of how blockchain is enabling innovation in the energy sector. In particular, I assess the use of blockchain in activating novel peer-to-peer energy markets. As primary sources, I assess three business whitepapers of early moving startups in this space. Rather than performing a wide analysis, I focus on creating a granular technical review and assessment of these three case studies. Following a careful evaluation, I triangulate the results and detail the benefit of dual-layered blockchain platforms, which consensus protocols appear to be leading, and how early movers are developing competitive advantages. I also expand my findings to recommendations for new entrants in this space. I recommend utilizing the tokenization of energy, using AI and machine learning to remove human agency, and employing centralized actors as network decision makers.

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Chapter 1: Introduction

In 2011 only 16,000 electric vehicles (EV) had been sold in the United States. By December 2020, this number topped 1.7 million, and by mid-2021 over 2 million had been sold. These figures help illustrate the massive progress the US (and the world) has made towards decarbonization in the last decade. Comparing 2020 to 2011, the US now produces 23 times more solar energy, 3 times more wind energy, and has 18 times more battery energy storage (Dutzik, et al). A revolution is occurring in the energy space, and it continues to gain momentum. However, while progress is being made, the numbers also demonstrate just how far we must go. In 2021 alone, solar accounted for less than 3% of US electricity scale electricity generation (EIA, 2022). Fossil fuels, on the other hand, accounted for over 60% of electricity generated. While renewables move the US closer to a carbon-neutral future, they also create a host of other complications. For example, renewable energy does not generate in response to energy demand. As such, the US grid continues to rely on carbon-dense energy sources and lacks the flexibility to maximize renewable energy usage. Ultimately, a case is made for blockchain-enabled energy trading as an important technology.

The rise of prosumers and distributed energy resources (DER) holds promise in increasing grid flexibility (Anisie and Boshell, 2020). My research lies at the heart of this development in the energy markets. I examine companies creating products that connect DER to the grid and enable peer-to-peer (P2P) energy trading amongst various market participants. I aim to use energy as a case study for how technologies are being used to facilitate these micro markets. Specifically focusing on blockchain technology, I hope to understand the advantage of this technology in activating new markets.

The energy sector presents an ideal ecosystem to study the impact of blockchain, as blockchain has the potential to avoid the curtailment of renewables and support the efficient operation of electricity markets. Our daily life is predicated on the assumption that our cars will charge when we plug them in, our WIFI will work, and our lights will turn on. On Maslow's hierarchy of needs, electricity has nearly become a physiological need. Our national security depends on the safety of our electric grid, and our future will be defined by it. Paramount to the prevention of climate change is decreased reliance on fossil fuels and carbon-rich energy sources. The urgency to save our planet has never been higher. Nevertheless, the energy industry has been one of the most resistant sectors to change. It is widely known that stiff regulation has stifled innovation in the energy space. I consider immense carbon emissions and a historical lack of innovation two multipliers for the disruption blockchain may cause in the energy space. The technology has the potential to reorganize the energy infrastructure landscape dramatically, and while this is likely years or decades out, I am eager to discover how it may come about.

Purpose of Study

Exploding into the mainstream over the past decade, blockchain technology has been a wildly popular subject amongst most tech communities. Looking back, many describe blockchain as a "solution looking for a problem". Even in 2022, blockchain is still working to prove itself. Most know blockchain technology for its affiliation with the viral cryptocurrency Bitcoin, but the technology holds far more potential as a tool in the digital revolution. In simple terms, a blockchain is a shared, immutable ledger that facilitates the process of recording transactions and tracking assets in a business network (IBM Blockchain). Businesses are adopting the technology worldwide to create tamper-proof ledgers, without a central authority or government, that can only be accessed by permissioned network members. The benefit of transparent, trusted transactions is incalculable, as modern businesses run on information. The faster and more accurate this information is, the better the business.

The purpose of this study is to conduct a deep dive and create an intricate, technical “snapshot” of how blockchain is enabling emerging P2P energy trading platforms. I hope to create a succinct and digestible study to improve understanding of how blockchain holds real-world applications outside of crypto. This research study treats the energy industry as a case study for blockchain. I aim to get deep into the weeds of how new P2P markets are being developed and am working to identify where blockchain is providing value on a granular level. By studying the early formation of new micro-markets, I hope to uncover the comparative advantages of new advanced technologies. While blockchain is my core focus, I will also be assessing AI and machine learning as they come up for comparative analysis. Communicating these rapidly developing benefits in energy and deriving insights can provide value to other industries, potentially informing supply chain or medicine companies on how to implement these technologies.

Research Questions and Methodology

The overarching goal of this study is to perform an archival review of technical business documents to understand how blockchain is activating P2P energy markets. I aim to understand a uniquely complex underlying process and mechanism. I assess three case studies by close reading and coding their business whitepapers. These documents are primary source documents in which the company describes its software systems in the greatest possible transparency and depth. These are the “north star” when it comes to my research. The business whitepapers I assess directly pinpoint the intersection of blockchain and energy, providing an ideal source. Following the assessment of these documents, I triangulate my three case studies with each other. I look to find patterns and derive insights as to how blockchains solve different problems. My research will be entirely qualitative, as a research project of this nature, with targeted, probing research questions does not lend itself well to a deductive design. An inductive approach is a better fit. My observations lead to generalizations and explanations, offering rich qualitative information.

Before my formal research, I performed six exploratory interviews with P2P energy trading professionals. These interviews are not included in my research and were used to orient myself within the industry. From my exploration, I formed my core research question, “how is blockchain technology assisting the activation of P2P energy markets?”. I recognize that in some cases fully answering this question will be impossible, but I aim to get as close as possible. A myriad of other considerations come along with this, including, how is data aggregated and collected? Which consensus protocol was chosen and why? Is there a hardware product? And how is the blockchain solution structured? I aim to create a holistic technological review of how these systems operate to triangulate them as best as possible.

I prioritize depth over breadth in my research, and only assess three startups developing P2P markets. The number three was chosen to provide a sample just large enough to enable triangulation and comparison while providing as much evaluation as possible. There were certainly more than three whitepapers to choose from when picking my cases. I initially identified 15 whitepapers to assess and narrowed these down using two key considerations. First, I narrowed whitepapers down to those that offered P2P energy trading as the core product offering. This eliminated many startups from the mix, as most startups offered P2P capabilities in conjunction with their product portfolio. While the companies I chose do offer other services, P2P trading is their primary product. Of the remaining qualified whitepapers, I then narrowed them down to three with a considerable description of their blockchain structure. Considering my research lies at the intersection of energy and blockchain, I sought maximum information on both. The framework I use to assess my cases is, however, meant to be used by others. I hope that my research will be continued and applied to any cases I missed, as well as new market makers entering the space.

Literature Review

When it comes to the literature regarding blockchain in the P2P energy trading space, there is a small body of work that is continuing to quickly grow. Materials generally range from highly theoretical to highly technical, with few offering the necessary background for a newcomer to the space. The Institute of Electrical and Electronics Engineers is highly active in this space, publishing extensive literature on smart contracts and consortium blockchain-enabled P2P energy trading. What perhaps differs in this space, compared to less-business-related topics, is that much of the relevant research is published by consulting firms, technology incumbents, and company blogs. Some of my sources came from recognizable companies such as Deloitte and IBM. On LinkedIn, there are several prominent thought leaders. Dr. Jemma

Green, the CEO of Powerledger, is one such example. Her posts on LinkedIn have been influential in shaping my understanding of P2P products and keeping up with developing trends.

If there was one piece of work that influenced my research more than others, it would undoubtedly be *Blockchain technology in the energy sector: A systematic review of challenges and opportunities.* This is “one of the first academic, peer-reviewed works to provide a systematic review of blockchain activities and initiatives in the energy sector” (Andoni et al, 2019). The study reviews 140 blockchain research projects and startups across the industry, briefly reviewing them and systemically classifying them in different fields of study. It was from this literature that I understood the technical challenges blockchain technology could solve in P2P energy markets. From this literature, I also extracted a list of 50 projects identified as “decentralized energy traders”. It was from this initial list that I eventually narrowed it down to my three specific use cases. While Andoni et al do an excellent job creating a sweeping, broad review of blockchain projects in the energy space, the research does lack depth into each use case. I expand upon this research by providing more depth. Instead of going for quantity, I aim for a closer review.

I hope to see more academic professionals weigh in on the intersection of blockchain and energy, and specifically P2P energy trading in the future. With this research, I aim to contribute towards and foster a more robust group of academics researching blockchain in P2P energy markets. Research literature in this niche is laying a foundation for more extensive works to come.

Chapter 2: Energy Sector Context

Introduction

Beginning to understand the energy sector is no simple feat. The industry is bursting with buzzwords, acronyms, and concepts unfamiliar to the casual reader. I do my best to describe the fundamentals of the industry in a comprehensible way, beginning with the economics of the industry and steadily zooming in, and including as much relevant terminology as possible. In this section, I ultimately discuss the problems requiring innovative solutions in the energy industry, and why a decentralized P2P energy trading platform holds promise for solving these issues.

Natural Monopolies

An introduction to the energy sector begins with understanding one consideration: most energy markets are regulated natural monopolies. Creating the necessary grid infrastructure to supply power is extremely expensive, and once installed, the per-unit price of power goes down with each additional consumer. In effect, the more consumers that use an energy utility, the more the fixed costs are shared. Should multiple companies be duplicating these fixed costs and competing for consumers, it would drastically increase the price of electricity. Considering this, the energy sector has regional monopolies that own their market and drive down costs. Historically, this also means the energy industry has been unwelcome to innovation. Stiff regulation protects the sector from change, the same monopolies have dominated the industry for decades, and the US energy grid has changed very little in the last 100 years.[1]

Wholesale vs Retail Electricity Markets

A concept core to understanding energy markets is the difference between wholesale and retail energy markets. The difference here is simple in theory but much more complicated in practice. Described as simply as possible, wholesale markets are business-to-business (B2B) markets where suppliers sell large quantities of energy to retailers. As the name suggests, retail markets are business-to-consumer (B2C). Retailers purchase energy from wholesalers, distribute it to end-users, and sell it for a profit. Within these two markets, and admittedly, varying from region to region, these market structures differ.

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[1] Stiff regulation is, however, needed to reliable and affordable service. Otherwise, monopolies would be free to extract 100% of the economic surplus.

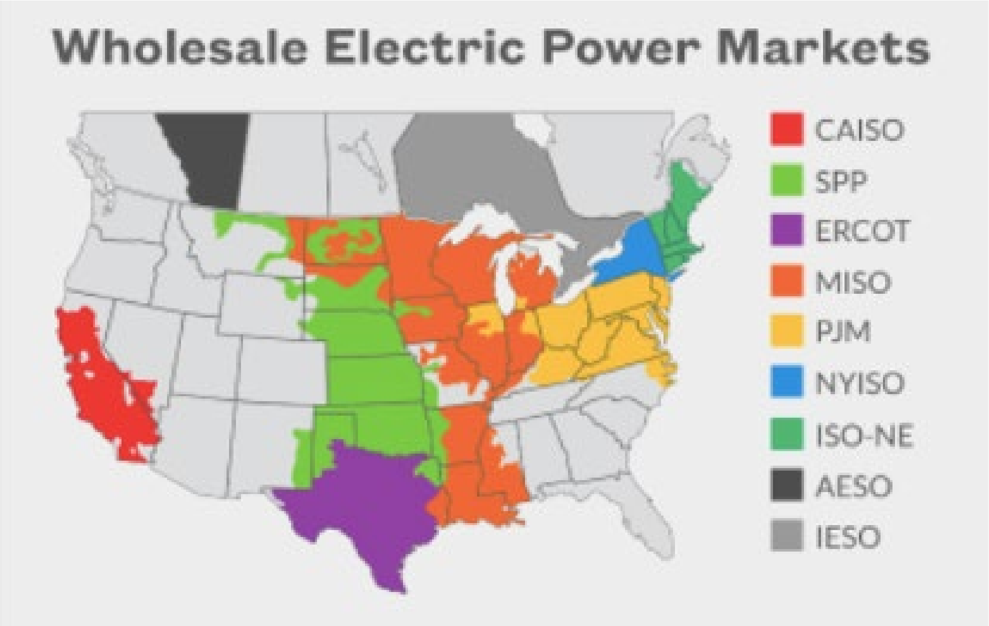

Figure 1: Map of Wholesale Electric Power Markets in the US

To understand how these markets can form it is useful to have an example, and in my opinion, the US provides one. In the US, the Federal Energy Regulatory Commission (FERC) provides federal oversight of all electricity markets. FERC sets policies in place that reduce the risk of major power outages. As a result of FERC, power generators, utilities, and transmission owners banded together in the 1990s into Independent System Operators (ISOs). These are private and non-profit organizations that have FERC approval to oversee the dispatch, generation, and distribution within their jurisdictions. As depicted by the colored areas in Figure 1, there are 7 ISOs in the US, that cover approximately 2/3s of the US and 214.8 million people (Barron, 2019). These regions are unique in that ISOs manage a competitive market for energy supply. In these regions, the market sets the price of energy, and it fluctuates between different areas. In wholesale markets, the retailer is the consumer. Consumers (retailers) have "consumer choice" and can choose from a variety of electricity suppliers. In the other 1/3 of the US, the wholesale market is vertically integrated. In these more regulated areas, mainly the West and the Southeast, consumers can only purchase electricity from one public supplier.[2]

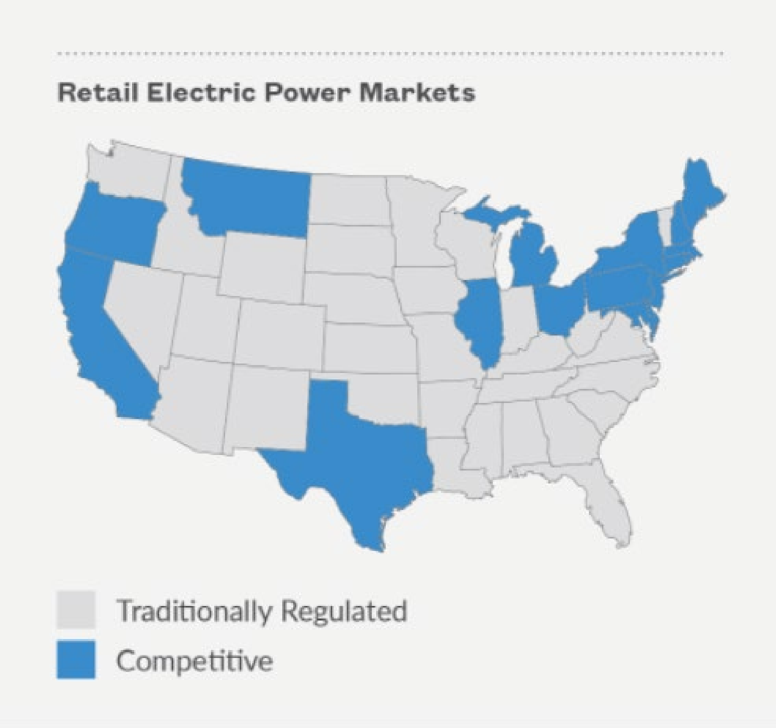

Figure 2: Map of Retail Electric Power Markets in the US

On the retail side of things in the US, things continue to get complicated, as there are also regulated versus non-regulated regions. This does not correlate to whether that same region is vertically integrated or deregulated on the wholesale side. A region can be regulated in retail and wholesale, deregulated in one and not the other, or deregulated in both. The same principles described in the wholesale market apply to the retail market in terms of these implications. If a retail market is deregulated, consumers (in this case homes and businesses) can purchase from a variety of competitive suppliers. In the regulated regions, they must purchase from the incumbent utility

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[2] In this case, consumers would be retailers.

monopoly. The division between regulated and deregulated retail markets can be seen in Figure 2 (Barron, 2019).

Suffice to say, electricity market regulation can be very complex. A solution to said complexities is “regulatory sandboxes”, in which regulators create controlled testing grounds for innovative P2P energy trading solutions to be tested and iterated under supervision. Thailand is one such example, with the Energy Regulatory Commission adopting measures for limited P2P energy trading deployments (Beckstead et al, 2021).

Centralized vs Distributed

In recent years academics, innovators, and legislatures are beginning to consider that decentralizing the energy market may benefit the consumer. With so many words starting with “de” in this industry, what does decentralization mean in this context? To be concise, decentralization means less large-scale, public renewable energy generation, and more individual investors producing energy near consumption. The rise of rooftop solar, EVs, and batteries are all decentralized assets (Baral, 2021). In effect, DERs are synonymous with decentralized energy assets.

Germany is an excellent case study of the tension between a centralized and decentralized approach to renewable energy. While Germany has the highest penetration of variable renewable energy (VRE) assets in the world, it also has the highest costs for electricity in the world. Taking a centralized approach to renewables, Germany built expansive solar capabilities in Northern Germany and transports this electricity to the bulk of its population in the South. In transmission, a significant portion of this electricity is lost which hurts the consumer and drives up prices (Kalkine

Media, 2021).[3] In a decentralized market, energy costs would be significantly lower. As prosumers produce and consume energy in the same location, electricity wastage is minimized as there is significantly less transmission.

Grid Flexibility

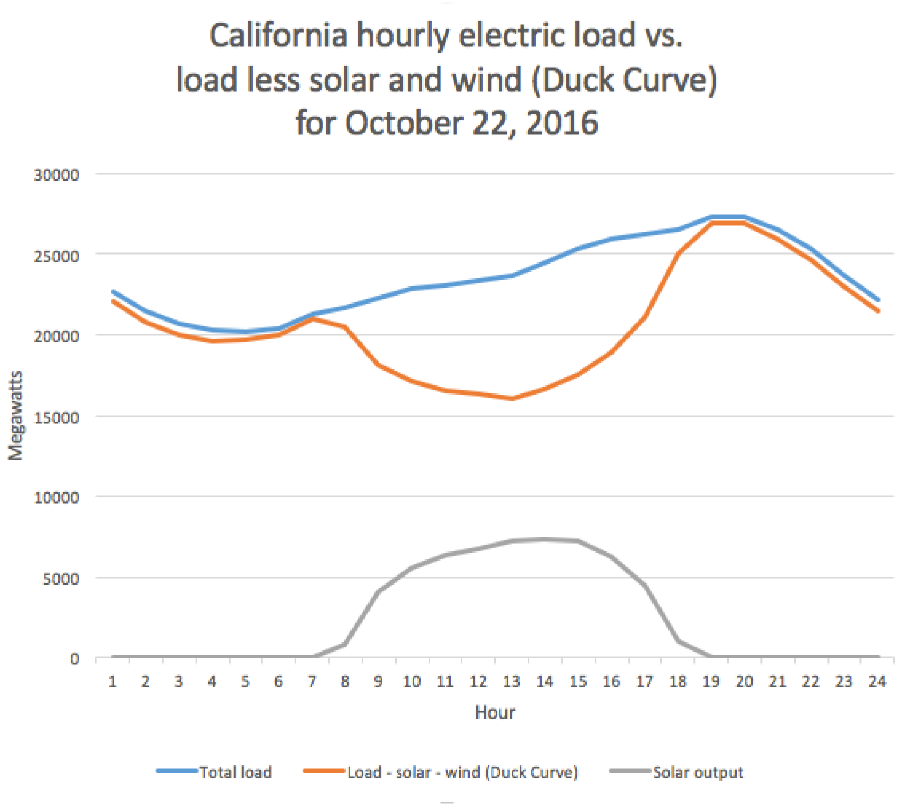

Figure #3: California Duck Curve

Renewable energy sources create a variety of complications, one of which is the issue of dispatchability. Non-renewable energy sources are highly predictable. A natural gas power plant produces the same kilowatt-hours of energy every hour of every day and can be scaled up or scaled down to meet energy demands. Solar and wind are quite the opposite. On a scorching hot summer day, when AC units are being pushed to their

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[3] It is worth noting Germany's increased prices are not exclusively caused by transmission losses and congestion. As an early mover, Germany deployed wind and solar when industries did not have scale were expensive.

highest in the afternoon, there may not be an ounce of wind. Similarly, when energy demand is at its highest in the middle of a winter night due to residents turning up their heat, photovoltaic (PV) produces no energy (Roberts, 2018). This imbalance between peak demand and renewable energy production is commonly referred to as the "duck curve" and is depicted in Exhibit A (Confronting the Duck Curve, 2017). From 8 am to 6 pm, solar and wind generate clean energy that reduces the need for dispatchable power. Once wind and solar taper off in the evening, grid operators must once again ramp up dispatchable power to meet demand.

The varying demand for electricity combined with the variable generation of renewable energy creates a uniquely complex problem. The problem that the duck curve represents can be succinctly referred to as "grid flexibility". In short, this refers to the capability of a power system to shift and modify generation and load during uncertainty, resulting in increased grid efficiency, resiliency, and the integration of variable renewables into the grid (Brasington, 2020). In other words, if the US power system can perfectly match electricity demand to renewable energy generation, the grid could become entirely carbon neutral. For this to occur there is a need for energy storage, and while industrial energy battery storage is growing in the US, the technology remains extremely expensive.

The Promise of P2P Energy Trading

An alternative to industrial energy batteries is needed to increase grid flexibility. To understand how P2P energy markets may form as a solution to grid inflexibility, it is important to first understand the concept of a "prosumer". In modern energy markets, consumers who also produce energy are quickly growing. This could be a residential home, office building, university, or even a shopping center so long as it has energy production capabilities such as rooftop solar.

These prosumers are considered private owners of DER. Simply stated, DER refers to small generation units located on the consumer's side of the meter (AEMC). These resources, such as small-scale solar energy generation or even EV batteries, present an opportunity to revolutionize the energy landscape.

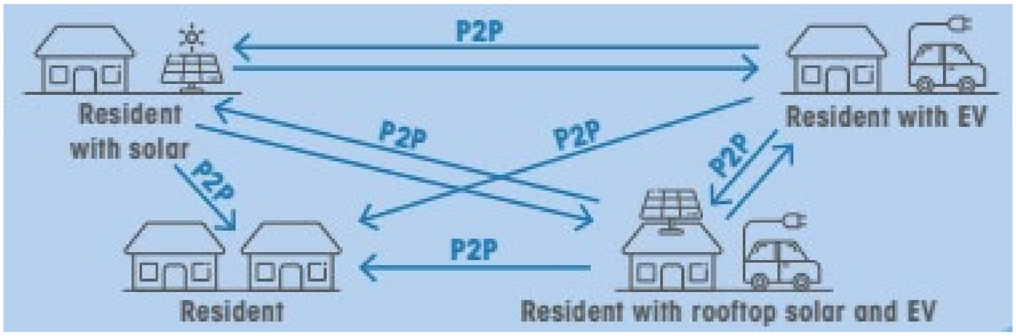

Figure 4: Graphic of a Fully Functioning P2P Market

The growing number of prosumers hold the potential to "firm up" the energy grid and increase grid flexibility. Adding DER to the edge of the grid reduces the need to transmit energy over long distances. Instead of relying on a solar farm hundreds of miles away, consumers can now generate and store their own clean energy onsite. Buildings can communicate with each other to match demand to generation, as participants buy and sell energy to each other in real-time. Using the example of a residential home (Figure 4), a homeowner could choose to sell energy generated by their rooftop solar during peak hours to other consumers (Anisie & Boshell, 2020). Instead of using their rooftop panels to power their home, homeowners could power their homes for a few hours off their EV battery. Doing this a few hours every day when energy is most expensive in the afternoon, consumers could save money every month on their energy bill and save on carbon emissions.

The P2P model truly benefits everyone. Should prosumers create a surplus of energy, they could sell it to their neighbors at a profit and their neighbors would be buying it at a discount. This is due to commodity tariffs utilities place on their energy. Traditionally, when a prosumer created a surplus of energy, they could sell it back to the grid in an event called “net metering”. While this sounds promising, prosumers could only sell their energy at a low “buy-back rate” and when needed, were forced to purchase energy at a tariffed premium (Anisie & Boshell, 2020). By selling P2P, the prosumer can earn profit while the purchaser receives discounted renewable energy. This online marketplace allows prosumers and consumers to preset buy and sell bids according to their preferences, where eventually, a matching trade takes place.

Far from just benefitting the participating traders, this holds a variety of benefits for the power sector. Most apparently, a widely adopted P2P platform would encourage VRE generation and increase grid flexibility. Additionally, however, this kind of platform would improve balancing and congestion management by “helping reduce investments related to the generation capacity and transmission infrastructure needed to meet peak demand” (Anisie & Boshell, 2020). While utilities would receive less VRE from small scale-generators through net metering, this would ultimately help reduce grid congestion. Energy demand is predicted to grow to 47% by 2050, and current transmission networks are ill-equipped for such rapid growth (Gordon & Weber, 2021). In some cases, particularly in isolated rural microgrids, P2P energy trading can even provide energy access for the first time to new users (Anisie & Boshell, 2020).

In Front vs Behind the Meter

The energy industry is rich with acronyms and terminology that are largely unfamiliar to those outside of the ecosystem. While my background on the energy industry describes most of the context of this research study, there are a few other concepts that may be referenced in P2P whitepapers. One of which is the location of an energy system in relation to the electricity meter. Energy production and storage on the consumer side are often referred to as “behind the meter”. This is behind the meter as, although the power can flow through an energy meter before it is used, it usually does not. Examples of energy systems behind the meter include rooftop solar panels, electric vehicles, and battery packs (Boston Solar, 2021). “In front of the meter” is also referenced in this text and refers to off-site systems that pass through a meter before being used. An energy utilities power line would be referred to as in front of the meter, as well as energy generation and storage that feeds the electric grid.

In this ecosystem, you may also encounter references to the “edge of the grid”. This concept is strongly related to behind the meter energy systems. The edge of the grid, grid edge, or even simply the edge, is defined as “the varying hardware, software and business innovations that are enabling smart, connected infrastructure to be installed at or near the “edge” of the electric power grid” (Lucas, 2016). Examples of edge hardware include solar panels, smart thermostats, and smart inverters. This also includes software such as automated demand response and grid optimization. P2P energy trading constitutes a technological innovation occurring on the edge.

Chapter 3: Blockchain Theory

Overview

While my research resides within the energy sector, the heart of my analysis focuses on new advanced technologies such as blockchain technology. This intersection, between energy and advanced technologies, presents a technical research study. To those unfamiliar with blockchain specifically, some education is in order.

Blockchain technology, often referred to as distributed ledger technology (DLT), is a distributed database shared amongst the nodes of a computer network (Yaga et al). It differs from previous electronic databases, in that the data is structured in “blocks”. Each block has a set storage capacity for information, and once it is filled, is strung to the previous block. By chunking up the data in this way and creating strings of data, DLT “guarantees the security of a record of data and creates trust without the need for a trusted third party” (Hayes, 2022). Historically, data is stored in one central location in onsite storage or in the cloud. This leaves it susceptible to tampering, inconsistencies, storage failure, and duplicate records. Blockchain effectively solves these issues, providing:

1. Time Savings – Significantly reduced transaction times achieved by removing verification from a centralized authority.
2. Cost Savings – Items of value can be transacted directly between participants with less oversight.
3. Increased Security – Reduced tampering and fraud due to a transparent shared ledger.

Blockchains are effectively an immutable timeline of data, as each block is given an exact timeline of when it is added to the chain, and the record cannot be altered retroactively without the alteration of all subsequent blocks and the consensus of the network. The value of blockchain, especially in transacting, is profound, “blockchain can be used to verify time, user, transaction data and protect this data with an immutable crypto signed ledger” (Mylrea & Gourisetti, 2017). This offers a myriad of benefits compared to past data storage methods.

Node Networks

Understanding blockchain theory begins by understanding node networks. A node can be defined as computer hardware that adds and verifies transactions while also maintaining a record of all transactions. These connected servers store blocks of data and update each other in real-time (The Times of India, 2021). Any bitcoin mining device is one type of node, as it transmits a new block of transactions to the other nodes in the network and stores it on top of the existing blocks. Blockchain exists on nodes, and it is the structure of this node network that offers the foundation of a blockchain. Node networks are a core distinguishing factor between blockchain networks. While a public blockchain such as Bitcoin may contain tens of thousands of nodes, a private blockchain such as Ripple contains a mere 36. Regardless, every blockchain must utilize a network of nodes to add, verify, and maintain blocks of data.

Permissionless vs Permissioned Blockchains

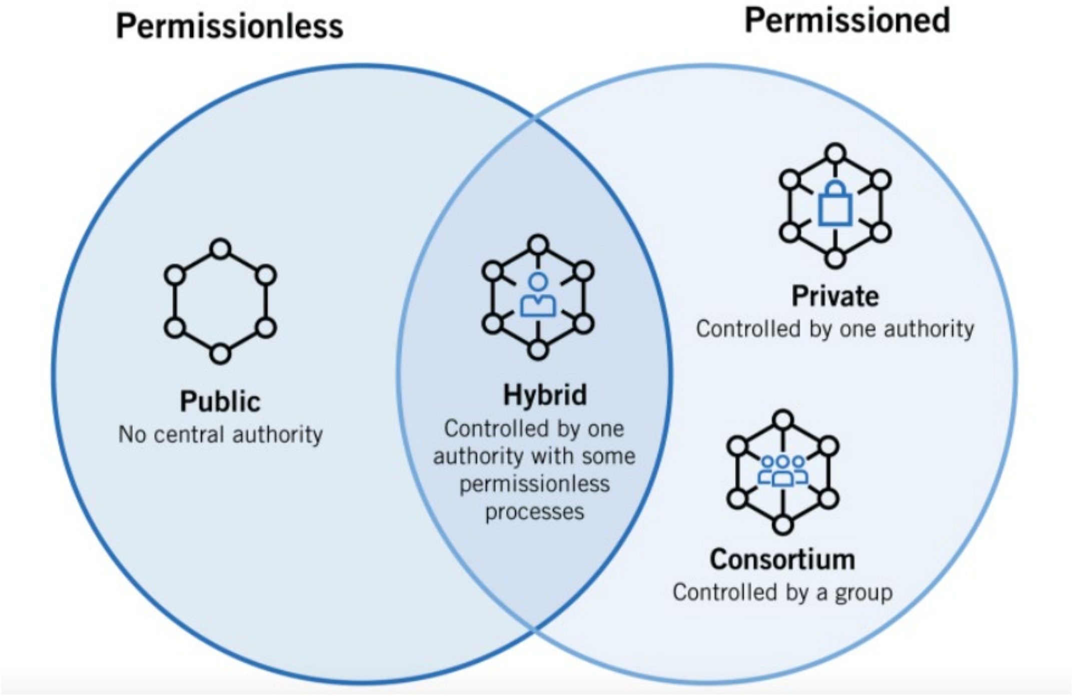

Figure 5: Venn Diagram of Permissionless vs Permissioned Blockchains

As demonstrated in Figure 5 (Wang & Wegryzn, 2021) blockchains are designed in numerous ways. While their structure can be changed in increasingly minute details, the first large division lies between permissionless and permissioned blockchains. Permissionless blockchains allow any partially anonymous individual to join the network and become a "node". These nodes are not restricted in any way and there is a vast number of them. As a result of so many nodes, these networks tend to be the most secure. Bitcoin, for example, is a permissionless blockchain and is known for being unbelievably secure. For someone to compromise the network they would have to gain control of 51% of the network, which is virtually impossible with such an expansive array of nodes. Unfortunately, due to the large number of nodes and transaction sizes, permissionless blockchains do tend to have longer processing times.

Additionally, such large-scale processing capabilities require enormous amounts of energy.

Permissioned blockchains offer a unique mix of public and private networks as they contain elements of both. What makes permissioned blockchains interesting is that, after verification of identity, they allow anyone on the network to perform certain designated activities (Seth, 2021). These specific functions vary greatly case by case, but generally, the power to configure a network by controlling participants' activities is very useful. Perhaps the greatest benefit of this type of platform is a high level of organization and structure. Administrators more efficiently update the rules of the network as nodes work together much more efficiently. Additionally, these networks operate more efficiently. Simply put, the limited number of nodes on the platform greatly reduces the number of computations required to reach consensus and improves performance. In terms of weaknesses, permissionless blockchains are more easily compromised as they rely on a much smaller node network contingent upon member integrity.

Types of Blockchain Networks

Beyond the difference between permissioned and permissionless, blockchains are subcategorized in different ways. Blockchain networks have a variety of "flavors" in terms of their configuration and build, and each configuration fulfills desired business purposes differently. The most common varieties are public and private blockchain networks, while consortium and hybrid blockchain networks are growing in popularity. I outline the differences in these networks as well as the general disadvantages of each.

Public Blockchain Networks

Public blockchain networks are permissionless blockchains that anyone can join and participate in. Bitcoin is a great example of a public blockchain network, as anyone can read, write, and audit activities on the network. Public blockchains are the most decentralized and democratized and encourage new members to join to keep the network agile. In terms of disadvantages, these networks require exceptionally high-power consumption to maintain large public ledgers. There is also a lack of complete privacy which less effectively protects individual identities (Seth, 2021).

Private Blockchain Networks

Private blockchain networks are permissioned, and as such, only allow a selected entry of verified participants. As opposed to public blockchains, private blockchains control who is allowed to participate, execute consensus protocol, and maintain the shared ledger. The private network operator can also edit and delete entries onto the blockchain as they see necessary. While private networks are not decentralized, they often boost trust between participants and build confidence. Private networks are more vulnerable to bad actors, as each individual node's power over the network is significantly higher than public blockchains. It is especially important to maintain member integrity in private networks.

Consortium Blockchain Networks

Consortium blockchain networks "straddle" private and public networks but lean more heavily towards private, permissioned networks. Instead of allowing anybody to validate blocks or allowing a single central authority to select block producers, consortium networks select several equally powerful validators (Singh, 2021).

Consortium networks are more decentralized than private networks, which increases security. However, these networks require a vast amount of cooperation, and often the network's rules can spell its downfall. While consortium networks allow for more efficient cooperation, this can also be immensely complex and logistical. Most often, consortium networks are useful for specific business use cases that require cooperation from a multitude of parties.

Hash Functions

If describing the energy industry was complex, describing blockchain theory makes it look simple. Several fundamental cryptographic theories build upon each other to form a holistic understanding of blockchain. One such example is that of "hashing", which can be considered the backbone of blockchain technology. In short, a hash function is a unique identifier for a specific piece of content. Within this process, plaintext data of any size is converted into cypher text of a predetermined length (Crane, 2021). No two pieces of content will have the same hash output, and if the content is changed the hash output also changes. Using hashing, any data sent to a recipient is guaranteed to have arrived in the same condition it left the sender, completely unaltered or changed. In a blockchain, after a block of transactions has been created, they are run through an algorithm that creates a single hash. This hash can be shared, upon which the receiver verifies the underlying transactions without gaining direct access to them. This is an incredible data storage tool, as it radically reduces the amount of processing power needed. The size of an average block is 350 gigabytes, which can be compressed to a unique hash of a fixed length. The resulting string of numbers and letters cannot be used to guess the size of the data it represents, making it incredibly difficult to decode. Content that has been hashed can also be strung together in creative ways, as further demonstrated by Merkle Trees.

Merkle Trees

Merkle trees, also known as “binary hash trees”, are a concept core to blockchain technology. Merkle trees are data structures where each transaction on a blockchain is hashed, in which case it becomes a “leaf” node (Chumbley et al). These leaves pair off with each other and are hashed again, to create “branches”. Branches also pair off and are once again hashed. This process is repeated until a block of transactions, often as much as 500, are progressively combined to form a single hash. This final hash is considered a “Merkle root” of a block and can be shared, allowing others to verify the underlying transactions in an incredibly efficient manner. Each block’s unique hash is linked to the next block, which means if any of the underlying transaction data changed, the unique hash value would also change, causing the entire string of blocks to collapse. This makes it impossible to alter recorded transactions and ensures the security of the data structure. If hashing is the backbone of blockchain, Merkle trees are the lifeblood, as it makes encoding files significantly less memory intensive. The benefits are massive, including increased data retrieval efficiency as well as immutability.

Consensus Mechanisms

A consensus mechanism is a process by which agreement is achieved when adding a data value to a distributed system. Consensus mechanisms, also referred to as consensus algorithms, are one of the fundamental building blocks of blockchain. There is no central authority in blockchain technology that verifies and validates transactions, yet blockchain is considered completely secure. Consensus protocol is the process through which this trust is earned. Described as efficiently as possible, "a consensus algorithm is a procedure through which all the peers of the blockchain network reach a common agreement about the present state of the distributed ledger" (Consensus Algorithms in Blockchain, 2019). This definition is intentionally vague, as there are over 30 consensus algorithms in use, with more to come. Regardless of the use case, however, each consensus structure sets the rules that decide on the legitimacy of contributions made by various blockchain participants. Each consensus algorithm has a unique structure designed to fit the specific blockchain within which it resides, although the three most common are proof of work, proof of stake, and practical byzantine fault tolerance. Most other consensus structures are modeled after these three core models, with variations designed to cater to the use case. A description of each of these three core mechanisms is included below.

Proof of Work (PoW)

The PoW consensus mechanism is one of the most common and was proposed for application on the Bitcoin blockchain by Satoshi Nakamoto. PoW allows nodes to trust each other in a trustless environment and is completely decentralized. The core concept here is that of "mining", in which anyone can become a node and use powerful computing hardware to solve computationally challenging puzzles and add a new block of transactions to the network. Having solved this difficult mathematical problem and linked the new block to the old block, the miner is rewarded with cryptocurrency. Over time, as more computational power is added to the node network, it becomes more difficult to solve these mathematical puzzles. This is to consistently find 1 block every

10 minutes, which the developers consider an ideal run rate for diminishing available coins.

The reason that PoW works is because the threat of malicious nodes is significantly reduced. The economic benefit of powering malicious nodes is zero, up until over 50% of the computers powering the blockchain are malicious. The existing network of nodes is so robust, that the financial possibility of powering so many malicious nodes is almost impossible. Another meaningful benefit of this system is that of decentralization. Due to nonbiased node selection for adding blocks and low barriers to becoming a node, these platforms are often very decentralized with the ability to add many users. Admittedly, this system is far from perfect. The complex puzzles these nodes are solving are somewhat useless. The only reason solving these puzzles is so difficult is to develop barriers for malicious nodes. In this case, the barriers are incredibly expensive computational hardware. There are ways to develop trust without such extensive computing. PoW blockchain causes massive energy consumption, and many would argue the energy usage for a PoW blockchain is unnecessary. While these platforms are very open and can scale quickly, they also have performance limitations and process transactions relatively slowly.

Proof of Stake (Pos)

Miners do not exist on Proof of Stake (PoS) blockchains and are instead replaced by "validators". While validators also verify blocks and add them to the network, they are selected differently. PoS validators have a financial stake in the blockchain network, and as such are motivated to see it succeed and unlikely to act maliciously. These owners offer their coins as collateral for the chance to be randomly selected to validate a block. This adds significant security to PoS blockchains and makes a 51% attack nearly impossible. Validators who attempt to control 51% of the cryptocurrency to alter its history will lose the coins they staked as a result. This effectively makes a 51% attack futile for any potential attacker. Ethereum is a PoW blockchain transitioning to PoS. Owners must own and stake at least 32 ETH to become a validator. Blocks are then validated by more than one validator, and after a specific number has verified the block is accurate, it is finished and added to the chain (hezhao, 2022). The core benefit of this style of consensus network is reduced energy consumption. PoS replaces computation with staking. While wealthier shareholders are rewarded most on PoS blockchains, this mechanism is considered significantly more decentralized and accessible.

Practical Byzantine Fault Tolerance (pBFT)

The Practical Byzantine Fault Tolerance mechanism derives from a hypothetical called the Byzantine Generals Problem. Each General has surrounded a fortress and is deciding whether to invade it or to retreat. Should they all make the same decision, they would all be successful, but should any choose differently, they would all be defeated. When differing decisions are made, these are called “faults”. In a computer system, the nodes are the Generals, and any nodes that act maliciously are faults. “Byzantine Fault Tolerance” refers to how many nodes can fault while the whole system remains operable and secure. Cryptocurrencies such as Bitcoin and Ethereum both have some fault tolerance, as both are operable even with malicious actors. Practical Byzantine Fault Tolerance (pBT) is another specific solution to the Byzantine Generals Problem. In this consensus mechanism, there are primary and secondary nodes that work together to reach consensus (Daly, 2021). A request to verify a block is sent to the primary node, which shares it with the secondary nodes, who process and verify at the same time. Should at least 2/3 of the nodes agree, the transaction is immediately confirmed and added to the blockchain. This consensus mechanism saves on energy consumption and offers nodes their rewards more democratically than both PoS and PoW. In terms of downsides, cumbersome volumes of communication between every node at the same time prevent this mechanism from scaling rapidly. As a result, pPFT currently serves itself most useful in specific use cases with small consensus groups.

Smart Contracts

Smart contracts have quickly developed as an integral part of blockchain with significant potential. The concept behind smart contracts is relatively simple: they are programs stored on a blockchain that automatically execute when all or parts of an agreement are met. Much like an actual contract, two parties develop conditions, which when met, result in an agreed execution. All participants can be immediately sure of the outcome, as the code is replicated across many nodes of the blockchain. As such, both parties benefit from the immutability and security that the blockchain offers (Lipton & Levi, 2018). By incorporating AI into blockchain in this way, one can create an automated workflow without intermediary involvement and loss of time. Smart contracts allow blockchain to become more customizable and offer faster, more transparent, and more secure contracts.

Chapter 4: Case Descriptions

Case #1: Energo Labs

Energo Labs hopes to create a unique blockchain-enabled P2P energy trading platform designed to enable local renewable energy trading. In their own words, they hope to build a future for **Distributed Autonomous Energy Communities (DAE)**. This platform is designed to work in conjunction with the traditional energy system, which will provide backup power to renewable energy generated locally. Energo is unique in that it places a strong emphasis on distributed energy storage equipment, hoping to develop an energy storage system that achieves a stable and quality power supply.

Blockchain Architecture

Energo is housed on the Qtum blockchain, which can be considered the core of Energo. Qtum is a highly scalable blockchain network to build on, as it incorporates elements of both Bitcoin and Ethereum. Similar to Ethereum, Qtum has extensive smart contract functionality that allows developers to create nuanced applications on the blockchain. Qtum is also underpinned by a PoS consensus protocol, allowing it to scale more quickly without the need for extensive hardware and energy usage. Considering Energo works to decrease carbon emissions, a PoS consensus model aligns with the company's philosophies. Like Bitcoin, Qtum also utilizes a highly secure **unspent transaction output model (UTXO).** In effect, this increases transactional security by allowing all users to track ownership of all portions of a cryptocurrency.

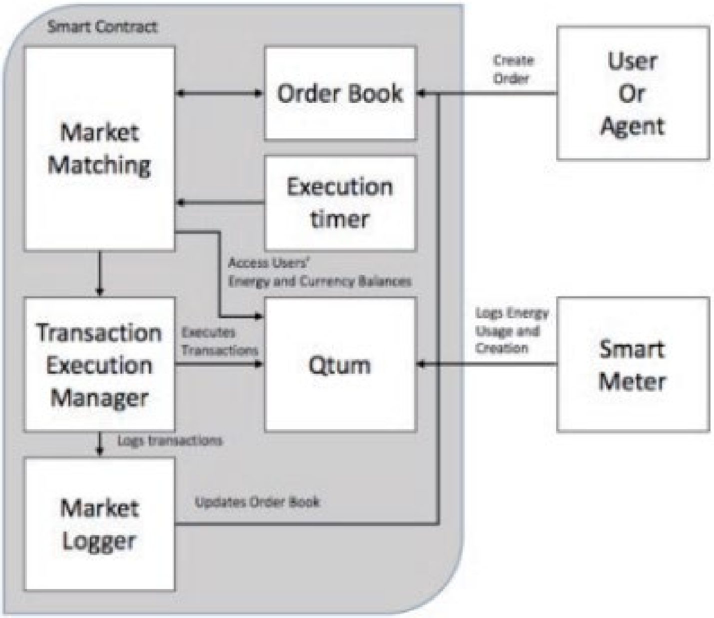

Figure 6: Energo Market Software Implementation Diagram

Layered on top of Qtum is the Energo Consortium blockchain. By developing a consortium network on top of a public network, a balance is struck between decentralization, security, and data processing. Energo cites the inflexibility of both public and consortium consensus mechanisms, suggesting a blend of the two "optimizes computing power in any given trusted network". Within the Energo consortium blockchain, distributed energy storage assets are the full nodes. The energy storage assets determine which transactions are and are not valid. Interestingly, this layer adopts a blended mechanism of **Proof of Time** and **Raft agreement** to optimize computing power.

The Energo software implementation makes use of three integral actors. Users and agents create bid and asks and operate over their order books. Business logic units utilize smart contracts to execute orders, hold data, and make calculations. These smart contracts use Oracles and data feeds, allowing real-world events to trigger events on the blockchain. Finally, smart meters report energy usage and production. In this software ecosystem, Qtum is the central data source that records all transactions, with smart contracts handling the business logic.

Energo makes use of two blockchain-based digital assets to enable transacting. The first is an energy asset called WATT. One WATT is equivalent to one kilowatt-hour of actual energy stored in a microgrid or distributed energy storage equipment. Energo monitors energy production and consumption, using smart contracts to automatically create and issue WATT tokens. The second digital asset is TSL. TSL reflects an owner’s access to power in distributed energy storage equipment and is used to purchase energy. Energo issues one billion TSL tokens in total, which remains constant.

Transacting

To sell or purchase on Energo, users input their bid or ask on the mobile app. Having done so, the **zero-intelligence agent** automatically buys and sells energy in real-time. This is true up until the point that a storage maximum is reached, in which case the storage unit must sell energy before it can purchase more. Like stock market trading, the price of energy will adjust in real-time. In this case, the price is for transacting renewable stored energy. Participants are motivated to contribute their distributed energy storage devices to the network, as there is a commission fee on the user stored energy which is charged every 15 minutes. 80% of this fee is distributed to energy storage equipment owners, while 10% is reserved for educating markets, and the final 10% is retained by Energo.

AI and Machine Learning

Energo currently does not provide any AI or machine learning-enabled products but hopes to manage energy use in smart homes in the future.

Hardware

Energo provides blockchain-enabled smart meters that meet the specifications required for the country of installation. Prosumers and traditional electricity consumers alike will need these smart meters, although almost no information is given about them.

Case #2: Verv

Verv has historically created disaggregation technology providing households with a detailed analysis of their energy usage. The company is using its existing traction to pivot into the P2P energy trading space, developing a nuanced, hardware-enabled platform. Verv has already successfully launched the Verv Home Hub (VHH), a powerful smart meter with AI and machine learning capabilities. They are extending their value offering by developing the Verv Trading Platform (VTP), an Ethereum-based energy trading platform. VTP is unique in that it relies on local aggregators to stake and broker VLUX tokens, which are used in every VTP transaction. Local aggregators act as the nodes of this platform, authenticating blocks and being rewarded. Rather than market itself as a blockchain company, Verv showcases its first-of-its-kind hardware, ultra-high-resolution energy data, deep learning, and AI.

Blockchain Architecture

Verve uses blockchain as a transacting tool in a few different ways. At the lowest level of Verv's technology stack is Ethereum blockchain. Verv chose Ethereum for a variety of reasons, including its global traction, team, and flexible open-source software. However, it is clear Verv is only loosely tied to Ethereum, even mentioning that their software is designed to be easily moved off Ethereum and onto a better public blockchain if need be. Verv's exchange structure reflects how little it relies on Ethereum, as token trading on VTP is only digested back onto the Ethereum network once per day. This intention is reflected again in the whitepaper, "(Verv) uses hash functions and transaction digests to reduce the volume of data stored on the public Ethereum ledger". Suffice to say, Verv spends no time singing the praises of Ethereum, rather viewing it as a practical tool that may be replaced.

Within the local community ledger (see figure 7), a **proof of authentication** framework is used to validate blocks. Local aggregators act as the authenticators and are rewarded and punished for the accuracy of their work. Later, this responsibility may move to a different actor, although little information is given.

Within the VTP trading engine (see figure 7), a **proof of delivery** framework is used to confirm energy transfer and is paired with smart contracts for settlement. Both blockchain uses, in the local community and the trading engine, are further described in the "transacting" section below.

Transacting

Verv transacts using smart contracts, which are incompatible with traditional fiat currencies. As such, Verv has created the VLUX token to enable energy trading. Every transaction uses the VLUX token in some way, although consumers and prosumers do not purchase VLUX tokens from the public VLUX exchange. To avoid transaction and broker fees, consumers purchase VLUX from a local aggregator, such as an energy utility, that purchases them in bulk from the public exchange and offers them to their local area. This is how local aggregators "stake" their tokens, by offering them for daily use to the 100-500 homes within their network.

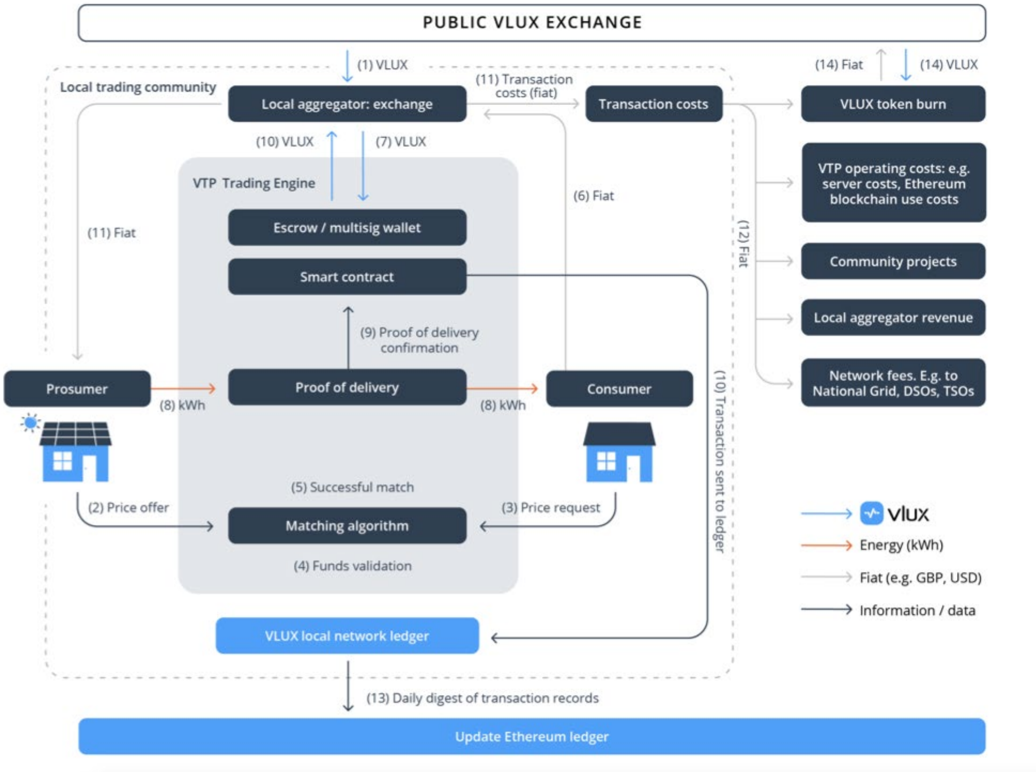

Figure 7: VTP Trading Ecosystem

Figure 7 demonstrates how VTP trading works in detail, using some of the concepts just described. The step-by-step process goes as follows:

1. A local aggregator creates a local trading community by purchasing VLUX tokens from the public exchange.
2. Assuming enough local prosumers and consumers are active, a prosumer with excess energy and VTP automatically places an offer to sell at a particular price, including transaction fees.
3. A consumer in need of energy automatically places a purchase request according to their preset preferences.
4. The matching algorithm confirms whether the purchaser has the necessary funds.

5. The order is sent to the trading algorithm.
6. The consumer sends the necessary fiat payment to the local aggregator, who in return provides the necessary VLUX tokens.
7. The consumer's VLUX tokens are held in escrow until the exchange has been confirmed.
8. The energy is sent to the consumer.
9. The exchange is confirmed using Proof of Delivery, in which case the smart contract executes a transaction.
10. VLUX tokens are released from escrow and the transaction is added to the local community ledger.
11. The payment for the energy is sent in fiat to the prosumer, as well as a smaller portion to the local aggregator to cover costs.
12. All relevant fees are distributed.
13. Daily, the VLUX local community ledger publishes a digest of all transactions to the public Ethereum ledger.

AI and Machine Learning

Verv started as a demand response company integrated with smart home appliances. As such, Verv has an extensive dataset of smart home technology performance entering the P2P energy trading space. Verv is capitalizing upon this strength, using machine learning to develop real-time profiles for key household appliances. Not only showing homeowners whether their appliances are on or off, but also at what percentage efficiency they are operating. These data inputs are made possible by Verv's hardware product, which enables ultra-high energy resolution. Using deep learning AI to create consumption and generation forecasts, Verv automatically optimizes energy trades hours in advance and guides the flow of energy most economically. This system also processes data feeds with neural networks that identify interconnected patterns, allowing the forecasts to constantly improve over time. Verv uses a variety of data inputs, including appliances, energy generation, energy storage, energy generation performance, weather, clouds, satellite images, user routines, and energy trading patterns. Verv's AI creates a highly customized and ever-changing experience that ensures long-term customer engagement.

Hardware

Verv considers itself the only P2P player with a commercially developed hardware product that has integrated high-speed data processing and trading capabilities. The hardware is referred to as the VHH. The VHH has associated machine learning AI and is fully ready for deployment. The pairing of in-house, developed hardware and extensive AI and machine learning capabilities is Verv's competitive advantage. The VHH is a non-intrusive load monitoring device that is fully patented, and self-installed. It samples electricity 5 million times faster than a traditional electricity meter, and trades energy 8x faster than other smart meters, although most smart meters are compatible with the Verv trading platform. Using a Zigbee chip, the VHH is WIFI enabled and acts as a central hub for controlling other smart home devices. This adds an extensive level of ultra-high-resolution readings. Whereas other smart meters may communicate how much energy was transacted within one hour, the VHH can communicate how much electricity each appliance in a home used within one-hour. By intimately pairing hardware and AI, Verv enables disaggregation of electricity readings. Ultimately, allowing consumers to procure electricity from the cheapest provider, and sell it to the highest bidder.

Case #3: Powerledger

Powerledger offers a nuanced P2P energy trading platform with flexibility in mind. Such flexibility is enabled by a dual token ecosystem with two blockchain layers in a four-layer software stack. The Sparkz token is given for generating electricity, while the POWR token grants individuals and application hosts access to the system. The blockchain structure of Powerledger is similar to Verv, also underpinned by the public Ethereum network, and utilizing a consortium blockchain network to create new markets. However, Powerleger appears to have less AI and hardware capabilities, instead prioritizing its software design in its whitepaper.

Blockchain Architecture

Powerledger has designed a scalable and adaptable ecosystem designed to adjust to different regulatory environments and use cases. Such market flexibility is enabled by a dual token ecosystem with two blockchain layers. These two blockchain layers comprise half of Powerledger's software stack, and to understand how any of these layer's work, a comprehensive understanding of the entire stack is necessary.

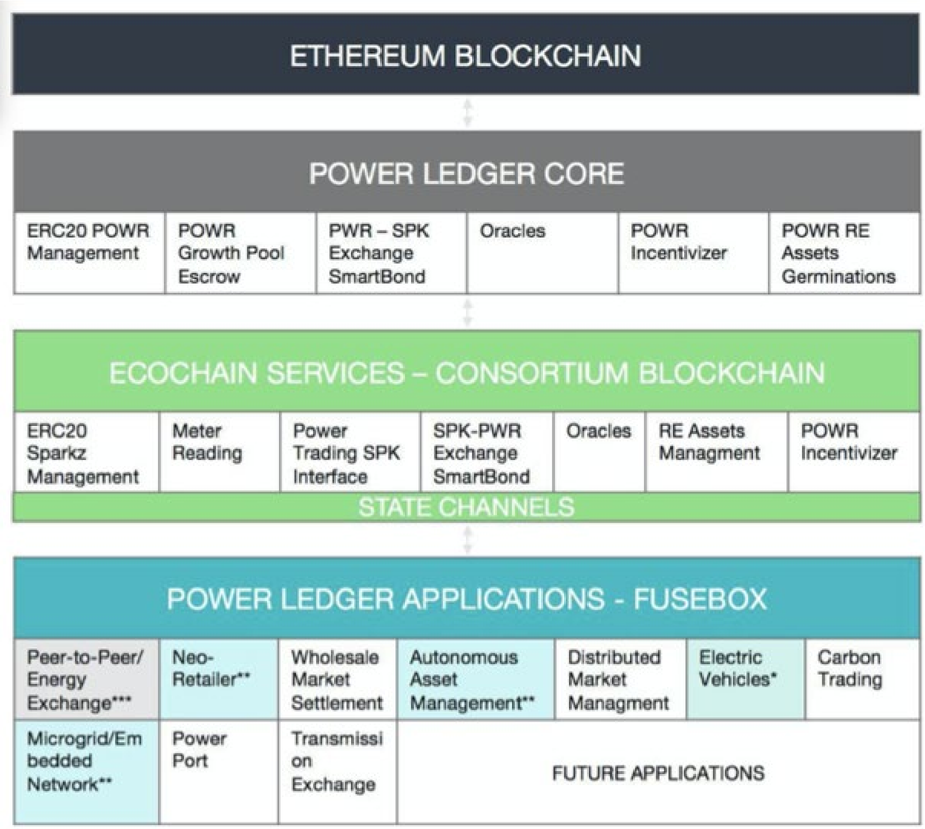

Figure 8: Powerledger Technology Stack

Underpinning the Powerledger ecosystem is a public layer that utilizes Ethereum blockchain. This is where the system interfaces with third-party token exchanges. Should an application host or individual look to purchase POWR, they would do so on the public exchange, which ensures the POWR tokens are as secure and decentralized as possible. The public layer is a relatively simple layer of Powerledger's technology stack, providing an independent mechanism for interfacing and transacting with other software layers by use of the POWR token. This layer can be considered an un-complex, but sturdy base that the Powerledger Ecosystem is built on top of.

The next layer in Powerledger's stack is Power Ledger Core. This is a public smart contracts layer that implements the core benefits of POWR tokens. Amongst other activities, the Core includes POWR and Sparkz exchanging and smart bond contracts for application hosts. The Core also utilizes **Oracle** smart contracts to gather data external from the protocol, which is required to communicate with the consortium layer. This layer is effectively a layer of self-executing components that help activate the ecosystem.

The third software layer is the consortium blockchain layer called Ecochain. Ecochain is a private PoS blockchain network that Powerledger has developed in-house. A variety of functions lie in this layer, which includes Sparkz creation and management, Fiat payment processing, and storage and verification of smart meter readings and trading-related data. Interestingly, the Ecochain layer has been transitioned to a fee-less consortium **Proof of Authority (PoA)** Ethereum network. The transition to an Ethereum-based layer provides many benefits. The layer is now benchmarked against the latest blockchain technology and is open to future Ethereum development and innovation. In general, this transition improves protocol functionality and the software's pace of improvement.

It is worth noting that state channels operate as a sub-layer of the Ecochain service. State channels are a unique way of executing blockchain transactions in an off-chain manner. After gathering the agreement of key actors, the blockchain state is effectively frozen for a set time. In this downtime, the same actors transact quickly with each other off the chain. Having done so, the blockchain is "unfrozen" with a single on-chain transaction (Agarwal, 2020). In this way, many transactions can effectively be condensed into a single transaction. Considering the high-frequency nature of energy trading, this is a useful way to minimize on-chain transacting and speed up settlements.

The final software layer of the Powerledger stack is a versatile P2P trading application called Fusebox. As summarized by the whitepaper, “it allows for direct trading between Prosumers and Consumers with or without the inclusion of industry intermediaries such as market operators, retailers, or transmission network operators”. The application is highly configurable and can adapt based on the market’s regulatory environment. Regardless of the environment, however, all energy is transacted with Sparkz tokens, which are pegged to the local currency. This allows the application to be applied to all countries.

Transacting

Pre-purchased tokens enable transacting on Powerledger’s diverse market. The first of which is a “low level” token called Sparkz, which represents a tokenized unit of electricity. Sparkz are used for ecosystem transactions, synchronizing the ecosystem globally and creating cross-market electricity compatibility. Sparkz are slightly different across geographies and are a local market token. This means that Sparkz are priced for the geography they are deployed in. In Australia, for example, one Sparkz is equivalent to 1 cent AUD.

Unlike Sparkz, the Power Ledger token, POWR, is considered the “fuel” of this ecosystem. In its simplest form, POWR is a frictionless token that grants access to the platform. They help facilitate low-cost energy, higher returns on electricity, and provide governance and security through smart bonds. The use of POWR is intimately tied to a key figure in the Powerledger ecosystem: application hosts. Application hosts are entities and businesses that run an application on the Powerledger platform. Application hosts create their micro-ecosystems, controlling the rate of disruption and onboarding customers. To do so, application hosts such as energy retailers and network utilities purchase enough POWR tokens from the public exchange to activate a market. The POWR is then converted to Sparkz, and the customer base is onboarded. Customers use Sparkz to transact electricity between each other, with the POWR tokens escrowed for Sparkz in a smart bond. The POWR is then unlocked upon the return of the Sparkz to the application host. Having followed a full transaction procedure, the prosumer can redeem their Sparkz for Fiat currency.

When it comes to the trading of electricity in a live region, trade matching algorithms match buyers and sellers equitably. Consumer orders on both sides of the market are filled in equal increments and continuously cycled until the queue is cleared. This allows even the newest of customers to on-ramp and immediately receive local renewable energy, while also minimizing transmission. Trading groups also provide application hosts flexibility in building their markets. They can choose to prioritize energy trading within the same buildings, or zoom out as much as they like, potentially even to trading with other network operators.

AI and Machine Learning

Very little mention of AI is used and none of machine learning. Powerledger does use unique matching algorithms to equitably match buyers and sellers.

Hardware

Powerledger collects data from smart meters via a suite of **application programming interfaces (APIs)**. As of yet, there has been no development of an in-house internet of things (IoT) enabled device.

Chapter 5: Findings

Energo, Verv, and Powerledger have many similarities and differences when it comes to their technology stack. I consider both important. I triangulate where the platforms have similarities, as it provides meaningful insight into how P2P markets are forming, potentially even offering applicable insight to other industries. I also value discussing how the three platforms differ, as these differences indicate where each startup finds a competitive advantage. I ultimately bucket my findings into six categories: blockchain, consensus protocols, electricity market positioning, centralization, data aggregation, and AI and machine learning. Figure 9 summarizes some of my key initial findings, succinctly comparing my case studies based on their core attributes.

	Energo	**Verv**	**Powerledger**
Double-Layered Blockchain Platform	Yes	Yes	Yes
Dual-Token System	Yes	No	Yes
Consensus Protocols	PoS, Proof of Time, and Raft Agreement	PoS, and Proof of Authority	PoS, Proof of Time, and Proof of Authentication
Electricity Market Positioning	Distributed Energy Storage	Demand Learning	N/A
Centralization	Low	High	High
IoT Hardware	Yes	Yes	No
AI Capabilities	Yes	Yes	No

Figure 9: Table Summarizing Case Comparisons and Initial Findings

Blockchain

Before conducting any readings, I formed my core research question, "how is blockchain technology assisting the activation of P2P energy markets?". Having assessed Energo, Verv, and Powerledger, I can now confidently answer this question. Perhaps the most apparent similarity between the three companies was their use of a dual-layered blockchain platform. Across every case, there was a public blockchain layer that underpinned the market and a consortium layer that performed more of the heavy lifting in terms of smart contracting and token protocol. This led me to my core takeaway, that **the singular most important factor enabling a successful P2P energy trading platform is system flexibility**. In this case, system flexibility refers to each platform's ability to efficiently scale and redesign itself to different use cases and geographies. Each company directly recognizes the importance of flexibility, which a dual-layered platform provides. Energo's whitepaper directly mentions creating a "more flexible" blockchain as justification for creating a double-layered software stack. Likewise, Powerledger's whitepaper emphasizes the importance of "dynamic agility", claiming it allows them to redefine where players are positioned in the ecosystem and who has market power. Rather than market their use of Ethereum, Verv makes the direct point that their platform is designed to potentially leave Ethereum. In an industry where regulation varies dramatically between geographic areas and using rapidly developing technologies, the ability to iterate and evolve is most crucial to a P2P energy trading platform. P2P market makers are focused on creating adaptable and customizable products, enabled by dual-layered blockchain systems.

Delving more into the inner mechanics of these systems, it is worth noting the prominence of dual-token systems. In both Energo and Powerledger, a lower-level energy asset tokenizes units of energy generation. Sparkz and WATT are the two examples in my case studies. Both are stable tokens, pegged to the per-unit price of electricity in the local market. "Access" tokens, such as TSL and POWR, are purchased to enter the marketplace and transact. These tokens fluctuate with market activity and can be staked to earn rewards. There is a clear need for dual token markets, as they "synchronize" these systems. Users can benefit from network effects, as tokens such as POWER and TSL increase in value. However, considering network growth will eventually motivate participants to sell these tokens, the second token separates economic interest and ensures energy providers are less prone to price fluctuations.

Ultimately, a balance is struck between network utility, value, and ownership. It is in everyone's best interest for the network to grow in utility and capture real-world value.

Both dual-layered blockchain stacks and dual-token systems contribute to the hybrid nature of emerging P2P energy markets. As such, my three cases offer real-world applications of the larger paradigm shift towards "blockchain 4.0".[4] Hybrid blockchain networks are on the rise, and P2P energy markets offer a tangible use case of the associated benefits. My cases demonstrate the many benefits of hybrid blockchain. These benefits include working in closed ecosystems, changing the rules when needed, protecting privacy while communicating with the outside world, and maintaining low transaction costs. Hybrid blockchains maintain the non-tampering and security of the public chain combined with the ultra-efficiency of the private chain. One of the larger blockchain-related insights of my research is that P2P markets demonstrate the wider transition to hybrid networks. Even amongst a sample size as small as three, there is significant variety in blockchain architecture. Blockchain is changing rapidly and evolving into exceedingly intricate and diverse networks. P2P energy trading networks offer a clear demonstration of this larger industry trend.

Consensus Protocols

Entering my research, I was very curious about which consensus mechanisms P2P market makers used. I included the three most popular consensus mechanisms in my background research, thinking any of the three could be the most common. A clear consensus "winner" emerged in my research, which is the proof of stake consensus

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4 Blockchain 1.0 being digital currency trading through bitcoin, 2.0 being smart contract enabled platforms such as Ethereum, and 3.0 being permissionless and public blockchains.

mechanism. Considering P2P markets are designed to increase renewable energy usage, it only makes sense for these markets to rely on a low carbon blockchain network. On a philosophical level, using PoS makes the most sense. On a technical level, PoS is also the ideal partner for P2P markets. Unlike PoW mechanisms, PoS offers substantially faster processing speeds. Considering the large transaction quantities in this ecosystem, transaction speed is of utmost importance.

Admittedly, suggesting PoS is the "winner" of P2P energy markets is a generalization. As previously discussed, these markets consist of two blockchain layers that are designed very differently. PoS mechanisms indeed dominate the public blockchain layer, as Qtum and Ethereum are both (or will be) PoS.[5] However, this is not the case for the consortium layers. Out of the three use cases, none of the companies are currently using a PoS consensus mechanism on their consortium layers. Energo utilizes a blended mechanism of Proof of Time and Raft agreement, Powerledger utilizes Proof of Authority, and Verv utilizes Proof of Time and Proof of Authentication. A winner in this realm has yet to be determined, likely, a winner may never be determined. When it comes to the consortium layers, each company in the P2P energy trading space must pick a consensus protocol unique to their customer base, node network, and use cases. For the consortium layers especially, there is no one size fits all.

Electricity Market Positioning

Across my case studies, each company positioned itself within the electricity market differently. Energo stands out, having placed a sizable bet on distributed energy

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[5] Ethereum utilizes a PoW consensus protocol but is working on transitioning towards a PoS protocol. In this study I classify it as a PoS network.

storage systems. While the price of utility-grade energy storage has fallen by nearly 70% between 2015-2018, commercial-grade energy storage has yet to reach scale (Hoff & Mey, 2020). Distributed energy storage, however, has reached scale. Over 200,000 Tesla Powerwalls have been installed, offering a sizable and quickly growing initial node network (Alamalhodaei, 2021). By making distributed storage their network nodes, energy storage owners have extensive market power. Energo has effectively tied the success of its platform to the success of this technology.

Verv has a markedly different approach than Energo and focuses on learning demand patterns. To do so, Verv employs advanced IoT-enabled hardware and AI. Extensive data collection and aggregation are needed to understand energy demand patterns, and these mechanisms come about as solutions. Verv's technology stack provides insight, demonstrating that blockchain is not enough to activate P2P markets. New, advanced technologies must be interconnected with blockchain to solve the various pain points involved in creating P2P markets. Hybrid technology stacks offer increased efficiency and a better customer experience.

Powerledger is ambiguously positioned within the electricity market. Offering a similar product as Verv, Powerledger does not niche itself or cite specific competitive advantages. The company is somewhat exempt from this assessment, and time will tell how the platform differentiates itself.

Centralization

By allowing prosumers to act as network administrators, Energo is the only truly decentralized platform in my research. In Energo's system, there are no publicly managed operators directing the flow of energy and verifying transactions. Instead, authority is dispersed amongst the lowest levels of the energy ecosystem. Verv and Powerledger offer a much more centralized approach. In these systems, local aggregators and application hosts can be energy utilities, commercial electricity generators, and property managers. Verv cites the need to create "future-proof" platforms, as represented by the variety of actors that can serve as authenticators. While Powerledger does cite DAO's as potential application hosts, this receives little attention. In the short term, centralized actors seem posed as P2P market operators for Verv and Powerledger.

It is worth discussing the implications of varied centralization as there are certainly tradeoffs between the two. While a centralized approach pools expertise and likely rarely results in erroneous decisions, it may have more drastic consequences when it fails. Erroneous decisions are likely more common in a decentralized system, although the consequences are confined to a local market. When I started my research, P2P markets appeared to represent decentralized technology developments. While this is certainly true to some degree, I realize now that this is not always fully the case. Albeit a very small sample size, amongst the leading players in this space, 2/3 of my cases utilize a centralized actor. Within the context of the industry, it does, however, make sense for centralization to permeate these software stacks. The energy industry has a long-standing history of centralization. **Monopolistic firms have traditionally had a stronghold on industry knowledge and infrastructure, potentially necessitating their prominent inclusion in activating P2P markets.** The introduction of blockchain technology offers a high level of disruption, and the exclusion of centralized actors may be a level of disruption too early for these budding markets.

Verv and Powerledger send a clear message: private DER owners currently lack the initiative, organization, and expertise to manage emerging P2P markets. Incumbents are still needed to facilitate efficient energy transfer, rapid transacting, and user onboarding.

Data Aggregation

I was unsure which inputs P2P markets would draw data from, but quickly learned **smart meters are the primary data aggregators in these systems and when developed well, are a unique competitive advantage**[6]. All three companies recognize the importance of smart meters in supplying reliable data. However, Powerledger is the one hardware-agnostic company. Energo and Verv create their own in-house IoT-enabled devices and out of the two, much more information is provided on Verv's. Verv's VHH provides ultra-high energy resolution, allowing the algorithms to improve faster. In general, this seems to be the primary benefit of having an in-house hardware device. Hardware and AI are intimately linked, as the purpose of an advanced smart meter is to better inform the algorithm and therefore better customize consumer trading.

AI and Machine Learning

As I first formed my research questions, I was intrigued with the use of AI and machine learning in these ecosystems. I thought that AI and machine learning would be mutually exclusive from blockchain, with some platforms using one while others used the other. To some degree, this is true, as Energo and Powerledger made little mention of AI. However, in all three use cases, it is apparent that AI can pair with blockchain.[7] I

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6 It is worth pointing out that Verv also draws data from external factors influencing electricity generation such as weather forecast data, geolocation data, and satellite data on cloud coverage.

7 I attribute this partially to marketing, with Powerledger and Energo intentionally portraying themselves as blockchain-centric companies.

was surprised that the two technologies work effectively in conjunction. One of my core findings is that **AI and machine learning are blockchain compatible, and a critical competitive advantage.**

Whereas blockchain helps perform transaction settlement, AI and machine learning help breathe life into these platforms. Verv is an excellent use case of AI and machine learning, considering it one of their core competitive advantages. Their deep learning AI technology creates consumption and generation forecasts based on historical data. The benefit of this is that Verv can optimize energy trading hours in advance and guide the flow of energy. Using neural networks, Verv can identify interconnected patterns and allow the forecasts to constantly improve over time. Compared to blockchain, AI is not a necessity in these systems, as these markets could hypothetically run without it. However, AI presents an opportunity to improve these emerging markets by learning consumers' electricity consumption behavior and developing trading strategies to match. Using AI eliminates the need for ongoing input and decisions from the user, creating a more sustainable customer engagement. Developing the blockchain infrastructure is an important first step, but it appears that Powerledger and Energo will inevitably have to catch up to Verv's lead in AI and machine learning.

Chapter #6: Recommendations to New Market Entrants

Blockchain has considerable disruptive potential in the energy space. As new organizations enter the sector and incumbents consider adopting blockchain technology, there are a variety of factors to consider. Based on my understanding of the three cases I studied, I offer several propositions to new market entrants below.

Utilize Benefits of Energy Tokenization

Perhaps my core recommendation to a participant considering integrating blockchain is to tokenize energy across the grid in a dual-token system. In my research, this came up as a crucial first step. Regardless of whether a new entrant in this space is developing a P2P product, creating tokens enables the use of smart contracts, as Fiat currency cannot be used in smart contract transactions. The technical attributes of a dual-token system with a low level and access token have been discussed in my findings section, and I support this model. There are many benefits to creating a dual-token ecosystem, which includes the ability to automate the execution and settlement of transactions. Blockchain can enable firms to remove middlemen in the wholesale and retail market, securely and quickly transacting between members. Using a consortium network layered onto a public network, transaction costs are also bound to be cheap. In many of these systems, there are few network nodes, allowing the hybrid blockchains to utilize state channels and work in a closed system. Doing so would allow a new entrant to take advantage of blockchain technologies' many benefits with the guarantee no sensitive information would be leaked. A double-token system pairs well with a double-layered market and creates coveted "grid agility". New entrants create the flexibility to adapt quickly and act nimbly in an ever-changing market. Using a double-token system also allows new startups to offer an ICO and fund the creation of their market.

Use AI and Machine Learning to Remove Human Agency

Other advanced technologies pair well with blockchain in this sector. AI and machine learning are two such examples, which I recommend using. From my study, it is clear AI and machine learning can be used to reduce human interaction with the energy trading markets. This is an extremely useful tool in the long run, both for the energy markets and for P2P prosumers and consumers. While P2P energy trading is an emerging demand sharing space, it differs from comparable startups such as Airbnb and Uber in that energy is not a top-of-mind product. Consumers rarely think about their energy consumption and are accustomed to having little interaction with energy markets. AI and machine learning can reduce friction with early adopters by allowing them to set and forget their trading preferences. I consider this a strong proposition to new entrants and recommend reducing consumer agency in this space as much as possible. AI and machine learning enable a superior experience for consumers, and in removing human agency, allow markets to operate most efficiently.

Employ Centralized Actors as Network Decision Makers

Employing blockchain in any capacity in the energy sector is a move towards decentralization. However, I caution against becoming to decentralized and removing centralized actors from new products and services. While regulation appears to be moving towards decentralizing energy grids, I predict there is a long way to go before fully functioning P2P markets begin to scale.

In the short term, it is prude to view centralized actors as partners instead of competition. Energy utilities commercial energy generators have extensive industry influence and can be used to onboard new users and activate markets.

Chapter #6: Future Direction

My research in this space certainly could be improved, and there are a variety of directions to take in future research. One way I could have improved my research was by adding a fourth case study. While three case studies are not too few, reviewing and comparing the technology of a fourth case study would have helped make this a more robust study. LO3 is a leading P2P startup in this space. While their business and technical whitepaper was not included in my study, they offer a logical next assessment. I feel confident that a fourth case study is small enough to maintain a deep, case-oriented analysis while contributing to a more richly textured understanding and analysis.

In terms of research questions, my work presents a representation of the technology behind the emerging P2P energy trading sector. It is clear, however, that this technology is moving at a rapid pace. Future research may assess the impact of Ethereum's transition to PoS when it comes about, changes in each case's consortium layers, and performance metrics of IoT-enabled smart meters. Each subsection of my research can effectively be extrapolated into its own research project. Documenting and educating others on the advances in this space are important measures to take, ultimately contributing to a carbon-neutral energy grid.

Moving forward, I am also curious about the economics and financial viability of P2P trading in the coming future. As the space matures, data will eventually come out regarding the profitability of transacting on these networks. Potential research questions may include: What is the return on investment of IoT enabled smart meters? Does P2P trade data suggest a clear superiority over net metering for the consumer?

And what are the cost savings for consumers purchasing VRE on P2P networks? Throughout my research. the P2P products I assessed were often compared to Uber and Lyft. Considering the long road Uber and Lyft are taking to try and achieve profitability, this may likely be the same case for P2P markets. Reviewing the driving factors surrounding the business model and market performance for my case studies is a logical next research study.

Chapter #7: Conclusion

One of the key limitations plaguing innovation in the energy sector is education. The energy industry is immensely complex, and the average consumer has little understanding of how the energy market is run. Likewise, blockchain is a new advanced technology that has captured the attention of many but is very confusing to others. For P2P energy markets to realize their full potential a large paradigm shift must occur away from centralized energy distribution and towards a decentralized energy market. Without a large body of advocates pushing for legislature reform, this change may be years or decades out. Providing consumers with a comprehensive understanding of P2P energy markets potential is the first step in accelerating this change. My research attempts to support the decentralization of energy markets. Rather than offer a sweeping description of companies operating in this space, I assess a small number of cases and communicate their technologies in depth. Beginning with a comprehensive description of the energy sector, I aim to create a piece that can systematically educate newcomers on the promise of blockchain in the energy sector and the need for P2P markets.[8]

Ultimately, this research presents a beginning rather than an end. We are all responsible for creating a better world for the next generation and without decreasing carbon emissions, our planet will become increasingly unfit for human life. P2P energy markets hold promise in substantially decreasing carbon emissions and increasing

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[8] This research also attempts to provide blockchain-related insights that can be applied to other industries. The deployment of blockchain technology is happening quickly and understanding its use in P2P energy markets can provide value to decentralized markets forming elsewhere.

renewable energy penetration. We can contribute to this change by educating ourselves and others on this promise and pushing for a conducive regulatory environment.

Glossary

Distributed Autonomous Energy Communities (DAE) – A decentralized autonomous organization operating in an energy market ecosystem.

Unspent Transaction Output Model (UTXO) - The technical term for how much digital currency that remains after a cryptocurrency transaction.

Proof of Time - A consensus algorithm based on DPoS, where the value of time is supposed to be protected and validated and is also the main wealth. Time is arranged in the form of tokens, and the only way to mint such a token is to spend time.

Raft Agreement – An easily understandable consensus protocol consisting of electing leaders, candidates, and followers.

Zero-Intelligence Agent - a simple algorithmic trader in a market based on the dumb agent theory who proposes to purchase (bid) or to sell (ask) randomly, subject only to minimal constraints

Application Programming Interfaces (API's) - a software intermediary that allows two applications to talk to each other

Proof of Authentication – A lightweight consensus algorithm designed to enable make IoT devices blockchain enabled.

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