A SYSTEM DYNAMIC MODEL FOR APPLICATION OF BLOCKCHAIN IN THE UNITED STATES ELECTRICITY SECTOR

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by

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The power industry has transformed over the years, with utilities embracing new technologies, new sources of generation, and relying on data to make operations more efficient. Since April 2016, the Brooklyn Microgrid project has become the world's first blockchain electricity transaction which has in turn leaped the energy industry into the future. The electricity system was originally designed and developed with a central production and a passive consumer at the end of the supply chain with their interests represented by electricity operators and distribution system operators. However, with the bulk production of renewable energy from consumers, there is high flexibility in how the electricity sector has turned, which begs the question of relevance of the current system in today's developments.

The future of electricity supply and demand is going to be a two-way (decentralized), accommodating supplies from energy suppliers and individuals who have become generators on

the grid. To achieve this feat of supply and demand of electricity, there is a need for digital communication between computer devices of suppliers and consumers to help manage time resolution, costs, and transactions without bottleneck complexities. Blockchain technology brings ease that could potentially solve the problem for the new electricity industry and allows the dependable and reliable transfer of an asset between two willing parties across a multitude of connected devices without the need for a central controlling party.

However, in all of these, there is a need to identify the use of system dynamics in the qualitative and quantitative control of the existing system to allow continuous feedback and causality to identify necessary system modifications through modeling for implementation.

The purpose of this study is to explore the influence of blockchain technology by establishing relationships and dynamics within the United States electricity ecosystem. We will be creating models from the parts that make up the system and establish their impact in the electricity sector.

The main research question that will be answered is – What will be the consequence of implementing blockchain technology as a foundational technology within the business ecosystem configuration of the United States energy sector?

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AI	Artificial Intelligence
CAISO	California ISO
DAM	Day-ahead Market
DAO	Decentralized Autonomous Organization
DER	Distributed Energy Resources
DSO	Distribution System Operator
ERCOT	Electric Reliability Council of Texas
HVAC	Heating, Ventilation and Air Conditioning
IoT	Internet of Things
ISO-NE	New England ISO
ISO	Independent System Operators
NVA	Network Value Analysis
NYISO	New York ISO
MISO	Midcontinent ISO
P2P	Peer-to-Peer
RTO	Regional Transmission Operator
RES	Renewable Energy System
SPP	Southwest Power Pool
TCE	Transaction Cost Economics
TSO	Transmission System Operator

CHAPTER 1: INTRODUCTION

"Due to growing world population and increasing wealth, demand for energy – specifically electricity – is rising" (Helder, 2015, para. 1). With the United States as the global leader in the production and supply of energy, consuming more than any country in the world. The US economy basically runs on electricity that needs to be reliable, affordable, and sustainable, which is not at present with only 17% of total US electricity generation from renewable sources (EIA, 2019). To have reliable energy systems, demand and supply need to be balanced with the Distributed System Operators (DSOs), Transmission System Operators (TSOs) and Regional Transmission Operators (RTOs) working together as operational regulators responsible for the stability of the energy infrastructure.

Electricity is traded in an electricity market, which is different from traditional capital markets in the US. It is traded in the long-term market, the day-ahead market (DAM), the intra-day market, and real-time market (Jean-Philippe, 2019). The intraday and real-time market are managed and operated by Independent System Operators (ISOs) and Regional Transmission Operators (RTOs) that fosters competition for electricity generation among market participants. There are ten such power markets, with some single covering states like New York ISO (NYISO). The other markets cover California ISO (CAISO), Midcontinent ISO (MISO), New England ISO (ISO-NE), Electric Reliability Council of Texas (ERCOT), Northwest, PJM Interconnection, Southeast, Southwest Power Pool (SPP) and Southwest (FERC, 2019). It is noteworthy to say that the power system considers customers as passive consumers, and their interests are represented by the energy providers because most electricity markets are centrally or regionally organized (Jacobs 2016).

The energy landscape, however, is changing very fast from an encouragement to halt climate change and has brought new technologies to produce and store electric energy. This change has tilted consumer behavior from a passive role of consuming to an active producer or hybrid prosumers. There is a significant increase in renewable energy (EIA, 2019) sources like wind and solar to accommodate the goal of producing green energy that will be sustainable and inexpensive. Also, there is a growing trend to generate and distribute energy closer to consumers in a decentralized form, which does not fit the current centrally generated system (Jacobs, 2016). Digital communication is required between consumer and producer devices as a replacement for outdated systems. As a result, there will be a balance in production and consumption on a real-time basis. Also, consumers can be left assured of lower costs and unnecessary disturbance. Blockchain allows the dependable and reliable transfer of an asset between two willing parties across a multitude of connected devices without the need for a central controlling party (Donker et. Al., 2016). Blockchain technology can overhaul the relationships to create new policies and interdependencies and brings ease that could potentially solve the problem for the new electricity sector.

1.1 Blockchain Technology

In 2008, Sathoshi Nakamoto reported a new payment system used in the financial sector to serve as the basis for the cryptocurrency called bitcoin (Nakamato, 2008). The blockchain has been proven to be inherently secured by design. It has enabled more and more new applications to emerge by focusing on its core functionality – decentralized storage of transaction data and trustless electronic transactions. It uses a peer-to-peer network system that disallows double-spending using a proof-of-work to store history of transactions publicly, Zibin et al. (2017) provide five key characteristics of blockchain

i) Decentralized database: The network is well distributed with every node recording and storing transaction data to maintain the data blocks generated. The consensus algorithms are used to ensure that data is reliable in the distributed network
ii) Peer-to-peer network: a centralized control server will not be needed because communication takes place between peers
iii) Anonymity: Data exchange between nodes follows an algorithm where each user interacts with blockchain with a generated address that cloaks identity of users
iv) Irreversibility of Records: As soon as a transaction is registered on the database, it cannot be changed. The connection has a history of unchangeable transaction records.
v) Computational Logic: For every transaction, computational work must be done that triggers the automatic transaction between users.

The blockchain technology may be in its infancy stage of broader use, but it has so far exerted a great force of disruption. The first experience in the financial sector, its broadening scope in other industries, makes it a technology suitable for more discovery. Even established energy giants are taking it seriously in managing trends in renewable energy sources and distributed energy resources.

1.2 A Changing Industry

Blockchain is often seen as a new technology that could be adapted to different fields. However, it is a new technology to be a replacement for the current transactional model of electrical energy generation and transmission. Blockchain is an essential foundational technology from an economic perspective because it assists consumers to economically manage their transactions. This means that blockchain has the capacity to ensure that transfer of an asset between two people is valid and reliable while eliminating the need for a central controlling body. The present energy system has many transitional roles, and blockchain technology could result in changing many of these roles, upturning some, changing some, and creating newer relationships and interdependencies that will be different from the current system. It is assumed that there is an emergence of a new configuration of the energy system.

1.3 Research Focus

So far, the current trend in the energy system, including the improvement of renewable sources and storage, does not follow the conventional, outdated grid system. Hence, blockchain technology has the potential to ease the transition into decentralized grids. Although this technology is still at its infancy, a few possible incremental applications are added to the electricity landscape and ecosystem. This has limited the scope of this research to view the interaction of the elements affecting the system in the causal loop.

1.4 Problem Statement

It is evident that there is a need for a change with the current energy system to accommodate an increasing development in renewable energy and storage in combating climate change. These developments should give room for the existing electricity system to accommodate innovation because it was initially designed on a centralized system where electric energy is generated from a source and transferred to passive consumers. In fact, the concern is that the present electricity system is obsolete and outdated. It is harder and more expensive to predict the balance between demand and supply without a perception of millions of consumer devices and distributed energy resources popping up outside the grid. Renewable energies like wind and solar give consumers the opportunity to produce and consume concurrently, creating a path into the future of the electricity system, including prosumers, electric providers, and network operators.

Blockchain technology is unlocking newer possibilities to an emerging industry. Many organizations are currently creating use cases for the technology with pilot projects developed into practical use like LO3s' Brooklyn Microgrid, Grid+ and Power Ledger. These are all promising with an incremental change, focusing on different parts of the electricity ecosystem. Which, in turn, will revolutionize and redefine the business of many companies (Marco and Karim, 2017). However, we do not know where the disruptive power of blockchain technology will impact the most.

Subsequently, we know blockchain technology has the potential to veer off the existing electricity ecosystem to create a completely new one. A knowledge gap is imminent for these new possible configurations, and this research will address the implications of the new energy ecosystem in the United States electricity sector.

1.5 Research Objective and Research Questions

More modern technologies have the potential to change the ecosystem of any field. The implementation of blockchain in the electricity sector will significantly improve its ecosystem, affecting the roles, activities, and relationships that make up the electricity sector. Renewable energy resources are going to catalyze the fast adoption of blockchain technology since general consumers are just starting to advance the use of renewables. The uncertainties around the quantifiable impact of blockchain on the ecosystem will make the approach of this study explorative with a future prospect of having it qualitatively analyzed.

The objectives of this thesis are

- to study how blockchain technology can influence the United States electricity ecosystem by citing the use cases already deployed,
- to develop future scenarios on the ecosystem configuration within the United States electricity sector to explore the disruption of blockchain technology, and
- to examine the consequence of implementing blockchain technology as a foundational technology within the business ecosystem configuration of the United States electricity sector.

The business ecosystem is used as a convergent to see blockchain applications for the United States electricity sector. For the purpose of this research, the business ecosystem is defined as a network of organizations, including suppliers, distributors, customers, and government agencies who are tied to each other through relationships and interact corporately and competitively. A theoretical framework based on the business ecosystem in describing the United States electricity sector will be explored in the next chapter.

1.6 Significance of the study

This research study presents a clear explanation of blockchain's functionality on United States electricity. Also, it discusses the following aspects:

- activities or parts that constitute electricity ecosystem in the United States,
- causal loop diagram modeling the system developed with blockchain technology in play, and
- develop scenarios from the model created above.

1.7 Structure of the Thesis

The thesis starts with an introduction to the United States electricity sector and also highlights the purpose of this thesis. Chapter 2 presents the literature review for the subject and why this thesis is necessary. Chapter 3 details the theoretical framework describing how changes in the ecosystem apply to the electricity sector. It details the blockchain technology concept and how it applies to electricity. Chapter 3 also outlines the different actors in the United State Electricity sector.

Chapter 4 discusses the qualitative model used for this thesis. Chapter 5 briefly discusses four different blockchain scenarios in the electricity sector. The study is concluded in Chapter 6 depicts recommendations for future research.

1.8 Summary

The energy sector needs to be digitalized to enhance the development of smart grids and accommodation of renewable energy sources. The introduction of blockchain technology in the electricity sector will allow energy to be traded without the need for a central actor creating a system. In the next chapter, the study is analyzed to have a better understanding of the subject.

CHAPTER 2: LITERATURE REVIEW

This study utilizes a combination of the approaches identified by (Voets, 2017) (Burger et al., 2016) and (Webster and Watson, 2002) with a framework that ensures consistency in results and conclusions. The major sources of contribution are from large academic journals (IEEE, Energies, ScienceDirect, Proquest resource and energy economics, energy and fuels, and renewable energy research journals, etc.) and within most energy conferences. We also look at the general research contribution from Google Scholar to establish a general baseline of the topic and to identify all relevant literature. With the identification of relevant literature, the results are analyzed and synthesized to identify gaps and propose frameworks for future research (Muller-Bloch and Kranz, 2015). A conclusion will be established to provide researchers with the main contributions of the paper.

The related literature is in on the following topics: (1) the inter-organizational network concepts, (2) system dynamics (3) blockchain in the electricity market, (4) the roles of actors in the transmission and distribution of electric energy. The related research section focuses on four research studies that are similar to this proposal in subject matter and methodology.

2.1 Intergovernmental Network Concepts

Davidson et al. (2016) explained this concept using the neoclassical analysis of economics that every technological improvement should lead to lower production costs. Blockchain, as technological innovation, may lead to lower production costs resulting from organizational efficiency. Gary (2018) argues that while institutions can promote lower transaction cost to boost economic growth. Transaction costs mostly come from ambiguous sources, like the cost of writing a contract or enforcing it with a resolve to weigh in on trust. However, if these transactions were clear without hassles, there would be no need for trust, which would be impossible in business. Business transactions need a reliable recorder or ledgers that leads to derivative costs from keeping such records. A centralized and strong organization is required to create high trust resulting in a cost.

2.2 System Dynamics

System Dynamics was founded by Jay Forrester at MIT in 1961 (Forrester, 1961), has been described as a "rigorous method for qualitative description, exploration and analysis of complex systems in terms of their processes, information, organizational boundaries, and strategies; which facilitates quantitative simulation modeling and analysis for the design of system structure and control" (Wolstenholme, 1990). Using system dynamics involves the use of qualitative and quantitative structuring tools such as causal loop diagrams and stock and flow networks, respectively. The use of system dynamics can be performed in either isolated or participative modes. Traditionally, the system dynamics modeling approach involves (from the System Dynamics Society website, 2019):

• Defining problems dynamically, in terms of graphs over time.

• Striving for an endogenous, behavioral view of the significant dynamics of a system, a focus inward on the characteristics of a system that themselves generate or exacerbate the perceived problem.

• Thinking of all concepts in the real system as continuous quantities interconnected in loops of information feedback and circular causality.

• Identifying independent stocks or accumulations (levels) in the system and their inflows and outflows (rates).

• Formulating a behavioral model capable of reproducing, by itself, the dynamic problem of concern. The model is usually a computer simulation model expressed in nonlinear equations but is occasionally left without quantities as a diagram capturing the stock-and flow/causal feedback structure of the system.

• Deriving understandings and applicable policy insights from the resulting model.

• Implementing changes resulting from model-based understandings and insights.

2.3 Blockchain in Electricity Market

With the rapid development of sustainable electric energy technologies and network technologies, the electricity internet is expanding on innovation in the electricity sector. The involvement is decentralized, bringing in more participants in the generation and transfer of electric energy, which brings challenges such as control, trust, verification, and audit mechanism. In November 2008, Sathoshi Nakamoto proposed a new payment system used in the financial sector to serve as the basis for the cryptocurrency “Bitcoin." He presented two radical concepts that had metamorphosed into different applications. The first was the Bitcoin, a virtual cryptocurrency that preserves its value without support from a central authority or financial entity. It maintains its value over a decentralized peer-to-peer network where the entity of ledger is held securely and can be verified and audited. The other concept is blockchain, which has proven to be of further practical application than the cryptocurrency method.

Blockchain application to electricity is about the management of activities within the energy internet that contains the microgrids and the internetwork where production, consumption, and transaction need to be managed autonomously. Furthermore, the energy and information between these systems are well interconnected, requiring transparent and secured transactions. Having this principle, if the traditional approach is considered, a centralized institution would act as the throughput for all transactions. However, the openness of the transactions and energy mix will be assumed. The characteristics of blockchain technology, on the other hand, will remain consistent, open, and transparent. The blockchain has been proven to be inherently secured by design and has enabled more and more new applications to emerge by focusing on its core functionality – decentralized storage of transaction data. With mechanisms like smart contracts that operate on individually defined rules like quality, price, and quantity - an autonomous match of distributed providers and their prospective can be made feasible.

2.4 The roles of actors in the transmission and distribution of electric energy

As the adoption of new technologies, which includes smart meters, renewable energy, and improved battery system increases, and electricity companies are radically improving their value and business models to accommodate customers' use patterns and preferences (GE, 2017). The new wave of prosumer users has also extended the roles of every actor and their relationship with the national grid. End-users have an increasing choice that is giving them more control over their electricity use managed with a mobile experience.

2.5 Summary

According to the study of previous research, blockchain as technological innovation is both necessary and important in bringing in new participants in the generation and transfer of electric energy, while maintaining trust and control. This study expounds on the blockchain concepts in relation to the United States Electricity sector and has not been understudied in any thesis. The next chapter expands on the theoretical framework relevant to the study.

CHAPTER 3: THEORETICAL FRAMEWORK AND CONCEPT

In chapter 2, the literature review was examined. Chapter 3 presents a theoretical framework for the concepts that affect the ecosystem as it applies to the electricity sector in the United States.

3.1 Inter-organizational Network Concepts

This thesis focuses on the disruption effect of blockchain in the United States electricity sector. To view the entire electricity sector, the inter-organizational network concept is applied in this section. The concepts include the business ecosystem, porter value chain, and value network.

The framework defines the focus of the inter-organizational network concept, which comes in two different directions. The first direction considers as an organization or single entity firm, referred to as egocentric. The second direction is socio-centric, a perspective seen when observed as a network. Because the electricity system is not a single entity, a socio-centric view is chosen. Furthermore, the network should be broad enough to accommodate possible future configurations. And lastly, the criteria will include a network system where competition and cooperation can both exist.

3.1.2 Business Ecosystems

A business ecosystem involves a network of organizations, including the producers, suppliers, distributors, customers, competitors, and government agencies (Hayes, 2019). It is noteworthy that these networks are structured business processes. Business ecosystems are modeled after the natural ecosystem, a word coined by the British botanist Arthur Tansley in 1930. Like the natural ecosystem, the business ecosystem undergoes the same phenomena, such as competition, specialization, corporation, learning, growth, exploitation, and more (Rothchild, 1990). James Moore was the first to adopt the biological concept of ecosystems to relate it to the business environment in his 1993 Harvard Business Review article titled “Predator and Prey” (Moore, 1993). It applies to say that every company is part of a whole big picture within the business environment where they participate through competition and collaboration to create the future. The economic community produces goods and services of value that are consumed by members of the ecosystem. Moore’s view of the business ecosystem involves suppliers, producers, competitors, collaborators, and other stakeholders. He also added that there were no clear-cut boundaries in defining a business ecosystem that contains actors who were in competition and collaboration concurrently.

Another approach to view the business ecosystem is an organizational approach, where it describes a changing structure consisting of organizations working together. Peltoniemi et al., (2004) described the organization as any party that can influence the system, which can be a small firm, a large organization, universities, public organizations, and more. The emphasis here is their interconnectedness, a notion that extends to mean if the interconnection is down, it can lead to failure of other members in the ecosystem.

3.1.2 Ecosystem Members

In the previous section, the inter-organizational network was created. In this section, we will describe the ecosystem configuration for the United States electricity sector, which will include the members of the business ecosystem. The business ecosystem consists of participants that are sustaining the ecosystem and can be a single entity, groups, organizations, and a group of organizations. These participants, as before mentioned, can be a part of a different network, from a different value chain or different sector. While each participant act in their specific function, they are also connected through relationships maturing from exchange processes. Every actor can also be assigned unique roles outside their activities in the ecosystem.

3.1.3 Participants and Relationship

Participants in an ecosystem can be visualized with respect to their relationships in the network, another approach is using a business model to describe their function, and lastly, we can use Network Value Analysis (NVA) to recognize where the value was created in the network.

The first approach visualizes the actors in the ecosystem. Nodes and links are elements representing the actors and links between them. The nodes are tagged with names of the actor, the class it belongs to, and other attributes that define it like its geospatial position. The links can be either direct or indirect are the connections between different nodes whose attributes are the strength and duration of the relationship.

In the second approach using the business model, the actor's relationship consists of value creation and revenue gained from the value created. The actors' position in the ecosystem can change if its resources, capabilities, and financial standing (Kinnenen et al. 2013).

The latter approach uses network value analysis (NVA) to describe business ecosystems. With this approach, NVA assesses the resources from the actors that contribute to the network through their linkages and relationships using their network influences.

Having discussed the three approaches, they can be said to be complementary to each other. Though each approach differs, they all describe participants and their relationship in the ecosystem.

3.1.4 Transaction Cost Economics

The changes that are introduced into the electricity ecosystem due to the blockchain introduction will be discussed in this section. Transaction Cost Economics, TCE provides an insight into this. TCE is an economics term used to describe the cost of making an economic trade when participating in a market (Williamson, 2007). The main question TCE asks is why some transactions take place in the market and some in hierarchies? This question can be extended to blockchain; why will some transactions take place in blockchain rather than in the market or organization?

Blockchains can help in facilitating transactions based on their trustless and decentralized attributes. With this, blockchains can enable new types of contracts through a consensus of nodes on the network. Then, blockchain can deliver a way to control transparency by eliminating the need for trust which will also drive down transaction costs (Shyamasundar, 2018). Compared to other ledger technologies, blockchain is more reliable in a decentralized business framework.

3.1.5 System Dynamics

System dynamics models can simulate the outcomes of different combinations of interventions to help in identifying the best leverage points for enabling change. Over the decades, system dynamics has proven to be a very effective and useful tool in mapping out the relationships and basic dynamics within complex organizations. The basic idea behind system dynamics is that of feedback loops that try to capture the interactions between parts and how they lead to an overall pattern of behavior over time. The results can show which leverage points result in the most desirable outcomes and suggest the timeframe in which results would be expected. Models may also highlight potential unintended consequences.

3.1.5.1 Main Tools in System Dynamics

3.1.5.2 Causal Loop Diagrams and Feedback Loops

Atwater and Pittman (2006) suggested that causal loop diagrams are the basic starting point for system dynamics because drawing these diagrams is fairly simple and can be handled easily. A causal loop diagram is a simple map of a system with all its constituent components and their interactions. By capturing interactions and consequently the feedback loops, a causal loop diagram helps to reveal the basic structure of the system. The feedback is the process in which changing one quantity changes the second variable, and the change in the second variable, in turn, changes the first.

For an in-depth review see Sterman (2000), but for a brief explanation, Atwater and Pittman's explanation (2006) is useful: "In each two-variable link, the variable at the back of the arrow is said to cause a change in the behavior of the variable the arrow points to. The type of change is depicted using either '+' or '−' signs. A '+' means the two interconnected variables change in the same direction, and a '−' means the two variables change in opposite directions.

For example, if two variables are linked by an arrow with a '+ 'sign, it means that an increase in the cause variable results in an increase in the effect variable. Similarly, two variables linked by an arrow with a '−' sign is read as an increase in the cause variable, resulting in a corresponding decrease in the effect variable. Basic loops are created when two or more variables are linked together using arrows, which result in a closed-loop. A closed-loop is the basic piece for describing dynamic behavior in a system." (p. 280) Sterman (2000) provides an important clarification in terms of the conceptualization of the links between variables: "Link polarities describe the structure of the system. They do not describe the behavior of the variables. That is, they describe what would happen IF there were a change. They do not describe what actually happens." Closed feedback loops can represent two types of behaviors. First, goal-seeking or stabilizing behavior arises from a feedback loop when there are odd negative signs in a loop (Sterman 2000). This basic rule of thumb arises from a simple conceptual simulation around the loop: if there is a small change in one variable, the change disseminates around the loop to cancel out the initial change because there is a reversal in the change in one of the links between two variables (which can only occur if the sign is '−' (negative). This type of feedback loops is called 'negative' or 'balancing.' Second, reinforcing or amplifying behavior is obtained when a feedback loop has zero or even negative signs. This type of feedback loops is called 'positive' or 'reinforcing' since a small change is amplified around the loop.

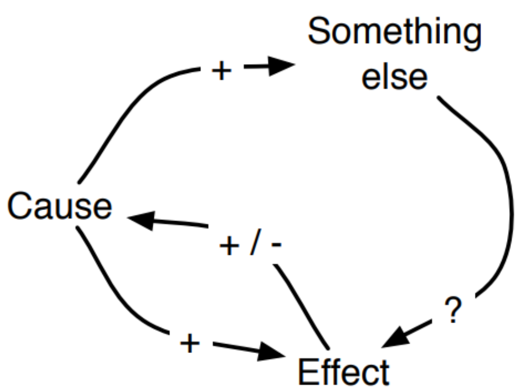

Fig. 1 Causal Loop

3.1.5.3 Stocks and Flows

Stocks represent the accumulations existing in a system and characterize the state of the system (Sterman 2000). For example, the number of people waiting in an Accident and Emergency (A&E) area in a hospital can be considered a stock. Stocks increase due to inflows, e.g., people arriving at A&E, and they decrease due to outflows, e.g., people leaving A&E after being treated. Stocks are responsible for the delays as they accumulate the difference between inflows and outflows (Sterman 2000).

3.2 Blockchain Overview

Blockchain is a data structure formed from a sequence of linked blocks. The block holds a complete list of data transaction records, which is more like a public ledger. The data structure is composed mainly of a block header and a block body. The previous hash is contained in the block header. The block has one parent block that connects previous blocks to maintain the integrity of the chain. The first block is called the genesis block and has no precedent. Information in the genesis block is encapsulated and passed down with a hash value header for subsequent blocks as shown in Figure 1.

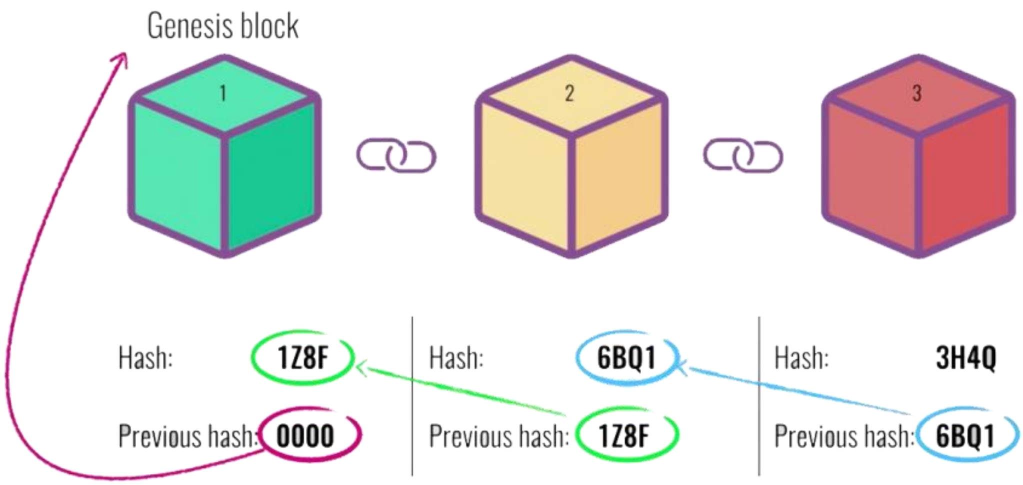

Figure 2: Blockchain block structure (Evelyn, 2018)

In the bitcoin scenario, the transaction information includes the sender ID, the recipient ID, the amount, time, the block ID, a timestamp, and a hash value relating the block with a previous one. The information is broadcast in real-time and shared with an entire peer-to-peer network that records the historical information of the block. When verified, it becomes a block in the network that is reliable and transparent to the entire database (see Figure 2).

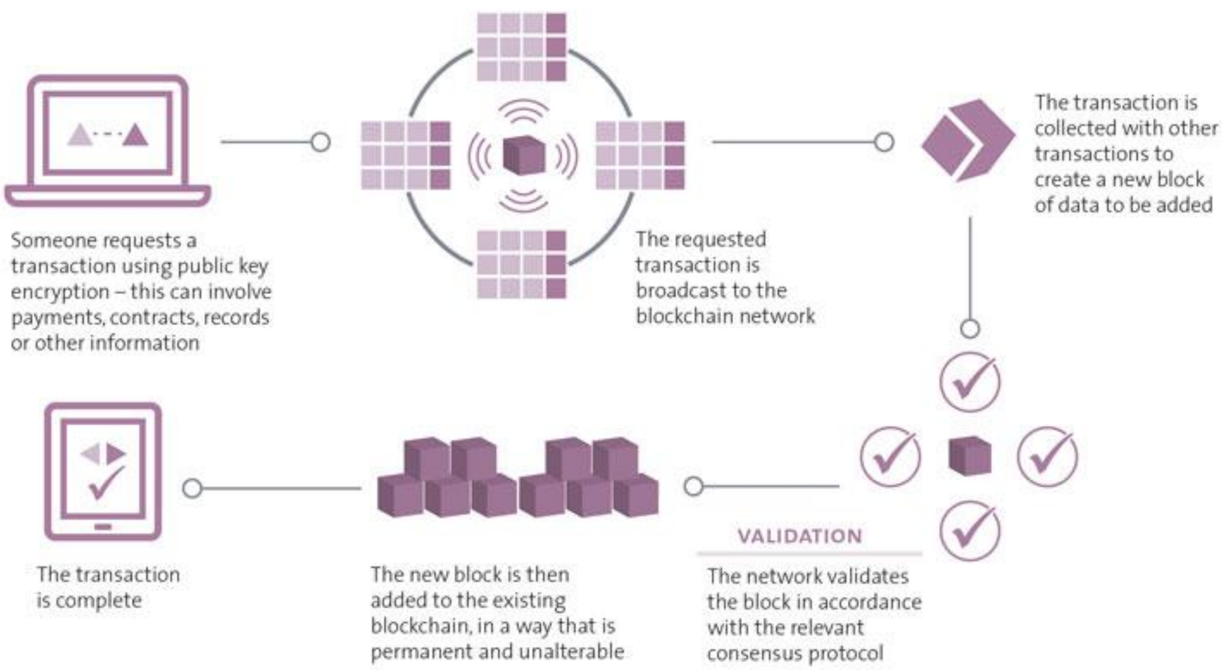

Figure 3: How blockchain works (Ashurst, 2017)

3.2.1 Block

A block is a structured data composed of – a block header and a block body, as shown in Figure 3. The data would bundle all set of transactions and distribute them to all nodes in the network. The block contains a header, which is the metadata to verify the validity of a block. Particularly, the block header is made up of the following elements:

(i) Block Version: it shows the current version of the block structure

(ii) Merkle tree root hash: a cryptographic hash of all the transactions in the block.

(iii) Timestamp: current time to the seconds in universal time

(iv) nBits: target for a valid block hash.

(v) Nonce: a 4-byte field, random value creators can use as they want.

(vi) Previous block hash: a hash value is refereeing to the parent block.

The block body contains transactions created by users to submit to the network. Consensus rule applies to the blocks such that only valid blocks with the longest and most valid chain will be worked on and accepted by the greater community of nodes or computers. When a block is created, each node in the network processes and decides to where it fits in the blockchain ledger.

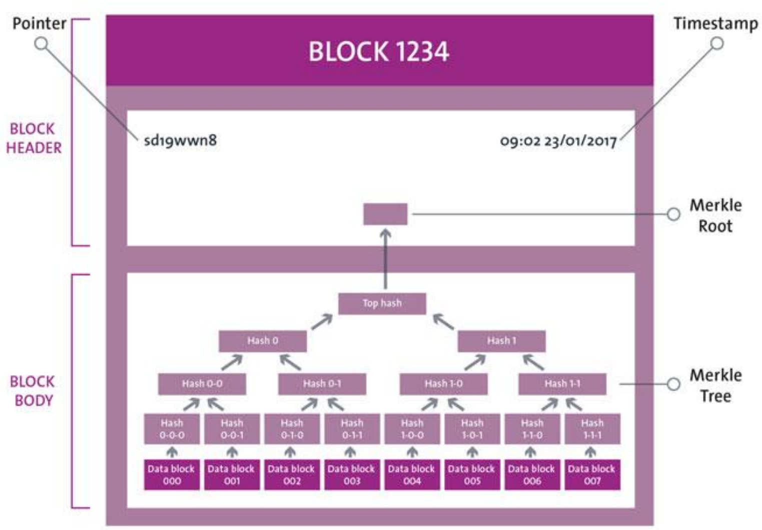

Figure 4: Taxonomy of a block (Ashurst, 2017)

3.2.2 Key Architecture Concepts

The key architecture of blockchain consists of the data layer, consensus layer, mining layer, contract layer, and the application layer (Xiao, 2016). The data layer is the primary medium that transports bits that are made up of the underlying data block and timestamps. The consensus layer is a protocol that describes the format of the ledger to be publicly visible, and a function that allows anyone to identify the consensus ledger out of a pool of several ledgers. It must also allow new blocks to be added to the ledger. The mining layer integrates economic factors with the blockchain. The protocol allows the issuance and distribution of economic incentives to attract participants in contributing to computing power. The contract layer captures various script codes, algorithmic mechanisms, and smart contracts. This layer creates a protocol for verifying conformity with the specification. The application layer implements desired functionality by allowing overlays, API integration, and applications.

3.2.3 Key Characteristics of Blockchain.

Blockchain, at its core, is a good database like the web developed to manage transactions of assets. It is, however, more transformative than the web with unique characteristics, as highlighted below.

a) Decentralization: Since a blockchain system adopts a Peer-to-Peer (P2P) network mode, a centralized control server will not be needed. The network is well distributed with every node recording and storing transaction data to maintain the data blocks generated. The consensus algorithms are used to ensure that data are reliable in the distributed network.

b) Anonymity: Data exchange between nodes follows an algorithm in which each user interacts with the blockchain via a generated address that cloaks the identity of users. Although a flawless privacy is not guaranteed, procedural rules of blockchain ascertain some trust.

c) Trustless: The blockchain system verifies every transaction with a mathematical algorithm to confirm the transfer of value and create a history of the ledger of activities. Although trustless sound counterintuitive for a trustworthy system, the operating rules are open and transparent. All transactions update on all nodes around the world that require mutual authentication of multiple nodes before one can make a change.

d) Secure: Within connected block to precedent and successor blocks, there is a chain of unchangeable transaction records. A hacker will need to change the single record and precedent records to successfully change the record without detection. And, blockchain has mechanisms to guaranty its security. All records are protected with cryptography. Every participant has their private keys assigned to the transaction made and acts as a digital signature.

3.2.4 Distributed Consensus

The distributed consensus is an elaborate, largely mathematical model by which anonymous individuals can transact in a peer-to-peer network. Miners add new blocks to the chain after validating new blocks, which are then added to the chain. The distributed consensus algorithm (DCA) is employed as the protocol for adding new blocks to the existing blockchain. Since miners are rewarded, and a limited block can be added, DCA becomes useful in facilitating these new additions (Salimitari et al., 2017). Examples of DCA include:

1. Proof of Work (PoW): It is a consensus protocol used for Bitcoin networks. POW operates by setting a target value that must not surpass the worth of the hash in any given block for it to be integrated into the blockchain. Each node of the network calculates a hash value of the block header containing the nonce. By so doing, one node in the network will averagely find a block with the given value in a set time range. The block will broadcast to other nodes that will mutually

confirm the correctness of the hash value. The algorithm rewards miners who solve mathematical problems, while validating transactions and creating new blocks.

2. Proof of Stake: While evidence of work reward miners who solve a cryptographic puzzle to validate transactions and create new blocks. Proof of stake works by choosing a new node to form the next block on a random selection. A set of validators then takes turns proposing and voting on that block, with each validator's vote depending on the size of their deposit (stake). The selection is randomized to stop a single richest person from being dominant in the network. Compared to PoW, PoS potentially result in faster blockchain because of its lower energy consumption and a decrease in the possibility of an attack. While most blockchain adopts the PoW at the beginning, they slowly move to PoS. For example, Ethereum's Ethash (PoW) is switching to Casper (PoS).

3. PBFT: The practical byzantine fault tolerance algorithm is used to deploy consensus in a blockchain system. They have their origin with the byzantine army, where a consensus of the generals is needed to advance a plan. Coordination between the army generals is needed to attack a fortress in the Byzantine army. Blockchain nodes also need to reach a consensus to either validate or reject a block. The main challenge is to have a veto consensus of reliable nodes superseding the malicious ones.

4. Delegated Proof of Stake (DPoS): This method counteracts the effect of massive stakeholder power as with proof of stake. DPoS works like PoS system, except individuals, elect delegates to generate a block. Thus, those with smaller stakes can team up to magnify their representation, thereby creating a balance in the system. These delegates are responsible for protocol rules and system parameters, such as transaction fees, transactions per block, block size, and more.

3.2.5 Three Phase of blockchain evolution

Just like the internet went through developmental stages, blockchain is also undergoing similar progression and development. In this section, the development of blockchain technology is discussed.

1. Cryptocurrency: Blockchain technology began with Bitcoin, and many developers still consider it as a more suitable fit for the future of monetary systems. Blockchain derives its name from the underlying structure consisting of 1-megabyte files called Blocks, which are ledgers containing financial transaction information shared publicly. The entire network relies on a complex mathematical puzzle called Proof of Work that is chained with previous blocks. Other nodes in the network can validate the correctness of blocks generated from every transaction. However, bitcoin does not support creating complex distributed applications on top of it.

2. Smart Contracts: They are transaction protocol that runs on the blockchain to facilitate, execute, and enforce the terms of an agreement. This feature was technologically unviable until the emergence of blockchain technology, specifically smart contracts, which has significantly contributed to the momentum of blockchain. The main aim of the smart contract is to automatically execute the terms of an agreement once the specified conditions are met. The system releases digital assets to all or some of the involved parties for predefined rules.

The idea came from Nick Szabo in 1993, where he defined a smart contract as a computerized transaction protocol (Szabo, 1997). It executes the terms of a contract while based on the emergence of blockchain 2.0. The smart contract code is stored on the blockchain, with each contract identified by a unique address that users operate with. The blockchain consensus protocol enforces the correct execution of the contract. Advantages such as speed, transparency, efficiency, and low cost is making smart contract useful for many applications.

3. Decentralized Autonomous Organization (DAOs): DAOs are presently the most complex version of smart contracts. Its underlying concept is to decentralize traditional organizations like governance by embedding the bylaws of the organization into a smart contract code by using complex token governance rules. The entity of the code lives on the internet autonomously and depend on people to perform specific tasks that automation cannot do. Modern DAOs use complex smart contracts on another blockchain.

3.2.6 Blockchain applications in the electricity sector

The peer-to-peer (P2P) network and distributed time-stamping server establish how blockchain technology becomes completely decentralized while relying heavily on cryptology to guarantee security. The four distinct applications of blockchain in energy sectors are (Andoni et al. 2019).

1. Utility billing: Applications where utilities and third parties use cryptographic identities to manage meter and help customers navigate electric usage.
2. Certificate of origin: These are applications where renewable energy generators and certificate buyers use smart contracts to structure the overall process.
3. Demand response: Blockchain application where utilities and third parties use smart contracts to conduct aggregation, offering time measurement and verification, reimbursement, and trading for electrical efficiency.
4. Transactive energy: Any blockchain application integrated to trade electricity during a time frame and allows devices to automatically respond to local conditions on the distribution grid in real-time.

3.2.7 Ethereum

Ethereum is an open-source blockchain platform introduced in 2015 with an objective of providing platforms for decentralized applications, DApps helps developers to build and publish distributed applications (Buterin, 2013). It modifies the blockchain concept by becoming a computing platform and a scripting programming language (Turing complete), which runs on blockchain architecture.

The applications on Ethereum run on its platform-specific crypto-token, Ether. It is used to store, transfer, and pay for computation and transaction costs. Ethereum's idea is to run applications on its virtual machine with gas (Ether). Just like bitcoin, Ether is mined with Ethereum, to pay for the gas for every transaction. Ethereum enables user-created smart contracts for transaction-based DApps. The applications are open-sourced, functioning in an autonomous manner with all data and records kept on a public and decentralized blockchain.

The two terminologies used for the gas are;

(i) Gas limit: how much computation a user would use, and

(ii) Gas prices: the price a user will pay for the Ether per unit, which is used by miners to rank transactions. Every requested transaction need gas that will be declined without it.

3.2.8 Blockchain Smart-Grid Rationale

The smart grid is more than an upgrade to the existing electric grid. It is an intelligent network of sensors and equipment to manage the production and transfer of extensive decentralized energy resources. The main advantage of smart grids is its ability to integrate several energy sources that provide a supervisory platform for production and consumption. Other advantages include the active participation of consumers, it provides accommodation for storage systems, provides power quality that meets the demand in the digital economy, anticipates and responds to system disturbance in self-healing manner, operates relentlessly despite cyber threats and natural disasters. A smart grid increases the reliability and sustainability of the power grid.

There are growing opportunities in the use of smart grids by adding battery storage systems, ESSs with renewable energy system RES, creating the buffer between the demand and supply. Such that the power system optimizes the voltage using electronic devices at their highest efficiency and allowing fault tolerance in the electrical grid.

Both ESSs and RES are essential to how a micro-grid can be sustainable when the primary grid is out. The smart storage system is vital in solving the duck curve scenario. As depicted in Figure 4, Duck curve was coined by California State grid operator (CAISO) named after the shape of a grid with midday solar bellies and steep evening neck in its supply-demand curve. ESS will be dispensing electric energy stored as demand rises above supply.

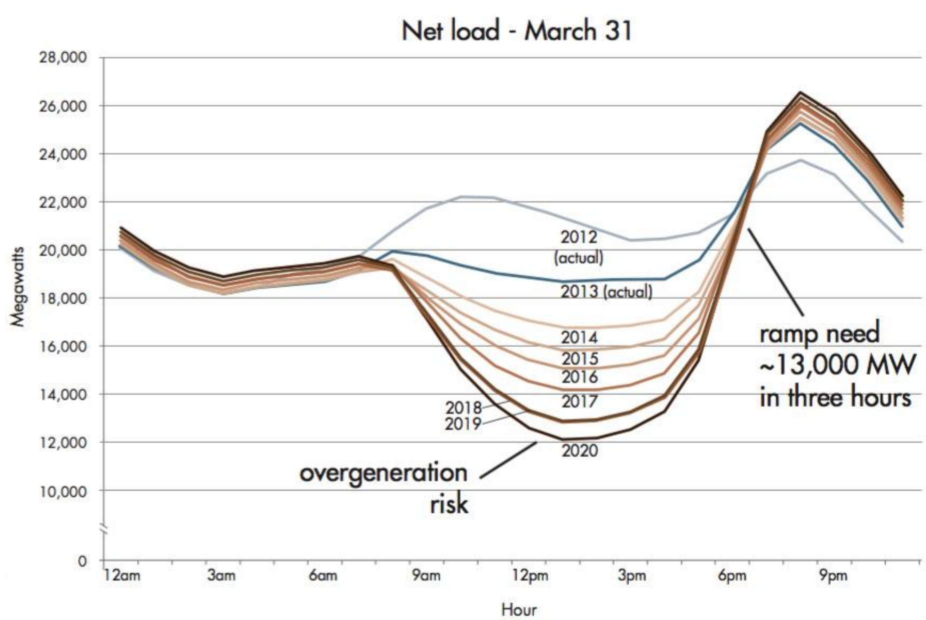

Figure 5: Duck-Curve, (CAISO, 2013)

3.3 Electric Energy Domain

This section aims at examining the blockchain cases in the US electricity sector. This would result in a profound understanding of the trends and potential applications currently happening in this domain.

The Electricity sector is currently experiencing the transformative potential of blockchain in the energy sector, as shown by increasing startups, pilots, trials, and research projects. Electricity sector decision-makers and utility companies are resolved to the solutions offered by blockchain to challenges faced in the industry. The German Energy Agency reports that blockchain technologies will significantly improve the current energy enterprise practice (Burger, 2016) improve internal processes, enable better customer satisfaction, and reduce overhead costs. The task of integrating small-scale renewables, distributed generation, consumer participation, and flexible service in the electricity market can be daunting. With Blockchains' inherent attributes, the solution to control and management of decentralized complex electrical systems and microgrid can be made possible. Blockchain can also be used as a trading platform for prosumers and consumers to trade interchangeably through a peer-to-peer network surplus energy. Consumer involvement is active and will be secured and documented with an immutable, transparent, and reliable smart contract. By allowing automated trading platforms, there exists an efficient way to manage information on the price and costs of electricity to consumers while at the same, provide them with incentives for demand response and smart managing their consumption.

One other advantage of blockchain is that it empowers local electricity and a community-based microgrid that supports local power generation and consumption (Canto, 2017). With a community-based microgrid, there is a large reduction in electric energy loss in transmission, which in turn reduces expenses on network upgrades. However, electricity is still delivered through a physical grid; hence demand and supply still need to be prudently controlled to fulfill the technical requirements and power stability. According to Eurelectric, (Eurelectric, 2019), the adoption of blockchain in electricity is hindered because of the physical exchange of electric power compared to its application in other sectors like finance. However, it can be used to record ownership and origins of the energy supplied or consumed. This finds an application in solutions designed for smart charging and sharing of resources as with community grids. Other applications include data storage for smart grids when integrated with IOTs; it helps to enable a more efficient flexible market, securing supply, and improving network resilience (Otuoze et al. 2018).

According to Deloitte (Deloitte, 2018), electricity market operations could become more transparent and efficient. Then, this could improve competition and facilitate consumer mobility and the switching of energy suppliers. If cost savings opportunities are realized, we could leverage the technology to improve on fuel poverty and energy affordability issues.

3.3.1 Blockchain potential on US electricity sector operations

The use case application of blockchain for energy companies and platforms is enormous. The potential applications and business model which might be affected are briefly discussed below

1. Billing: Blockchains through smart contracts and smart metering can be used to authenticate billing for customers. It will help to increase the speed of exchange, reduce transaction backlog, makes auditing verifiable in almost real-time. The potential for use with utility companies includes; energy micro-payments, pay-as-you-go, and prepaid platform solution (Canto, 2017).

2. Sales and Marketing: Value-added solutions can be added as a sales mechanism. Along with artificial intelligence (AI) and machine learning, blockchain can build a consumer energy profile and tailor energy solutions to them.

3. Trading and Markets: The market operations are being disrupted as blockchain becomes a trading platform for wholesale market management and commodity trading.

4. Automation: Because blockchains are inherently decentralized (Burger et al. 2016), they can enhance control in energy systems and microgrid (Indigo, 2017). P2P electricity trading is enabled by adopting the local energy system and can increase “behind the meter activities” – a phrase known for electric self-production and self-consumption.

5. Smart grid applications and data transfer: Blockchain’s application can be further experienced with communication devices. In the smart grid, intelligent devices like advanced meters, monitoring equipment, control, and energy management systems can provide secured data transfer and standardization, all empowered by blockchain technology.

6. Grid Management: Blockchain helps in providing flexible service to a decentralized network in managing assets. By providing a flexible trading platform, the networks can be upgraded in an inexpensive fashion, thereby lowering the cost of network use.

7. Security and identity management: Transactions made through the blockchain platform will benefit from its cryptographic method, thereby protecting the privacy and confidentiality of the parties.

3.3.2 Possible Use Cases of Blockchain

In preparing for current and future energy use with blockchain technology, the following use cases are considered to help a responsible, productive task for production and consumption of electricity.

1. Tokenization: One way to launch smart consumption of electricity is by using cryptocurrency to tokenize the grid facilitating various energy market transactions. Energy will become easier to

exchange between consumers and producers, making electricity a tradeable commodity with a defined value. Grid+ is an American startup using a tokenization concept.

2. Microgrids: Centralized power grid used to be the focus of power engineering. However, they are also inefficient as bulk energy between 6-8% (EIA, 2017) is lost during transmission. Microgrids are positioned to stop these losses of electric energy from long distances. By localizing the grid, there is also a significant stop in energy losses. Blockchain technology can use its distributed ledger properties to build digital blocks for the microgrid to monitor electricity generation and consumption. Example of companies using this concept includes drift and LO3

3. P2P Energy Trading: as energy storage battery systems progress, the opportunity to become a prosumer to sell electricity on a peer-2-peer basis gets even better. Blockchain can provide the digital platform to track energy storage and help to promote transactions with energy trading peers.

4. Accelerating adoption of Electric Cars: electric vehicles' adoption is rapidly increasing with the corresponding response from manufactures and regulators. Blockchain technology can help monitor peak energy prices and help to charge station owners in tokenizing charging and conducting transactions.

5. Reducing and Tracking Carbon Emissions: Personal and communal carbon emission data can be tracked to lessen its rate of increase and improving our behavior. Blockchain offers the opportunity to tokenize energy credits for easy disbursement. These credits can be procured by companies or people as a punitive measure to encourage devotion to emission standards. Veridium Labs is an example of a startup that tokenize carbon credits.

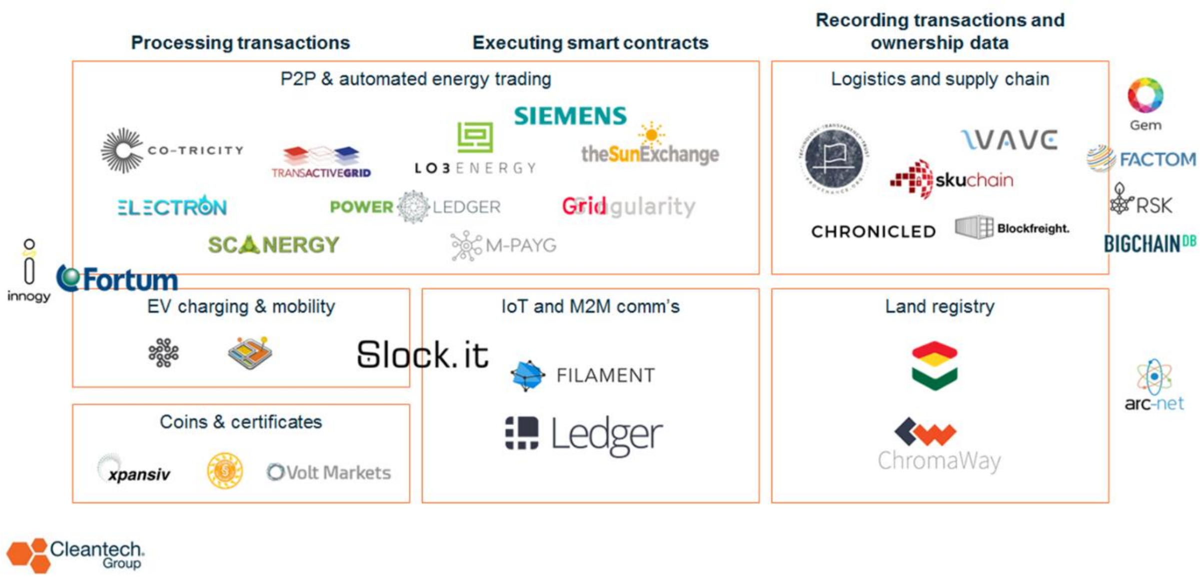

Figure 6: Blockchain use case in the energy industry (Cleantech Group, 2017)

3.4 Actors in the United State Electric Transmission and Distribution

End-users increasing different choices will lead them to seek out power providers that offer them control over their electricity usage and costs via well designed mobile and other customer experiences. Utilities and power providers are aggressively gearing towards the prosumer-centric energy model to catch up with disruptors entering the market. Now, the different players in the United States electricity generation and distribution can be identified. The United States power system is a large complex system of systems (shown in Figure 6) that encompasses the generation, transmission, and the numerous institutions of operations, scheduling, and oversights. The system is incomplete without distributed energy resources (DER) and the end-users.

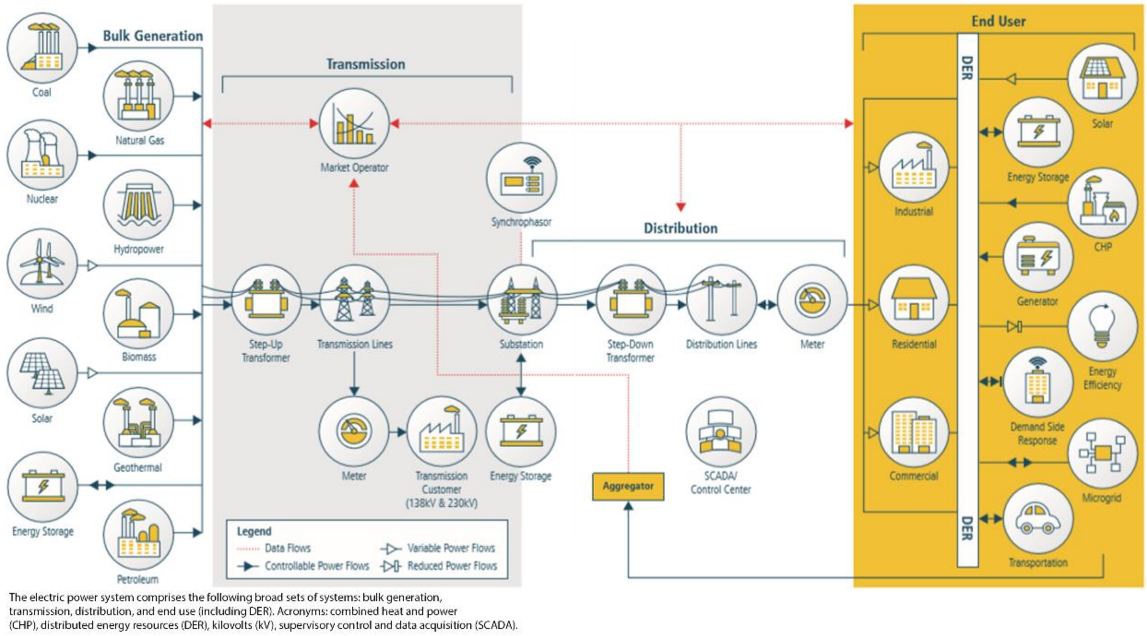

Figure 7: Schematic representation of the U. S Electric Power System (Energy.gov, 2017)

3.4.1 Generation

The electricity sector is undergoing revolutionary changes, with the focus of generation changing from coal dominance to other sources like natural gas, nuclear energy, and renewables. Global focus on reducing CO2 emissions and the discovery of natural gas resources that can be recovered through hydraulic fracturing (EIA, 2010) is making this trend possible. In 2014, there are over 6,500 running power plants delivering at least one megawatt of power, delivering in total near 3764 billion kWh of electricity that powered over 147 million residential, commercial, and industrial customers. The United States power generation mix is diverse and often changes with market growth, advancement on power generation technologies, policies, fuel costs, and events.

Today, coal and natural gas account for 62.7% of generations, nuclear energy is 19.7%, hydroelectric, and renewables, including wind, hydro, and solar contribute 17.6% to the energy mix (EIA, 2020). The United States Energy information administration estimated that an additional 30 billion kWh was added from the small-scale photovoltaic system in 2018.

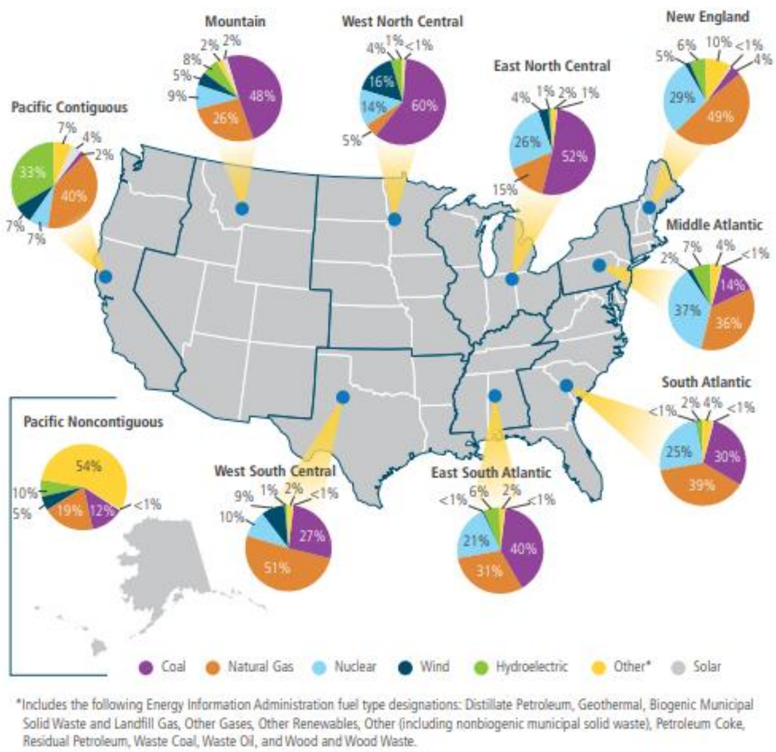

Figure 8: Electric Power Regional Fuel Mixes (Energy.gov, 2017)

The availability of primary energy resources like coal and natural gas and renewable sources like wind and solar differs across the nation (Figure 8), and this greatly influences the uniqueness of power generation from different regions.

3.4.2 Transmission

Generating stations and local electric companies are linked in the power grid by transmission network power lines. These transmission lines are networked in the continental US of 48 states. The network that operates with alternating voltage has nearly 697,000 circuit miles and around 21,500 substations that operates at 100 kilovolts and above. Two hundred and forty thousand circuit-miles of the network are high voltage, operating at 230 kV and above (Energy.gov, 2017). The transmission network also contains substations that are situated at the intersection of the bulk electric system, composed of transformers, circuit breakers, and control equipment. System operators cannot control electricity flow over the AC grid because electric power generated flows from generation to load through many paths at once, and the current follows the path of the least electric resistance.

The transmission and distribution systems face losses associated with electrical resistance and conversion losses that amount to a significant loss of up to 5 or 6 percent of the total electricity that left the generation plant (EIA, 2017). Every transmission line has a physical limit to how much power it can move at a time, and that depends solely on the power system. These physical limits are the primary drivers determining the power price differences in the specific market or utility area.

3.4.3 Distribution

The distribution system includes a large array of stakeholders involved in the final delivery of electric power to the end-users. At this stage, distribution transformers step down high voltage to a useful low voltage for lighting, industrial equipment, or household appliances. The distribution operators are responsible for delivering efficient and reliable power that meets the minimum standard of quality. Power quality refers to no fluctuations in the voltage and current, which could damage equipment or reduce the quality of service.

High voltage transmission lines are fed into a substation that steps down the voltage from very high voltage to low voltage. Several of the distribution feeders are connected by a collection of switches on the distribution bus, and as they pass through more transformers, the voltage can then be further stepped down before it reaches the end customer.

3.4.4 Distributed Energy Resource (DER)

DER is electricity-producing resources or controllable loads that are directly connected to a local distribution system or connected to a host facility within the local distribution system. They are located on a utility's distribution system or at a customer's premises. They are uniquely different with respect to their attributes, with the main one coming from a grid management perspective. DERs include solar panels, combined heat and power plants, electricity storage, small natural gas-fueled generators, electric vehicles, and controllable loads, such as heating, ventilation, and air conditioning (HVAC) systems and electric water heaters. Increasing DERs create a more decentralized electricity system and changes the traditional dynamic between local distribution systems, and the province-wide transmission system

3.4.5 End-User

The electric infrastructure on the end-user consists of components that use or convert electric energy to everyday functional use by the customers. Electrical use has increased ever since it first lit up in New York City, today all part of United States has gained access to electricity and electricity use is at the center of everyday life and the engine of today's economy. The residential and commercial sectors consume about the same share of electricity at 38% and 36%, respectively. The industrial sector accounts for the rest at 26 percent of electricity demand.

3.4.6 Energy Ecosystem

As stated in the previous section of this research thesis, there are numerous benefits that come with blockchain; however, individuals or corporate entity seeking to transact using the blockchain platform should know that they will be exposed to federal regulations and current regulatory requirements.

Before the United States electricity was restructured, the prominent players in the electric power business are vertically integrated, consisting of generation, transmission, and distribution structured with state regulations. The electricity reforms will not start until the 1990s with California and Texas states leading the way while many states especially in the south, did restructure and are still using the vertical integration model. The restructuring process consists of the following:

i) The vertical integration model was broken into three companies – generation, transmission, and distribution.

ii) Price regulation was removed. Generation companies can charge prices on the market of demand and supply. The Federal Energy Regulatory Commission. FERC regulates the market instead of individual states.

iii) Transmission prices are also regulated by FERC instead of individual states.

iv) The faster accounting process is put in place to allow faster depreciation of power plant assets.

3.4.7 Regulatory Landscape

Blockchains is designed to circumvent regulations by earning trust through decentralization and not through a centralized body (PWC, 2018). However, the energy sector is a commercial entity where all transactions are regulated. The number of companies and regulatory agencies in the electric energy supply chain increased after restructurings. This is an irony for the deregulation of the industry, which now has more players and regulations in the power business. Some of these players include Primary State Public Utility Commissions (PUC), the Federal

Energy Regulatory Commission (FERC), Regional Transmission Organizations (RTOs), Independent Power Producers (IPP), Electric Utilities, and North America Reliability Corporation.

The State PUCs regulate oversight of utility planning, siting of generation, setting prices, and deciding whether and how to address utility incentives related to energy efficiency and distributed generation. Each states' PUC regulates the retail sale and distribution of electricity. They may choose to regulate smart contracts and related electricity sales if they choose to assert that authority, such that people and entities may need to be approved before using the blockchain platform to trade. The requirements might vary from obtaining a license to sell in unbundled states (states where generation, distribution, and transmission are sold as a distinct service), or having a PUC's retail approved rate for bundled states.

FERC is an independent agency that regulates the transmission and wholesale sales of electricity in interstate commerce. Additionally, FERC

i) reviews mergers and acquisition,

ii) review certain siting application for electric transmission

iii) oversees utility accounting practices and conventions

iv) monitor and investigate energy markets

v) reviews the interconnection of transmission grid (FERC, 2016)

Figure 9: Regional Transmission Organization (Energy.gov 2017)

RTOs operates up to 75% of the electric energy consumed in the country (Blumsack, 2016). They operate a high voltage transmission grid and oversee the electricity market (Figure 8). They actively plan the system to avoid blackouts by ensuring there is enough generation and transmission.

IPPS is a derivative of the vertical integration that owns power plants. They sell electricity into the market overseen by RTOs.

Electric Utilities appears in different forms in states that chose to stick with the traditional model of vertical integration, and they are regulated by the state public utility commission.

Other regulatory bodies include the Department of Energy ("DOE"), and the U.S. Commodity Futures Trading Commission ("CFTC") all have oversight control. NERC with FERC oversees consistencies in the North America Grid; DOE is a policy arm of the government overseeing various energy policies, including nuclear energy programs. Lastly, CFTC regulates future and option's energy market transactions.

While startups and users of blockchain are here to change the regulatory landscape of energy use. It is important to recognize these independent bodies, understand their roles before applying blockchain and smart contract technologies disruptively.

3.4.8 Reliability Consideration

Blockchain technology, as a disrupting technology, potentially facilitates transactions over transmission and distribution systems. However, using the present model, together with blockchain, can potentially compromise the reliability of the system. There are risks associated without regulatory oversight as regulators may not have comprehensive information on systems during increased traffic times of peak demand. This could cause catastrophic effects of overloading on these systems with blackouts and outages as a result. Thus, to use blockchain with the traditional model, it is necessary to allow DSOs, TSOs, and regulators to be able to effectively monitor blockchain transactions.

CHAPTER 4: QUALITATIVE MODEL

4.1 Introduction

This thesis applied an exploratory method investigating the disruptive power of blockchain technology. By doing this, the thesis has examined how blockchain technology could influence the United States electricity ecosystem. This has required an understanding of the technical and conceptual aspects of blockchain. An exploratory method with qualitative data divided into literature and case studies have been applied to ensure that both technical and non-technical perspectives have been included in the research.

First, a pre-study was conducted to read up on as much new information about blockchain as possible. The thesis also studied how blockchain disrupts the electricity sector using inter-organizational network concepts like a business ecosystem, value networks, and system dynamics. Thereafter, a model was created to represent the interactions between the application for blockchain technology in the electricity sector.

4.2 Qualitative research

When exploring a subject such as a blockchain, where the field is immature and software and applications are updated continuously, there is a need for flexibility in the research. By working with a type of flexibility and openness, there are opportunities to gain deeper knowledge and new insights about blockchain that was not obvious from the beginning. For this reason, this thesis has applied a qualitative method. It has also been important to be flexible and open to preserve ambiguity. By collecting data in a qualitative way, the result shows the total situation from a system perspective. The aim has also been to clarify both the understanding of blockchain and its context in the energy industry. To do this, questions as “how” and “what” have been asked, meaning that an explorative method has been applied to this thesis with start in a broad focus that has narrowed as the research progressed. Therefore, the interactions between the parts of the model were emphasized to keep the research flexible and open to change. The explorative method needs to be inductive, and a technique where the scientists try to draw general conclusions from the empirical data without predetermined ideas is ordinary and sometimes necessary.

4.3 Material

A literature study has been conducted to gain an understanding of the technical and conceptual sides of blockchain technology, and an overview of the energy industry. The literature study has introduced these areas but was also added to the result together with the scenarios. During the work process, new material in the form of articles and reports were studied and have clearly affected the possibility of the thesis. Even though not all articles that have been read is a part of the study, the deepening, and broadening of knowledge they have given have made it possible to work with the empirical data and the analysis. This was especially important since blockchain is a technology with several advanced attributes. The material used in this thesis range from peer-reviewed research papers to white papers, PowerPoint presentations from seminars and information from forums like GitHub. Most of the early research about blockchain is about Bitcoin. The word Bitcoin gave 15 248 hits in Morehead State University library database, and only 18762 hits with the word blockchain and a search using the word blockchain and energy as keyword gave only 818 hits. That indicates that blockchain, and especially in the electricity sector, is not well researched, and therefore, this thesis has complemented research papers with other sources of material to give a fair view of the area.

4.4 Method Discussion

This thesis has applied a qualitative method based on mainly non-peer reviewed sources, and it has been important to view the data from a critical perspective. Also, the big hype around blockchain has hampered the understanding of blockchain's potential. With this in mind, the central theme of this thesis, energy management as a system, and the application of blockchain technology has been extensively discussed and represented in a causal loop diagram.

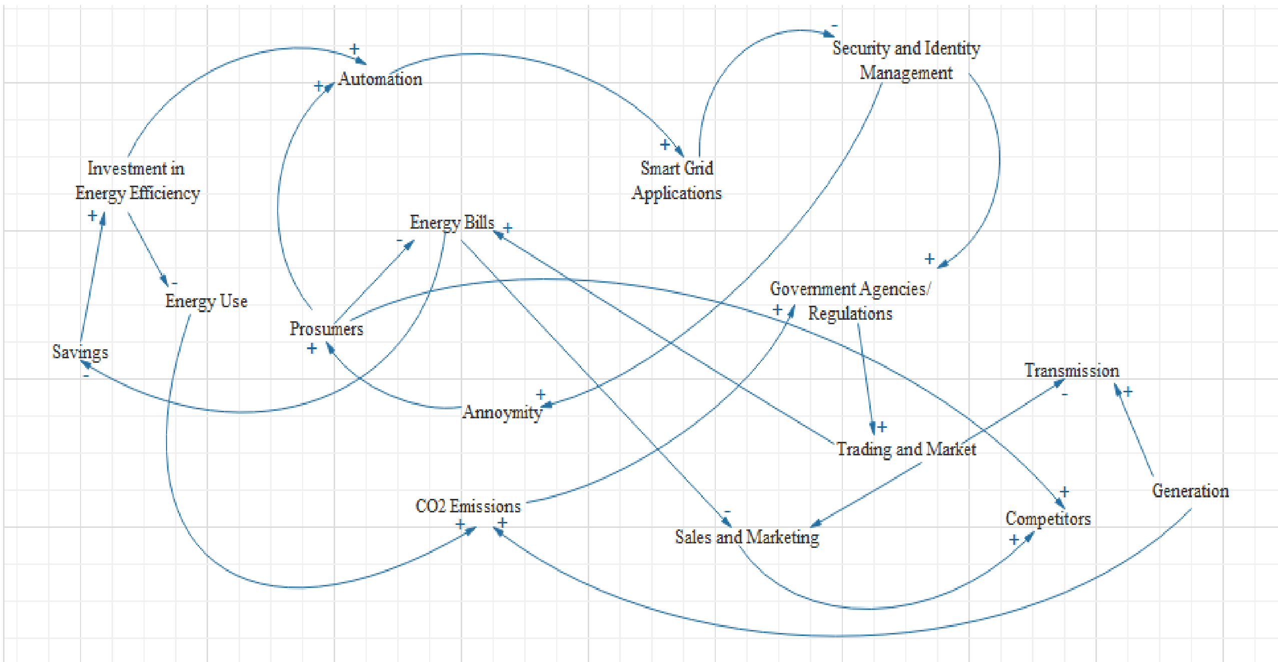

Fig. 10 Causal Diagram of Blockchain Technology

Today in the US, blockchain technology influence can be expressed with the casual diagram, Fig 10, that considers how different elements potentially affect each other. Industry stakeholders, utility companies, and decision-makers have taken great interest in blockchain technologies fundamentally to create a path to decarbonize our environment. Different smart grid plications have been developed as trials, pilot projects, and practical, innovative projects which have also brought up challenges like security and identity management.

In transactive energy, it is crucial that the consumer's energy data be accessible by the market both for settlement and determination of price. The market must have access to production and data consumption to settle obligations, and the distribution utility must have access to energy data to track the physical state of the network and ensure stability. In addition, blockchain could potentially be used to safeguard data privacy, identity management, and resilience towards cyber-threats.

One of the alluring attributes of the blockchain network is that participants have a considerable level of anonymity because participants are not identified by personal information but random cryptographic addresses. This anonymity is limited by a possibility of reverse-engineering of identities, which make a positive impact in fighting money laundering. However, in a small locale where peer-to-peer transactive energy applications are used, the anonymity of encrypted addresses is not enough because of rigorous data privacy that will be needed.

Blockchain can reduce transaction costs with wholesale energy trading while providing data for access from several parties, which includes bodies that can certify regulatory compliance. Blockchains could eliminate the intermediaries to reduce transaction costs and possibly trading volume, thus enabling prosumers to participate in the energy market (Singhi, 2019).

The system is unbalanced without reference to the transmission and distribution of the existing grid. Several projects aim to provide platforms to all energy system stakeholders. Bittwatt is a digital platform based on Ethereum, that is open to distribution and transmission system operators, regulators, energy suppliers, producers, and consumers (Bittwatt, 2019). It uses blockchain protocols to share and synchronize near real-time operational information between stakeholders enabling a decentralized service for energy delivery, balancing, metering, and billing.

CHAPTER 5: SCENARIOS OF USE

The fundamental goals of blockchain have associated costs like efficiency, scalability, certainty, reversibility, and privacy. The degree of each cost varies with blockchain implementation and lingers on. While some of these costs can be eliminated in the future with efficient energy computing, the other costs are rooted in the structure and may not be affected by further innovation. The fundamental question in evaluating blockchain as a transactive platform is if the tradeoffs are worth the costs.

5.1 Weighing the Upside of Blockchain

On the upside, there is a significant value that premise disintermediation of central authority with examples with joint ventures and supply chains, where members involved are mistrusting and unwilling to pay a mediating third party. In an energy transaction, there exists two aligned and acknowledged authorities in power distribution; state regulators and the utilities they oversee. The regulators' responsibility is to make sure that the public policy goals of having a reliable, affordable, environmentally friendly power generation and distribution are met. Utilities are required to maintain the grid, ensure reliable power delivery and public safety. Customers on the receiving end can rely on utilities for delivery but not on the metering on the power flowing through and especially on the billing associated with it – especially with a long history of precedent on the subject matter. Therefore, it became imperative that a future entity is designed by the state regulator to act as an authority in transacting energy, possibly contracting out implementation or management but maintaining oversight and control. Remarkably, the three energy restructuring models presented by MIT Energy Initiative in its pioneering *Utility of the Future* report (Kumar,

2019) features a centralized market operated by DSOs, acknowledging the important role this central authority plays in maximizing social welfare.

Despite their well-defined role and responsibilities in retail energy, utilities have a bad reputation with customers. Accenture has found that upwards of 76 percent of consumers do not trust their local utility, which affects the utilities' prospect in a transactive energy future (Katherine, 2013). A key area of mistrust is in the area where customers fall victim to large scale data breaches. Blockchain however, offers a dramatic departure from the centrally managed data model. Rather than trusting confidential data to individual institutions and relying on their cyber and ethical diligence, data is widely spread but encrypted. This model relies on publicly validated cybersecurity techniques and hiding it from hackers in plain sight.

5.2 Weighing the downside of a blockchain

While the upside of blockchain tradeoff is questionably remarkable, we also need to consider the cost implication of using blockchain as a transactive energy platform.

1.Efficiency: In contrast to traditional distributed systems where network resources work cooperatively to solve problems by sharing data and computation, blockchain peer nodes are trustless and only work together in reaching a consensus on ledger state. In the blockchain network, the extensive peer network replicates each other's data and computation so it can catch fraud. Each peer holds the entire transaction ledger, which has surpassed 100 gigabytes (GB) as of 2018 with Ethereum (Etherscan, 2019). Every unit peer is expected to perform every line invoked for every smart contract function, and the smart contract library has to be executed with care to make sure other peers agrees with the outcome. This enormous amount of resource, which includes millions of computers and complex cybersecurity network, creates an inefficient outlook on the blockchain use (Loi et al., 2016).

Even though replication is very important in database systems where it enables parallelism and can eliminate single point of failure, however, in the blockchain context, the extreme degree of replication is hard to justify from resource efficiency or resilience perspective. With this as a problem, researchers are considering importing techniques such as sharding, used in database systems (Lucas, 2019). In blockchain sharding, each node will only be required to be responsible for the portion of overall data, which will also require a new form of consensus and mechanism to deciding which nodes will act to verify. Even if this method becomes plausible, it will be difficult for it to resolve the resource inefficiency that is inherent in the blockchain.

2. Scalability: Platforms scalability is very significant to transactive energy because it involves enormous data from meter readings to bids and trades. A midsize metropolitan city, for instance, will have millions of meters; the data captured might include power and voltage reading, which are pushed into one single blockchain transaction. Assuming each of these readings are submitted every fifteen minutes, which is conservatively enough for a real-time market. The network will generate over 1100 transactions per second – the transaction rate. A blockchain transaction rate is the product of block size and block rate – a number of blocks mined (Kai and Sam, 2018). Blocks are shared among peers for consensus to happen, but they can be constricted with internet bandwidth. The more transaction volume, the slower the consensus, so also is blockchain settlement, so also are peers who are unable to handle the data volume get knocked out.

The transaction processing speed of the network is proportional to the speed of a single validator and not the number of validators in the network. Permissioned chains like Hyperledger Fabric channels support the private subnetwork of peers, where transactions are maintained and validated independently of each other. This can increase transaction rates to an extent but will be limited by the number of subnetworks their distinctiveness and the size of the biggest subnetworks, which is already a smaller blockchain and will be facing the same scalability challenge. Even under best tuning, Hyperledger Fabric can only handle aa fraction of transactions mentioned above. The challenge pose by an estimated transaction rate of 1100 per second (Kai and Sam, 2018) does not yet include bids, trades, settlement, and other market activity that will accompany raw energy data, which will stretch the blockchain capabilities.

Given these concerns over scalability with blockchain, several solutions have been proposed. The most prevalent one is to transfer calculations of the chain, which will reduce the calculation demanded on the network. It is proposed that blockchain should only serve a fiduciary role, in that blockchain should perform as much business logic as possible outside of blockchain and submitting only transactions where consensus is necessary.

3. Certainty: Blockchain, at its core, is fundamentally defined by group consensus voting to validate a transaction ledger. The cryptographic method used by blockchain is used in conjunction with punitive and reward incentives to make validators act honestly in determining the validity of the blockchain. This combined method relies on participant’s self-interest to rationalize in following the rules. The main uncertainty is that the rules may not be followed or be sabotaged by the actions of participants, which is a risk that public utility commission will be

unwilling to take with retail energy payment, or the diffusion of responsibility in transaction processing.

Although manipulation of the consensus process has been uncommon in most blockchain use today, there are still areas in blockchain security relating to participants with ruthless intent that will not behave as rational economic actors. These actors' goals are mostly not to maximize gains but to cause damage or destabilization of the network. Even in absent brutal behavior, the consensus process introduces uncertainty into the ledger. The rationale behind this is how consensus happens over time, as new transaction blocks are formed and shared by peers, it must decide which of the challenging blocks is to be updated on the ledger. A ledger query from a single peer can be compared to querying a database that is not guaranteed to return the official result of the primary one. This made Hyperledger Fabric recommend applications to issue a blockchain query to more than one peer because the result from individual queries may be different or out of date.

An example of a project addressing this challenge is the Dfinity project (Timo and Dominic, 2018) that has developed a consensus mechanism producing blocks every few seconds and finalized its transactions after two blocks. While this improvement is impressive for a four-plus second window to finalize a block, it will take time for it to be validated and prove against exploits.

4. Reversibility: The inherent property of blockchain ledger unalterable makes a critical factor in the validation process, with certainty that existing blocks cannot change. The entire transaction history can be checked quickly with cryptographic methods but could also amplify a trail of fraudulent transactions. Encrypted transactions should be made reversible so it can make

the platform viable for real-world applications. The real-world applications include the physical/digital interface where data from numerous devices like sensors and meters enters the blockchain and also enterprise data interface that continuously revises data (Kevin, 2018).

This quality is very important in the automatic transactive energy market where smart software agents and smart appliances are used. Also, third-party service providers and aggregators will use these smart agents to managing energy use in both residential and commercial properties, where it will be both ineffective and impractical to manage with direct human management (Josue C.P et al., 2018). Many transactions on the blockchain are already impenetrable, but it is hard to have it reversible. Credit card companies and retail banks, for instance, would have easy ways they would reverse a transaction if an error occurs. Blockchain, which could use this tactic would not find it as straightforward, because a refund or even a token could trigger an error on the smart contract and then invalidate the previous transaction.

An error invoked on the smart contract can cause a plethora of effects of rendering a transaction very complex and extensive instead of a simple transfer. The interdependence between smart contracts and the arbitrary complexities in its internal state may be hard to unwind. Smart contracts may contain bugs or be vulnerable to security after deploying on the blockchain, which could occur from insecure machines where peers execute the software code. It becomes difficult to address afterward because its immutable nature will not allow the contract to be patched.

5. Privacy: Blockchain consensus protocols require transparency for the ledger content, which is the trade-off of blockchain with privacy. A validator node must be able to track the balance in an account or the internal state of the smart contract, else, it will be nearly impossible to verify if the account is overspent or how the smart contract should be invoked. Although the

degree data can be accessed differs for platforms, participants on permissionless platforms like Ethereum will see all data, which in permission platforms, the validators have a level of access based on organization role.

In transactive energy that is the center of our concern, it is crucial that the consumer's energy data be accessible by the market both for settlement and determination of price. For instance, when there is an elevated voltage at a meter, the market should know so it can reduce the price of real power, thereby disincentivizing distributed generation, which worsens such conditions and – reactive power that is crucial for maintaining stable grid voltage. The market must have access to production and consumption data to settle obligations the distribution utility must have access to energy data to track the physical state of the network and ensure stability.

Other alluring attributes of the blockchain network are that participants have a considerable level of anonymity because participants are not identified by personal information but random cryptographic addresses. This anonymity is limited by a possibility of reverse-engineering of identities, which make a positive impact in fighting money laundering. However, in a small locale where peer-to-peer transactive energy applications are used, the anonymity of encrypted addresses is not enough because of rigorous data privacy that will be needed.

If, as a solution to the efficiency problem of blockchain, that energy data can be stored off-blockchain to improve efficiency, then market price formation and settlement can occur off-chain as well, which will significantly reduce blockchain role in the transactive marketplace. If on the other hand, the data is stored on the blockchain with addition to off-chain utility storage, then a privacy problem reemerges. However, in the face of these complexities, three methods to solve transparent privacy are under development that aims to give validators the required tool to verify transactions while shielding the details of the transactions. The first being that a zero-knowledge proof of allowing transacting parties to cryptographically prove to validators that they carried out a smart contract correctly without revealing any of its inputs or outputs. The second method is using a multi-party computation (MPC) that allows a network of untrusted computers to corporately carry out smart contracts, and only reference to the data cryptographically, and secure hardware enclaves built within specialized computer processors. Lastly, offer an isolated environment for an untrusted computer to operate on private data that not even the computer operating system has access to.

CHAPTER 6: CONCLUSION

The objective of this thesis is to explore how the introduction of blockchain can influence the United States electricity ecosystem. The research question is, “What will be the consequence of implementing blockchain technology as a foundational technology within the business ecosystem configuration of the United States electricity sector?” In order to answer the question, a theoretical framework on the electricity ecosystem in the United States highlighting different concepts on inter-organizational network concepts. The literature review was explored in chapter 2.

Chapter 3 focused on the theoretical framework of concepts, including inter-organizational network concepts, blockchain overview, electric energy domain, and the different actors in the United States electricity sector. Blockchain is seen as an enabler and can also compete with an established structure to disrupt how electricity has always been coordinated. The list of major startups using blockchain can be found in Table 1.

Chapter 4 discusses the qualitative model employed in this thesis. Chapter 5 discusses the possible scenarios that can be explored to know the consequence of introducing blockchain within the business ecosystem of the United States Electricity sector. Participants in the electricity sector are impacted by the introduction of blockchain as a foundation.

This report has been majorly optimistic about the influence of blockchain in affecting a rigid sector and disrupting the ecosystem. However, the uncertainties surrounding blockchain technology will make a general adoption in the sector an uphill battle.

Direction for future research

To further extend our knowledge on the impact of blockchain in the electricity ecosystem, a computer-simulated model will be appropriate. More energy sources can be included to improve its usability.

Future research on this project should quantitatively study the impact of startup use cases in more detail and how it can be extrapolated for wider use. More research is needed to increase the scientific efficacy for blockchain use, to reduce blockchain processing speed, to increase its security and lower associated transaction costs.

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Appendix 1

Startups	Blockchain Use	Location
LO3 Energy	A p2p electricity trading platform, renowned for the "Brooklyn Microgrid" (BMG) project in collaboration with Siemens used exclusively for the trading of electricity within a community in Brooklyn	NY, USA since 2017
Ponton Enerchain	a decentralized energy trading platform that integrate B2B solutions used for peer to peer trading. Traders send orders anonymously using the Enerchain platform. Enerchain allows over-the-counter trading, balance group management and wholesale trading.	Europe, 2016
Power Ledger	focuses on blockchain applications such as p2p electricity trading. This allows for the exchange of surplus energy of residential and commercial units in the grid or acting alone as a microgrid	Australia since 2016
Grid+	uses blockchain technology to create (software) applications in many different fields. Grid+ uses the Ethereum blockchain and a hardware device (Agent) to have access to wholesale electricity markets	US, 2017
Energo Labs	A p2p platform for a distributed energy system using blockchain technology with a special focus on microgrids. They also work with p2p EV charging	China, since 2016
OneUp	A software company that builds product with a combination of data science, IoT and blockchain. They allow customers and suppliers to communicate directly via the platform	Netherlands, since 2014
Volt Markets	uses blockchain to streamline the distribution, tracking and trading of energy. Also track and issue RECs (Renewable Energy Certificates)	US, 2016
WePower	A platform for P2P trading of renewable energy, and financing renewable energy projects and estimate supply and demand through AI	Gibraltar, Estonia and Spain, 2018
Pylon Network	a platform where users can trade energy p2p and get rewarded to produce sustainable energy	Spain, 2017
Electron	use blockchain technology to transform the UK's energy infrastructure. They use platforms like meter registration platform, flexibility trading program and smart meter data privacy	UK, 2015
Drift	uses a combination of blockchain, machine learning, artificial intelligence, high-frequency trading and other tools to provide their customers with cheaper wholesale energy prices while predicting their energy consumption	US, 2011

Spectral Energy	Allow energy share using blockchain technology to settle the transactions and provide transparency and security. Also use coin Jouliette to exchange goods.	Netherlands, 2017
NRG Coin	a mechanism and a smart contract that rewards production of renewable energy and makes its local consumption cheaper. Prosumers mint NRGcoins by supplying renewable energy to the grid	Belgium, 2015

Table 1: Summary of Startups disrupting the Electricity Sector with Blockchain Technology