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Degree of Master of Science

ENVIRONMENTAL COMMODITIES ON THE BLOCKCHAIN

A Case Study on the Potential of Blockchain Systems in the U.S. Voluntary Market for Renewable Energy Certificates

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Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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ABSTRACT OF THESIS submitted by:

Benjamin LAWLESS for the degree of Master of Science and entitled:

Environmental Commodities on the Blockchain: A Case Study on the Potential of Blockchain Technology Systems in the U.S. Voluntary Market for Renewable Energy Certificate

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The potential suitability of blockchain technology for environmental commodity markets and its impact on market efficiency, security and efficacy is being explored by a host of organizations, including the United Nations, and project developers. This thesis will analyze the potential of five blockchain projects being developed for use in a discrete environmental commodity market, the United States voluntary market for renewable energy certificates, a largely unregulated market used to commoditize the environmental attributes of renewable energy generation. The research will explore three fundamental premises that undergird the push for deployment of blockchain in voluntary markets: (1) voluntary markets are contextually and structurally well suited to commercial-scale blockchain deployment, (2) blockchain technology has the potential to improve the efficiency of voluntary markets relative to the current systems and structures and (3) blockchain platforms have the potential to improve the effectiveness of voluntary markets at causing the financing and development of additional RE generation capacity relative to the *status quo*.

The thesis concluded that the U.S. voluntary market possessed the contextual and structural attributes of a system for which blockchain technology presented value relative to conventional systems, particularly due to the reliance on third-party intermediaries and inefficient transactional structures. When applied at commercial scale, blockchain technology should improve the transactional efficiency and market liquidity of the U.S. voluntary market. The findings were inconclusive with regard to any systemic impact blockchain technology could have on voluntary market effectiveness in financing and developing additional renewable energy generation capacity relative to the status quo.

Keywords: Blockchain, Renewable Energy Certificates, REC, Environmental Commodity, Certificate of Origin, Distributed Ledger Technology, Voluntary Market, Energy

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Chapter 1. Introduction

Blockchain technology is cited as having the disruptive potential in myriad industries and established systems, from achieving Paris Agreement's climate goals and to improving space exploration. (Mandl 2017; Baumann 2017) Potential applications of blockchain technology are being explored by established corporations, government agencies, international organizations and startups in a wide range of sectors, including financial services, energy, international shipping, land registry, international development and data security. (World Econonomic Forum 2016; IBM Institute for Business Value 2017; White 2018)

In the energy sector, environmental commodity markets are predicted to be one of the sectors with potential for near-term commercial-scale deployment of blockchain technology. (PricewaterhouseCoopers 2017; Burger et al. 2016; PricewaterhouseCoopers 2017) United Nations, established energy utilities and startups are actively exploring and developing blockchain solutions for carbon offsets, emission allowances, carbon credits and renewable energy certificates or certificates of origin. (Basden and Cottrell 2017; United Nations 2017) This thesis will explore the suitability of blockchain technology in environmental commodity markets in a discrete case study analysis of five blockchain platforms developed for application in the United States (U.S.) voluntary market for renewable energy certificates (REC). Voluntary markets are designed to commoditize the environmental attributes of renewable energy (RE) generation in order to provide additional capital for project financing and development, ultimately increasing the amount of RE generation capacity.[1] (Jones, Quarrier, and Kelty 2015)

An ever increasing number of blockchain platforms and projects are being developed for deployment in the voluntary market. (Ett 2018) There is considerable diversity in the scope, design and intended application of the blockchain platforms. However, the research will elucidate three fundamental premises undergird the push for deployment of blockchain in voluntary markets: (1) voluntary markets are contextually and structurally well suited to commercial-scale blockchain deployment, (2) blockchain technology has the potential to

[1] There is not inconsiderable variation in REC definitions, even within the U.S. voluntary market, and the environmental attributes conveyed by a REC can include reduced or avoided CO_2 and other GHG emissions as well as air pollutants. This thesis will focus solely on reduced GHG emissions due to the displacement of fossil fuel generation.

improve the efficiency of voluntary markets relative to current market systems and structures and (3) blockchain platforms have the potential to improve the effectiveness of voluntary markets at causing the financing and development of additional RE generation capacity relative to the *status quo*. The latter two premises would address existing deficiencies in the voluntary market identified by the literature and some subject matter experts. Specifically, that the structural and transactional dynamics of the voluntary market render it inefficient as measured in transaction cost, speed and labor, illiquid and ineffective at causing the financing and development of additional RE generation. (Gillenwater 2013c; Holt, Sumner, and Bird 2011)

1.1. Research Aims & Questions

The overall aim of this research is to develop and apply an analytical framework to understand whether the voluntary market presents a plausible commercial-scale use-case for the deployment of blockchain technology. A holistic analysis of such a broad research aim is not possible due to the nascent stage of blockchain technology development and deployment, the dearth of literature directly analyzing blockchain technology and the commoditization of the environmental attributes of RE generation, and the corresponding lack of data or commercial-scale deployment case studies.

As such, the narrower aim of this research is to qualitatively analyze whether the voluntary market is contextually and structurally well-suited for blockchain technology application. Beyond this threshold, the research will attempt to understand the extent to which blockchain technology, as it is being designed for application in voluntary markets, has the potential to improve the efficiency and efficacy of the voluntary market based on deficiencies identified in the literature. The final research aim is to determine whether blockchain platforms can improve the effectiveness of voluntary markets at causing the financing and development of additional RE generation and thus reduce greenhouse gas (GHG) emissions relative to the *status quo*.

The methodology and analytical framework developed are described in detail in **Chapter 2**. Briefly, to provide context for the research questions, the analytical framework was developed by analyzing the claims made by proposed blockchain platforms designed for use in REC markets (or similar markets) about the potential impact and improvements of blockchain technology and the literature on the effectiveness and deficiencies of REC voluntary markets. It is important to note that there is considerable diversity in the design and purpose of the proposed blockchain platforms surveyed and there is disagreement in the literature and among the experts interviewed for the research about existence and extent of the deficiencies in the REC voluntary market. The diversity and disagreement will be explored at length. Nevertheless, a discrete set of issues could be identified that were implicated by both the blockchain platform claims and the REC market literature and the research questions were developed around these overlapping issues.

The research question can be stated as follows – does blockchain technology have the potential to improve the efficiency of the U.S. voluntary market's existing systems and structures for commoditizing the environmental attributes of RE generation and, in doing so, cause the development of additional RE generation and lower net GHG emissions relative to the *status quo*?

The general question will be addressed through the following narrower sub-questions.

1. Does the U.S. voluntary market have the attributes of a sociotechnical system or context in which blockchain technology can be expected to offer an improvement relative to conventional systems and technologies?
2. Do the proposed blockchain platforms have the potential to improve the efficiency of the voluntary market transactions and overall market liquidity?
3. To the extent blockchain platforms can be expected to increase voluntary market efficiency and liquidity, could these improvements be expected to enhance the efficacy of the voluntary market at causing the financing and development of "additional" RE generation capacity and thus reduce net GHG emissions relative to the *status quo*?

1.2. Limitations and Scope

Blockchain technology remains in its technical and commercial infancy. There are to date no commercial or large-scale blockchain projects or platforms deployed in the energy sector. (Mengelkamp et al. 2018) All of the proposed environmental attribute commoditization platforms analyzed for this thesis remain in the pilot or proof of concept phase. There is no academic literature on the application or efficacy of blockchain systems for establishing or improving renewable energy environmental attribute commoditization systems. Further, the literature and the experts interviewed for this thesis are far from uniform in their agreement about the extent and relevance of the deficiencies identified in the voluntary market and the relevant body of academic literature is far from robust.

While this situation renders infeasible any quantitative or definitive answers to the research questions, a more qualitative approach can yield useful information and results at this nascent stage of blockchain technology deployment. The research will thus attempt to analyze whether the proposed blockchain platforms, and the technology generally, have the potential to yield marginal improvements in the efficiency and effectiveness of REC voluntary markets. For example, it is impossible to say definitively that blockchain technology can improve the liquidity of REC voluntary markets and that liquidity improvement is sufficient to cause the development of additional RE generation relative to the *status quo*. However, it is feasible to take the body of literature on blockchain technology and voluntary markets generally and, when combined with expert interviews, try to understand if and the extent to which blockchain technology's attributes are well-suited to addressing the structural and systemic issues impacting the voluntary market.

The novelty of the research meant that, compared to more well-trod academic grounds, it was necessary to spend a significant amount of time establishing developing the research questions and then a framework through which to analyze them. Indeed, perhaps this thesis's most significant contribution will be its attempt to establish a framework for conducting an analysis of blockchain technology in the context of environmental commodity markets. The need to connect the two disparate subjects and develop and justify a framework necessitated a more robust literature review than may have otherwise been necessary.

Finally, it was necessary to limit the analysis to the discrete topics identified in the research questions and defer on a number of important issues relevant to the broader research aims. Some are directly implicated by the research and are of direct relevance to any holistic judgement on the use of blockchain technology from an environmental and climate change perspective. These issues will be noted in context, when relevant, but remain outside the scope of the analysis.

First, the blockchain is novel technology that synthesizes and builds on a diverse array of disciplines and existing technologies, including aspects of game theory, cryptography, computer science and accounting. (Nakamoto 2008; Bacon et al. 2017) A robust and nuanced technical understanding of the underlying technology and theory is well outside the scope of the author's capabilities. Blockchain technology and concepts will be explained at a high level, and a certain familiarity is necessary for this analysis. However, there are a number of technical issues and debates regarding transaction speeds, scalability, security and anonymity that are of direct relevance to blockchain's potential in many commercial and large-scale applications. (Dai, Zheng, and Shaoan 2016; Bacon et al. 2017)

Second, there is considerable diversity in blockchain systems, ranging from first generation public blockchains like Bitcoin, to hybrid public-private consortium chains, to "ledger protocols" like IOTA that, somewhat paradoxically, do not use blockchain infrastructure at all but share many of the common attributes of blockchain systems. (Bramas 2018) Some of this architectural and design diversity is of relevance to the application of blockchain platforms in REC voluntary markets and will be discussed. However, this analysis will not analyze the myriad permutations in any detail nor engage the debate on the particular merits of any given system.

Third, the energy consumption and environmental sustainability issues associated with blockchain platforms and their energy usage are an area of concern and debate. (Chen 2018; Digiconomist 2018) This is an important issue from an environmental and GHG emissions perspective but is outside the scope of this thesis.

Fourth, the adoption and use of blockchain technology raises a number of legal and policy issues, including compatibility with energy regulatory regimes, data security and privacy, legal status and enforceability of smart contracts and tokens, and the implication of U.S. securities laws. (Jaikaran 2018; Bacon et al. 2017; U.K. Government Office for Science 2016) These issues are all of direct relevance to the adoption and effectiveness of blockchain technology, particularly in a heavily regulated sector like the energy industry. Although they may be discussed where appropriate, these issues will not be analyzed in depth.

Chapter 2. Methodology

The research aim of this thesis is to analyze the potential of blockchain systems to improve the market efficiency and practical effectiveness of environmental commodity systems using the U.S. voluntary market as a case study. The primary challenge in developing the research aims and specific questions for analysis was the absence of academic literature that set out a rigorous and peer-reviewed theoretical framework or analytical approach for evaluating the potential impacts of blockchain technology in environmental commodity markets. As a result, a significant portion of the research was the development of a methodology for the analysis. For this reason, the methodology section has been moved to **Chapter 2** in order to give context and clarity to the literature review and explain the structure.

The guiding principles for the analysis were adopted from academic literature on research design and frameworks. Ostrom's (2007) "nested framework" approach was selected to form the basis of the diagnostic framework because it was designed to analyze the interaction of niche innovation or adaptation with an established system while avoiding simplistic panacea explanations. Practical methodological insights were borrowed from the body of the literature that analyzed blockchain technology's potential in analogous contexts.

2.1. Analytical Framework

The development of a diagnostic framework began with an attempt to adapt the principles of Ostrom's nested framework approach to construct a framework for analyzing the research question and avoiding the "panacea problem." (Van der Linden et al. 2005) In this context, the panacea problem would be attempting to understand whether blockchain could positively disrupt or revolutionize REC voluntary markets or the inverse. Instead, a more nuanced approach was developed that attempted to understand blockchain as an innovative but novel and multifaceted technology and REC voluntary markets as a complex system with a variety of incentive structures, diverse actors and a synthesis of technological, human and institutional components. Simply put, the framework developed attempts to understand how blockchain technology will interact with and impact voluntary markets in discrete contexts and pathways, diagnosing opportunities and obstacles, as opposed to drawing firm and overarching conclusions. In this framework, the voluntary market is the structure or system and blockchain technology is the "niche" that may improve, alter or impair current outcomes.

A review of academic and gray literature on the attributes of blockchain systems, structure of voluntary markets, and the potential of blockchain systems in different market contexts provided the substance necessary to build out a diagnostic framework for the thesis research question. Specifically, the analytical approaches used by Yermack (2017) in "Corporate Governance and Blockchains," PricewaterhouseCoopers' White Paper "Use Cases for Blockchain Technology in Energy & Commodity Trading" and Vos' "Blockchain-Based Land Registry: Panacea, Illusion or Something In Between?" and Pisa *et al.*'s "Blockchain and Economic Development: Hype vs. Reality" were used to guide the development of an analytical framework using the principles in Ostrom's "nesting framework." There papers develop a framework for analyzing the potential of blockchain technology by establishing a conceptualization of blockchain technology and its general attributes and applications followed by a conceptualization of the sector being analyzed. The potential applications and attributes of blockchain technology are then mapped onto the sector being analyzed and an analysis is conducted.

2.2. Research Design

The first step was to determine a case study. A number of environmental commodity markets were considered, including voluntary offset markets and the United Kingdom's Renewable Obligation market. The U.S. voluntary markets were selected for several reasons. First, the preliminary searches revealed frequent claims that REC markets could serve as an early use-case for blockchain commercialization. (Basden and Cottrell 2017) Voluntary markets were a particularly attractive use-case because market participation is, for the majority of participants, not mandated and the market is largely unregulated. (Gabison 2016) The absence of regulatory requirements and structures removed one of the biggest preliminary obstacles to blockchain technology commercialization in the energy sector. (Jaikaran 2018) In addition, voluntary markets have been in existence for several decades with established market structures and entities. (Jones, Quarrier, and Kelty 2015) This meant that there was a body of literature on the functioning of the market and its attributes and weaknesses to establish a framework. Further, a significant percentage of the blockchain platforms reviewed with environmental commoditization functionality were designed to integrate with existing REC markets or provide a functionality that was similar in purpose and function (*i.e.* commoditizing the environmental attributes of RE generation for the purpose of developing additional RE capacity). (Swytch 2018; Greeneum 2018)

The preliminary literature review further allowed for a determination of the premises underlying the claims about blockchain commercialization in REC markets and the purposes, markets and designs of the blockchain projects surveyed. The research aims and specific research sub-questions were developed at this stage. The REC market research suggested there was sufficient available data on REC market structure, transactional efficiency and practical efficacy in developing additional renewable energy to examine the premises of the blockchain claims.

The second step was to develop a multi-stage diagnostic approach with which to conduct the substantive research. The diagnostic approach contained the following stages:

1. Conduct a literature review to develop a working profile of blockchain technology as a niche technology, with a particular focus on its applicable attributes in a market context. At a high level, the attributes identified were (1) distributed ledger, (2) trust creation, (3) data immutability, (4) transactional efficiency, and (5) market liquidity.
2. Conduct a literature review to develop a working profile of voluntary markets with an emphasis on market structure, incumbent players and their roles, incentive structures, and attributes and deficiencies of the market. At a high-level, this analysis profiled the market as a relatively opaque over the counter (OTC) commodity market within the broader electricity sector, driven by demand for green attributes, and with several categories of incumbent players: RE generators, purchasers, tracking systems, registries, brokers and aggregators, and verification services and auditors.
3. Identify relevant blockchain projects to profile and analyze and interview subjects representing the different incumbent entities in the voluntary market. In addition to the blockchain platforms researched in depth, 5 projects were reviewed as part of the research. These include WePower, Volt Markets, Electricy.Asia, New Era Energy LTD's NERA Blockchain and Grid+.
4. Interview representatives of the stakeholders identified in Stage 3 regarding the interaction between blockchain technology and voluntary market structures.

The diagnostic approach was inevitably an iterative process. Early interviews with blockchain projects and voluntary market participants helped clarify and define the potential attributes of blockchain technology that were promising or problematic from the perspective of voluntary markets.

The universe of potential interviews was limited to entities and persons with familiarity with both green attribute commoditization systems and blockchain technology. Potential blockchain projects for analysis were limited to those with either the primary or secondary purpose of developing REC-like green token capabilities on their platform or were intended to integrate into existing REC markets. This threshold was used as a proxy for evidence of a degree of knowledge of green attribute commoditization systems. Representatives from voluntary markets were limited to those persons with a degree of understanding of blockchain technology.

2.3. Literature Review

With a case study selected and a research framework developed, the literature review focused on an analysis of the literature on blockchain systems, potential application of blockchain technology, and the U.S. voluntary market for RECs and analogous environmental commodity markets. The literature sources reviewed can be generally grouped in the following categories.

- Academic and grey literature on the technology underlying blockchain systems.
- Academic and grey literature on the attributes, drawbacks and potential applications of the technology from a policy and commercial perspective.
- Case studies of blockchain technology application in analogous sectors or markets, including commodity markets, supply chains, land title registries, carbon markets and the financial sector.
- Blockchain project White Papers and blog posts.
- Academic and grey literature on environmental commodity markets.
- Academic and grey literature on the structure, incumbent systems, and effectiveness of U.S. REC markets.

In addition, subject matter experts were contacted to generally discuss the research question and objectives and to ascertain additional literature recommendations and interview targets.

Table 1. Blockchain Subject Matter Experts

Expert	Institution	Subject Matter Expertise
Lauren Downes, *Esq*.	Queen Mary School of Law, University of London	Legal Researcher at the Cloud Computing Project specializing in the legal and policy implications of blockchain technology. Background in Energy law and transactions.
Kristina Hojcková	Chalmers University of Technology	Ph.D. candidate in Technology Management and Economic, Environmental Systems Analysis. Dissertation research involved detailed analysis of Power Ledger and Brooklyn Microgrid systems.
Dr. Esther Mengelkamp	Karlsruhe Institute of Technology's Institute of Information Systems and Marketing	Researcher focusing on blockchain-based microgrid energy markets. Co-Author of *Designing microgrid energy markets – A case study: The Brooklyn Mic* & *A blockchain-based smart grid: towards sustainable local energy markets*.

2.4. Stakeholder Interviews

The literature review and discussions with blockchain experts were useful in establishing a holistic baseline understanding of blockchain technology, its attributes and potential applications, and the structure, systems and functioning of U.S. voluntary markets. The literature review process also defined the criteria for blockchain projects eligible for analysis. Potential projects were limited to those projects (1) intended for use in REC markets or (2) that included a REC-like green token functionality as the platform's primary or secondary function (see discussion of "green token" platforms in **Chapter 6**).

Seven interviews were conducted in total. Six of these interviews were semi-structured interviews conducted via Skype. Interview subjects were selected using a hybrid of quota and snowball sampling methods. The universe of interview participants was identified as consisting of two key categories of stakeholders identified during the literature review – (1) representatives of eligible blockchain platforms and (2) representatives of voluntary market entities. (Robinson

2014) Criteria for participation in the second stakeholder category was further defined as having an understanding of blockchain technology application in voluntary markets. The relatively small number of people who met these criteria limited the universe of potential stakeholder interviews. Using quota sample methodology of setting out a minimum number of participants for each category, a baseline of 3 representatives was established. However, two interviewees had detailed knowledge of both blockchain technology and voluntary markets and were asked questions on each subject.

Table 2. Interviews Conducted & Medium

Category	Interview Medium	Interviewee
Green Token Platform	Skype Call	Power Ledger Representative
Green Token Platform	Skype Call	Assaf Ben Or, Founder GREENEUM Network Greeneum
Blockchain Platform & REC Market	Skype Call	Douglas Miller – Rocky Mountain Institute & Energy Web Foundation, Origin Market Development & Regulatory Affairs Manager EW Origin Blockchain Project Member
Blockchain Platform & REC Market	Skype Call	Alex Anich, Manger - Renewable Market Intelligence, NRG Energy, Inc. NRG Blockchain Project Member
REC Market	Skype Call & Written Question Responses	James Critchfield - Director, U.S. Environmental Protection Agency's Green Power Partnership
REC Market	Skype Call	Benjamin Gerber – Executive Director of the Midwest Renewable Energy Tracking System (M-RETS)
REC Market	Skype Call	Michael Leschke – Senior Manager, Certification Program at Center for Resource Solutions

The purpose of developing profiles of the proposed blockchain platform and this research was not to judge or evaluate individual projects prospects for success. Rather, the interviews and research into their White Papers and technical documents is intended to establish a more nuanced and tailored profile of how blockchain technology is being developed application in REC markets or similar contexts. This profile will supplement the literature on blockchain technology generally and use in analogous contexts. Within the blockchain category, two key sub-categories were identified – (1) green token platforms and (2) blockchain platforms designed for integration with existing REC market structures. These subcategories, described in detail in **Chapter 6**, represent two general approaches to applying blockchain technology in voluntary markets. Subcategorization will facilitate a more granular and nuanced discussion of the technology in the context of the research questions.

Finally, four of the interviews were with representatives of different entities in the U.S. voluntary market. Within the voluntary market category, several key categories of entities within the REC market were identified – U.S. Environmental Protection Agency's (EPA) Green Power Partnership (GPP), tracking systems, certification and verification entities, and market participants. A snowball method was used to find contacts within these categories and ensure that key stakeholders were not overlooked.

2.5. Limitations

Several factors limited the research. In the blockchain project category it was difficult to find projects to interview regarding their platforms for a variety of apparent reasons – the paucity of projects in this area, employee time constraints, and the proprietary nature of the platforms. As a result, part of the analysis will rely on information contained in blockchain platform White Papers and in the limited number of academic papers on this subject. Further, the universe of voluntary market stakeholders with sufficient familiarity with blockchain technology was limited.

Interview protocols were developed for each category, with variations between the two blockchain subcategories. (Turner 2010) For the green token platforms, a number of more detailed questions were asked about demand drivers, market structure, standards, and integration with existing organizations and markets. For the integration blockchain platforms, these subjects were covered but in a more open-ended format to understand how they viewed the voluntary market, its structure, attributes and weaknesses, and the general potential for blockchain technology to integrate and transform the market. Voluntary market representatives were asked a similar set of open-ended questions on the potential applications of blockchain systems in the voluntary market, obstacles, and opportunities. Follow-up questions were asked as necessary.

2.6. Data Analysis

The data analysis utilized qualitative content analysis principles to establish a systematic and rule-based process for analyzing literature and interview data to established a framework and elements for the analysis of the research question. (Schilling 2006) Inductive content analysis was the primary method used to develop a model and categories for analyzing the potential of blockchain technology to improve the functioning and efficiency of voluntary markets. (Elo and Kyngäs 2008) Deductive content analysis was used in part to inform the categories, particularly in areas where academic literature was more robust. In particular, factors limiting the effectiveness of voluntary markets in spurring increased development of renewable energy were identified using deductive techniques.

The literature reviewed was analyzed and outlined in detail to establish key components and structures of REC markets, deficiencies and strengths of the voluntary markets, and factors exacerbating these deficiencies and strengths. A broader outline was developed setting out the market structure and the specific categories of strengths and deficiencies. Interviews were transcribed, analyzed and coded to supplement the market structure and categories of strengths and deficiencies through which to analyze the potential efficacy of blockchain technology.

Voluntary market structure and a background on blockchain and its potential areas of application and drawbacks are detailed in the literature review section. Results of the data analysis on both subjects are set out in **Chapter 6**. **Chapter 7** analyzes the results of the research findings in the context of the research sub-questions.

Chapter 3. Literature Review

There is a dearth of literature, academic or otherwise, directly analyzing blockchain technology application and efficacy in environmental commodity markets. Thus, the aim of this thesis is to develop findings that will begin to fill this void. To do so, this section will first review two broad categories of blockchain literature. *First*, a review of the academic and gray literature on the technology, structures and concepts that constitute blockchain technology as a discrete category of technology. *Second*, a review of the literature analyzing the application of blockchain technology from a contextual and systemic perspective, which will allow for an analysis in the context the systems, institutions and structures of the voluntary market and REC transactions therein.

3.1. Overview of Blockchain Technology

Blockchain technology (sometimes referred to as distributed ledger technology) can be broadly defined as a distributed, transparent and cryptographically secure ledger or database that facilitates transactions without the need for a third-party intermediary. (Nakamoto 2008) Although the technology and architecture of a blockchain system draws on elements of cryptography, game theory and computer networking, at its most elemental blockchain technology can be thought as an innovation in accounting. A digital ledger is simply a record of transactions. (Burger et al. 2016) Indeed, research on the use of cryptographically secured blockchains dates to the early 1990s. (Haber and Stornetta 1991; Nakamoto 2008)

Blockchain refers to the underlying technology or system architecture, the digital infrastructure that can be engineered to serve a variety of functions. (U.K. Government Office for Science 2016) Blockchain technology can be configured in myriad permutations to serve different functions, ranging from public and permissionless systems like Bitcoin that allow peer-to-peer transactions in its native token (*i.e.* a bitcoin) between any two persons on the globe with internet access to private blockchains used for tracking digital records within a corporation or government agency. (Nakamoto 2008; Bacon et al. 2017)

Blockchain technology draws on four interrelated innovations that distinguish it from traditional databases and accounting protocols. (Bacon et al. 2017) Together, these innovations interact with one another to create what is frequently referred to as a "trustless" system. (The Economist 2015) Each is critical for an analysis of whether blockchain technology has potential to impact the efficiency and effectiveness of REC voluntary markets and will be discussed in detail. First, blockchains are distributed among all users on the system, making it transparent to all users and causing it to be simultaneously updated and reconciled across all distributed copies. (Jaikaran 2018) Second, blockchain uses cryptography to secure, or render immutable, the data contained in the database. (Bacon et al. 2017) Third, blockchains use a consensus protocol to govern who can transact on the system and avoid double-counting (or double spending) of the digital asset or record. This negates the need for trust between parties or a third-party entity to establish trust (*e.g.* the role Airbnb plays in securing and verifying the transactions between unfamiliar renters and landlords). Finally, blockchain's data recording and storage features ensure all data and transactional information is simultaneously immutable and traceable. (Nakamoto 2008)

3.1.1. A Distributed Ledger

The first, and perhaps most widely known, is the distributed nature of blockchain's ledger. Unlike a more traditional database, the blockchain ledger is not hosted or stored in one centralized location, or even multiple decentralized locations. Rather, it is hosted by all nodes on the system. For example, in 2017, Bitcoin had over 10,000 nodes and Ethereum over 25,000. The nodes host the public ledger and update it simultaneously to include all new "blocks" of transactions. Thus the data on the blockchain is shared between all users and not controlled by anyone entity. (Nakamoto 2008; Merz 2016) Further, because all nodes on the system validate all transactions on the blockchain and all copies of the blockchain updated simultaneously to reflect all transactions, the blockchain users do not have to reconcile their records with other users or confirm transactions. The blockchain is fully and simultaneously reconciled across all nodes, and thus all users.

Figure 1. Centralized, Decentralized and Distributed Networks (U.K. Government Office for Science 2016)

3.1.2. Immutable Data

The second significant innovation is the cryptographic functions called hashing that secures the data on the blockchain while allowing transparency (*i.e.* the ability to track the provenance of an asset or token). (Bacon et al. 2017) The method of block creation varies based on the blockchain architecture, but the general means of securing data is the same. Nodes are incentivized through various systems to "create" the blocks, which are made up of the records of a certain number of transactions. When a node wins the right to create a block, the block an all transactions contained therein are verified by all other nodes on the system. The block is then cryptographically sealed with a hash (a long alphanumeric signature), a timestamp and a reference to the prior block on the chain. Combined, this allows for all transactions and their associated information (*e.g.* identities of the parties, underlying asset being transacted, and the quantity and time of the transaction) on the blockchain to be visible to all users (transparent) while preventing tampering with the transaction information. This data structure allows any user to track the history and provenance of a token or asset on the chain without allowing the information to be changed or altered.[2]

[2] Even the most sophisticated and secure public blockchains like Bitcoin are theoretically vulnerable to attacks designed to alter past transactions. For the purposes of this thesis, it is sufficient that the data on a blockchain is extremely secure relative to a conventional database.

3.1.3. Consensus Protocols

To ensure a distributed system while maintaining order, a blockchain's consensus protocol establishes the rules for how blocks are added to the chain and who can add them. The consensus protocol also establishes an incentive structure to encourage nodes to host the blockchain and perform the work. Bitcoin and Ethereum use a proof of work protocol that requires solving a cryptographic puzzle in order to add a block to the chain and receive a reward (i.e. Bitcoins) This requires significant processing power but prevents against spamming and hacking. The first miner to solve the puzzle is allowed to add the next block to the chain and is rewarded in bitcoins. Other types of distributed consensus protocols exist, including proof of stake and proof of space. An understanding of the technical details and game theory behind each is not necessary for the purposes of this thesis. In centralized and private systems, a consensus protocol called proof of authority can be used that simply grants transaction validation authority to approved accounts.

3.1.4. User Authentication

Finally, blockchain platforms use asymmetric key encryption to secure transactions without the need of a centralized authority or facilitator. In short, the platform establishes identities on the blockchain and ensures that a user can only transact in their information or assets. (Bacon et al. 2017) Each user on the system has a public key and a private key. (Jaikaran 2018) The public key identifies each user on the system and the assets (*e.g.* records, tokens or resources) associated with that user. The public key could be real-world identifying information (*e.g.* a name or email address) or a pseudo anonymous identity (*e.g.* a string of numbers and letters). The private key allows Person A to decrypt their asset and send it to Person B's user's public key via a transaction. Once sent, Person B's private key encrypts the asset, ensuring that it is in their possession and secure.

3.2. Blockchain System Architecture & Design

A transaction on the blockchain is simply the exchange between two or more parties of a piece of information, resource or asset that is hosted on the blockchain. For example, Person sends 1 bitcoin to Person B to pay for a good or service. Some blockchain platforms use tokens as a means of transaction. A ***token*** is simply a digitally created, secure asset that is the means of transaction on the blockchain system, serving effectively as currency, security or simply a digital representation of some asset. (Buterin 2014) The token can have value in its own right (*e.g.* a Bitcoin) or it can represent an asset in digital form (*e.g.* a REC).

A blockchain can be ***public***, ***private*** or a ***consortium***. (Buterin 2015) A public blockchain is one on which, in theory, anyone with an internet connection can use, either as a user, a node or a miner. Bitcoin is a public blockchain. (Nakamoto 2008) The public ledger (*i.e.* the blockchain) and all its transactions are visible to anyone, anyone can transact on it, and any computer can participate in the consensus process by mining new blocks and validating the transactions therein (assuming the computer has sufficient processing power). (Dai, Zheng, and Shaoan 2016) Because anyone can access them, public blockchains use highly secure consensus protocols to prevent attacks, spam and double-spending. Bitcoin's proof-of-work protocol requires an immense amount of computing power to solve its cryptographic puzzles. This makes it extremely secure (*i.e.* it would take an enormous amount of computing power to overwhelm the system and alter past transactions or double-spend) but requires a lot of energy, leading to the sustainability questions about bitcoin's energy use.

Table 3. Taxonomy of Blockchain Architecture

	Public	**Private**	**Consortium**
Transaction Validation	Public	Restricted	Partially Restricted
Read Permissions	Public	Public or Restricted	Public or Restricted
Data Immutability	Immutable	Alterable	Alterable
Energy & Computing Requirements	High	Low	Low
Centralized	No	Yes	Hybrid

A consortium blockchain is one in which the nodes are limited to certain entities or persons and the consensus process is controlled by a pre-selected set of nodes. (Buterin 2015) For example, in an energy trading context, the nodes on consortium blockchain could be limited to 50 generators and consumers and the consensus protocol would require validation and verification by 30 nodes in order for a new block of transactions to be valid. (PricewaterhouseCoopers 2017) Consortium chains are useful in contexts with a higher degree of trust between users and sacrifice security for speed and efficiency. A private blockchain is one in which the ability to transact and verify transactions is limited to one centralized entity. (Bacon et al. 2017) Limitations on who has the ability to write permissions (*i.e.* transact and confirm transactions) are the hallmarks of consortium and private blockchains. The ability to read or view transactions on either of these two types of blockchains can be open to anyone or limited. Private and consortium blockchains are more common in situations where there is a greater degree of trust between users, and they require less security and computing power than fully public blockchains. Rules and transactions can be changed more easily.

Independent of whether it is private, public or consortium, blockchain can be permissioned or permissionless. (Jaikaran 2018) A permissioned blockchain is one in which a user has their access and capabilities assigned to them. For example, a user may only be able to see certain parts of the blockchain or may be able to view the entire chain but not have the ability to add blocks or serve as a node.

Finally, more recent blockchain platforms can host smart contracts, which are computer programs that automate many of the features of a contractual relationship. (Buterin 2014) Smart contracts are stored on the blockchain and contain the terms of an agreement between a buyer and seller. (“Investopedia” 2018a) Smart contracts are particularly important for many energy sector applications and use in peer-to-peer (P2P) market building functions because they allow for pre-set, automated transactions.

3.3. Blockchain Attributes and Contextual Applications

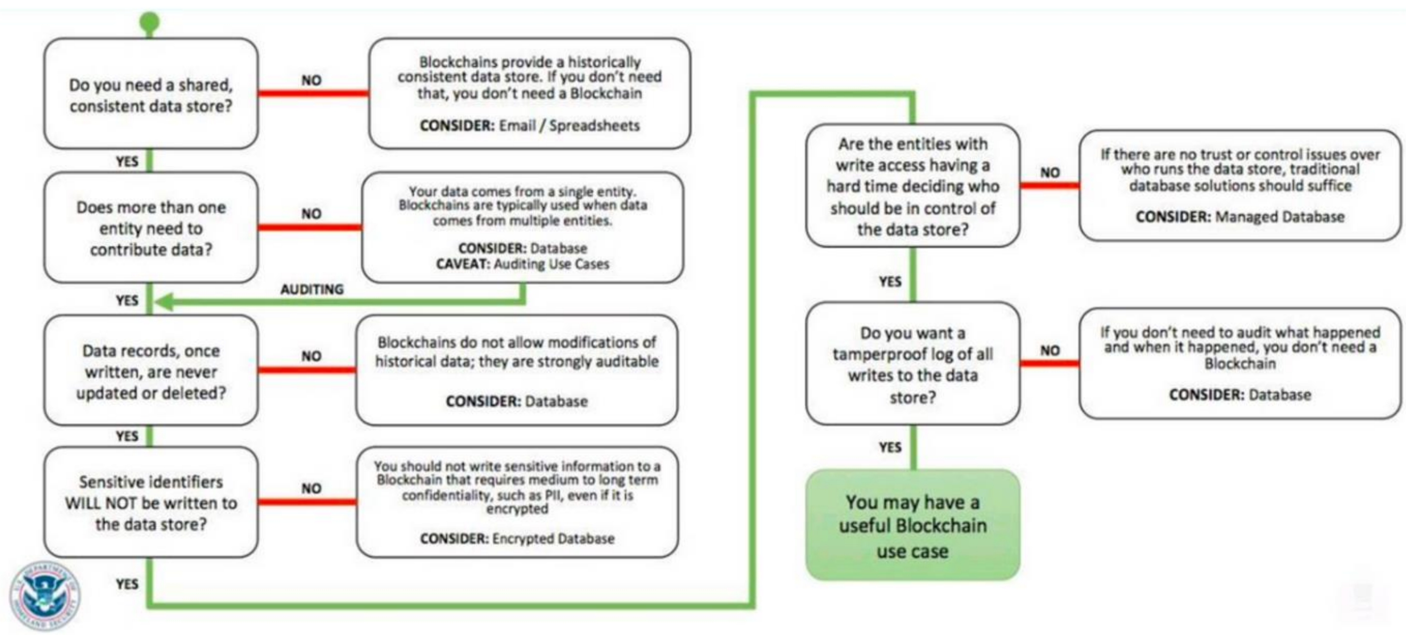
The advantages and efficiencies offered by blockchain technology's technical innovations, or more precisely its synthesis of extant and novel innovations, relative to conventional systems are contextual and situational, even in decentralized applications or settings. (World Energy Council 2017; Pisa 2018) The literature to date has analyzed the factors influencing blockchains relative advantages and disadvantages. This section will survey and analyze this body of literature.

3.3.1. Contextual Value Relative to Conventional Systems

Conventional technologies can offer similar functionality to blockchain. For instance, a cloud-hosted transactional database with permissioned read access for necessary parties offers similar functionality, at least from a technical standpoint, as a permissioned, private blockchain. (Singh and Michels 2017) Further, the distributed, immutable and trustless nature of the blockchain architecture have technical and legal costs that must be considered when determining the relative advantage of a blockchain-based system. Consensus protocols require computing power and limit, to varying degrees, the speed of the system, increase energy usage and increase the difficulty of changing transactions. (Buterin 2015) Centralized systems use energy do not require the amount of computational power necessitated by the consensus protocol because one party (*e.g.* Airbnb) is trusted with managing the database and transactions. The distributed ledger contains a record of all transactions and there is a cost to permanently storing the ledger on multiple nodes. These technical tradeoffs can limit the ability to scale the blockchain. (Bacon et al. 2017) Beyond the technical tradeoffs, distributed and transparent databases raise a host of confidentiality, privacy and other legal issues. (Gabison 2016; U.K. Government Office for Science 2016) Technical and legal issues are outside the scope of this analysis, but it is necessary to point them out as tradeoffs relative to conventional and centralized systems or databases.

The literature on contexts or situations in which blockchain offers a potential advantage can be summarized from a general, structural standpoint. Blockchain systems are more likely to add value in contexts where there are multiple parties working with a shared, consistent asset or record. (Meunier 2016) Blockchain's advantages are particularly acute if there are verification requirements or costly intermediaries. Blockchain's data structure means that all transactions are verified in real time, avoiding double-spending, and the transparent architecture allows third-party auditors to track provenance and chain of custody in one central location. (Nakamoto 2008) The presence of costly third-party intermediaries can also tip the scales in favor of a blockchain-based platform. The need for transactional privacy can be overcome to a degree by the blockchain design (*e.g.* a permissioned consortium chain) but can nevertheless be complicated by blockchain's architecture. Finally, situations in which data or information needs to be changed frequently or transported to other databases are not as suited to blockchain systems. (Jaikaran 2018)

Figure 2. Blockchain Use Decision Tree (Dept. Homeland Security)



3.3.2. Trust Creation & Double-Spending

Perhaps the single most important attribute of blockchain technology is its ability to create trust in situations with unfamiliar and disparate actors without the need for a third-party intermediary. (Meunier 2016; Singh and Michels 2017) The Economist famously described blockchain is a "trust machine" that allows for the commoditization of trust in distributed transactional settings. (The Economist 2015) Bitcoin is the most famous example of this. It is global, public P2P platform without a centralized governing authority or custodian but allows users spread across the globe can transact securely with one another without concern for double-counting.

The avoidance of double-counting is at the core of the trust creation function. (Bacon et al. 2017) In the Bitcoin context, the P2P system does not work if a person can “double-spend” the bitcoin. (Beck et al. 2016) That is, when Person A sends Person B a bitcoin, the consensus protocol and requirement that all nodes verify the transaction ensures that Person A cannot duplicate the bitcoin and spend it again. Without this core function, the cryptocurrency would be worthless. The same trust creation architecture applies when the blockchain platform is used to transact in an asset or piece of information. For example, in the land registry context, the double-spend protection would allow Person A to send the land title to Person B upon receipt of payment but would prevent Person A from duplicating the land registry.

The “trust machine” framework is not necessarily as clear cut in situations where the blockchain system is permissioned, private or more centralized. (Singh and Michels 2017) The more centralized a blockchain system, the more trust is required in the nodes selected to administer the system. Bitcoin is so energy intensive because its consensus protocol is so secure and labor intensive and it is distributed across thousands of nodes. Trust and efficiency are tradeoffs. As with any system, increased transparency and visibility can re-establish some of this trust but increased transparency can also come at a cost. (Yermack 2017)

In a situation where blockchain systems are used to transact information or assets that exist outside the system, the digital record on the blockchain is only as good as the input data. That is, it is necessary to distinguish between the reliability and authenticity of a record. (Lemieux 2016) The reliability of a record as factual or accurate is reliant on how the record is created and, in the case of a blockchain system, digitized on the system. The authenticity of a record requires establishing and preserving the identity and integrity of a record from its creation and through the chain of custody. However, blockchain cannot ensure the reliability of the record because reliability is reliant on the accuracy of the information entered into the blockchain. (Pisa 2018) For example, although blockchain architecture would avoid double spending or duplicating a land title, it cannot guard against fraud or inaccuracy in the process of creating or digitizing the land title.

The issue of information reliability can be even more pronounced when smart contracts are used. (Bacon et al. 2017) Unwinding fraudulent or mistaken transactions, or transactions caused by software flaws can introduce error in the blockchain. Resolving mistakes in a conventional contracting situation is not without complications, but there are existing systems for addressing this eventuality (*e.g.* arbitration or courts). Unwinding a mistaken smart contracts transaction requires coding the smart contract to allow for a revision or a fork in the blockchain. (Jaikaran 2018) Either of these options undermines the trust and immutability features of the blockchain system.

3.3.3. Provenance & Chain of Custody

Blockchain's ability to combine transparency with data immutability and identity authentication (*i.e.* protection against double-spending or duplication) make it useful for tracking the provenance of an asset, record or other transactional item. (Jaikaran 2018) Data immutability and double-spending prevention ensure the authenticity of a record or asset on the blockchain. The transparency nature of the blockchain system allows for users to follow the chain of custody of the record or asset from its inception to the present. The consensus protocol ensures that all users on the system agree on the chain of custody and the frequent and simultaneous updating of the blockchain ensures that the current blockchain shows the entire transactional history.

The robust exploration of the use of blockchain in the land registry sector to track the transfer of land is an example of blockchain's provenance benefit. Pilot projects testing this functionality have been tried or are underway in Illinois, Sweden, Honduras and Georgia. (Vos 2017) Transferring land title on the blockchain obviates the need for a central entity to record and track the transactions, improving efficiency and obviating the need to trust a single entity. The transparency element would allow anyone to verify seller's title by simply looking at the blockchain's record of transactions for the particular piece of land. (Mirkovic 2017)

However, data immutability that underlies blockchain's provenance feature does present complications. (Pisa 2018) Conceptually, it is not difficult to imagine situations in which a user will want data removed from a blockchain or where a registry or asset was improperly recorded. This is virtually impossible on a public blockchain. On a consortium chain, this would require properly constructed consensus protocols and reliance the administrating nodes. (Singh and Michels 2017) As of the time of writing, blockchain data is not easily portable between different blockchains, or from a blockchain to a conventional database. (Jaikaran 2018)

3.3.4. Supply Chain Management

When combined with the distributed nature of the blockchain database, the provenance tracking functionality of blockchain systems gives them particular promise in supply chain management functions. (Jaikaran 2018) Similar to the provenance of land titles, supply chains require the tracking of a good by multiple entities involved in various stages of a process, including creation, distribution, sale and use or retirement. (PricewaterhouseCoopers Gmbh 2017) Both provenance and supply chain management stem from the transparent and distributed nature of the blockchain architecture. Not only can parties to a transaction transact on the chain, but ancillary parties to the transaction can view the data. For example, an auditor can see a record of a given set of transactions and parties involved for a particular asset.

This functionality of blockchain is being explored in a variety of contexts. In the international shipping industry, Maersk Lines and IBM have created a joint venture to develop a blockchain platform for managing and tracking the paper trail of cargo containers. They estimate that nearly 30 organizations and up to 200 communications are required to sign off on a single shipping container and that the paperwork alone can add 10 days to the time between shipment and delivery. (White 2018) The blockchain platform is thought to have the potential to reduce delays from paperwork, reduce fraud and error, lower costs and improve efficiency. Walmart is exploring similar blockchain solutions for its supply chain management. (Milano 2018) Potential supply chain management benefits are being explored in environmental and social contexts as well. For example, a pilot project will track cobalt mined in Congo to its end-use in lithium-ion batteries in order to ensure that the cobalt was mined in a sustainable manner and without labor abuses. (Lewis 2018)

3.3.5. Transactional Efficiency & Disintermediation

Blockchain architecture has been found to improve efficiency in transactional contexts involving multiple parties, third-party intermediaries and compliance and asset tracking requirements. (U.K. Government Office for Science 2016) Increased transactional efficiency due to disintermediation is particularly pronounced in contexts where the third-party intermediary is currently necessary to establish trust and allow for the flow of information between transacting parties. (PricewaterhouseCoopers Gmbh 2017) Every person interviewed in a World Energy

Council survey of energy policy makers and industry executives highlighted the disintermediation (*i.e.* removal of third party intermediaries) as a strong benefit of blockchain. (2017) In these situations the third-party performs a necessary function but at a cost. Blockchain's "trust machine" feature allows for the removal of the third-party intermediary while retaining the trust necessary for the transaction. (Merz 2016)

Disintermediation efficiency has been found in commodity and energy markets. PWC specifically identified OTC transactional settings in energy and commodity trading markets as contexts where blockchain technology could improve efficiency and lower transaction costs. (2017) Traditionally, commodities could not be traded directly due to the fear of non-payment, known as counter-party risk, or errors. To mitigate these risks, parties used "confirmation matching" to confirm the terms of the deal via fax or in person. Blockchain-based transactions would be trust-less, allowing for direct transfers in return for payment. Efficiency gains are improved if the process is automated transactions using smart contracts. In microgrid energy trading, blockchain systems were found to increase trust in the system with regard to financial payment and electricity delivery. (Green and Newman 2017) The United Nations has highlighted blockchain's potential to improve carbon markets and GHG reduction tracking and North American policymakers and regulators have indicated interest in its ability to reduce the risk, time and costs in regulated markets. (United Nations 2017; IBM Institute for Business Value 2017)

The improved transactional efficiency facilitated by blockchain technology can lead to increased market liquidity. (Yermack 2017) The liquidity of a given asset is a combination of (1) relative ease with which it can be transacted (*i.e.* bought or sold) and (2) the level of costs associated with a sale, either in the form of transaction costs or in the need to accept a lower price than desired in order to sell the asset quickly. One of the primary effect of low liquidity is higher price volatility. (Elliott 2015) The greater the relative ease with which an asset can be transacted, the smoother and more predictable price movements tend to be, reducing price volatility. (Yermack 2017; Elliott 2015) Improved liquidity associated with the introduction of blockchain could improve overall demand for stocks and impact patterns of investment and ownership.

Chapter 4. Renewable Energy Certificate Markets Structure

Chapter 4 and **Chapter 5** of this thesis will develop a profile of the U.S. voluntary market and the contextual factors that could significantly impact that effectiveness of blockchain technology generally. This profile will serve as a framework for the analysis of the discrete blockchain platforms surveyed in **Chapter 6**. The voluntary market profile draws from a review and analysis of the available academic and grey literature on voluntary markets and information from interviews with subject matter experts, as identified in **Table 2**. Interviewees with expertise on the U.S. voluntary market and the potential application of blockchain technology therein were identified to supplement the voluntary market literature. Information gained from the subject matter expert interviews was synthesized with the literature on the voluntary market in order to situate blockchain technology as a potentially disruptive technology within the specific context of the voluntary market.

Specifically, **Chapter 4** will survey the structure of the voluntary market with an emphasis on the governance and administrative entities and systems, transactional dynamics and market structures. **Chapter 5** will survey review the literature on the interrelationship between voluntary market demand drivers and the significant factors influencing the effectiveness of the voluntary market at developing additional RE generation capacity.

4.1. Commoditizing Environmental Attributes

A REC is similar to a carbon credit or offset in that both are intangible environmental commodities created for the purpose of transferring legal ownership of the underlying environmental attribute. (Kluchenek 2015) In the U.S., RECs are generated by eligible renewable energy generation (*e.g.* wind, solar or hydroelectric) and the REC represents the environmental attributes of 1 MWh of that renewable electricity. (U.S. EPA 2018a) In a tokenized blockchain-based system, the green token would serve the same function as a REC. Similar to a carbon credit, ownership and retirement of a REC grants the owner the right to "claim" the benefit of that underlying environmental attribute. (Jones, Quarrier, and Kelty 2015) The environmental attributes can include avoided GHG or air pollutant emissions, fossil fuel displaced, or other environmental or social attributes, depending on the certifying authority and REC definition. (Crandall 2010)

Table 4. Voluntary Market Expert Interviews[3]

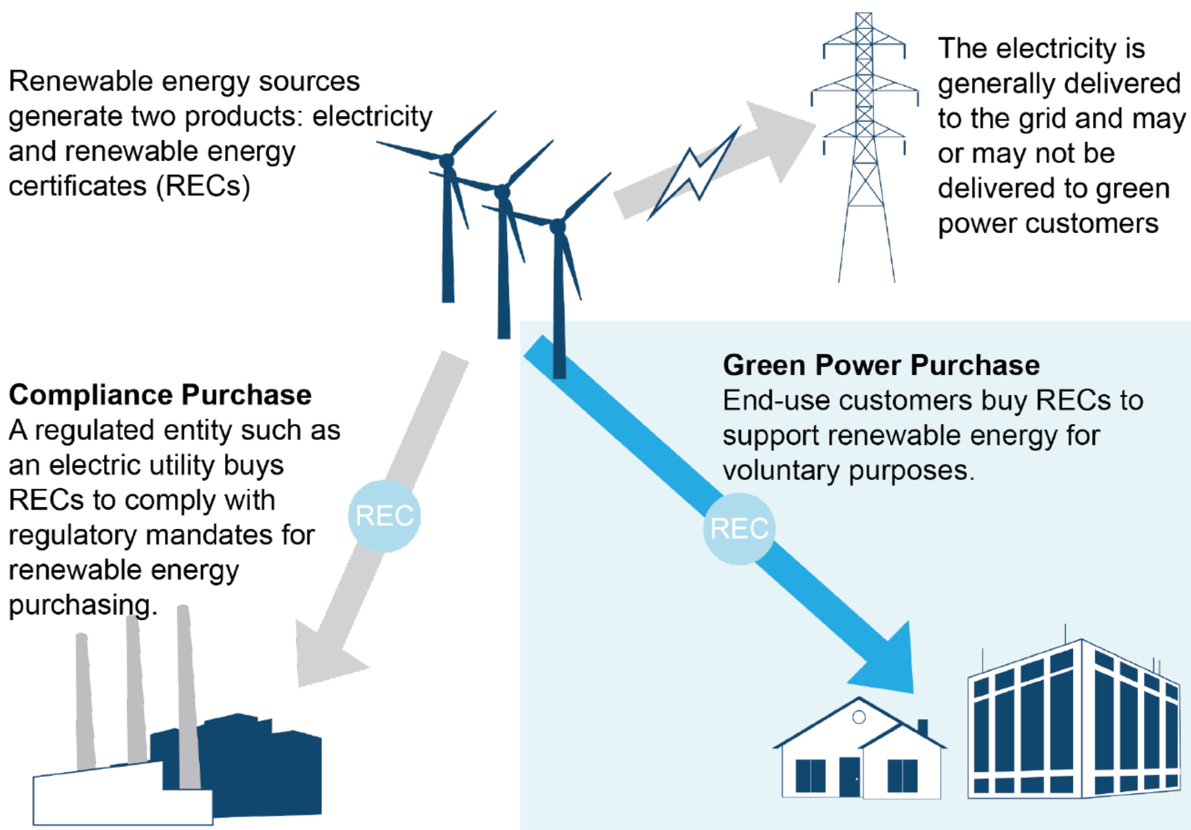
Interviewee & Expertise Category	Date & Format	Position & Expertise
Benjamin Gerber *REC Tracking System*	May 15, 2018 – Skype Call	Executive Director at Midwest Renewable Energy Tracking System (M-RETS) Developed an inhouse digital tracking platform for M-RETS, a regional REC tracking system. Experience with tracking systems, REC markets and blockchain technology integration.
James Critchfield *REC Standard Setting*	May 11, 2018 – Skype Call June 26, 2018 - Written responses	Director, U.S. Environmental Protection Agency's Green Power Partnership Oversees market policy and programs and tracks blockchain developments in the REC voluntary market.
Michael Leschke *REC Standard Setting*	May 18, 2018 – Skype	Senior Manager, Certification Programs at the Center for Resource Solutions/Green-e
Alex Anich *REC Purchaser*	May 15, 2018 - Skype Call	Manager of Renewable Market Intelligence at NRG Energy, Inc. Oversees the company's REC portfolio and is working on the development of a blockchain-based REC transactional platform.
Doug Miller *REC Market Platform Developer*	May 18, 2018 – Skype	Origin Product Manager at Energy Web Foundation. Manager of the development of EW Origin, an open-source blockchain-based trading platform for REC and carbon markets.

A REC serves two fundamental purposes – it solves a physics problem and creates a subsidy or second income stream for RE generation. (Jones 2017) The nature of electrons and grid electrification means that an environmentally conscious consumer cannot, in practice, buy renewable energy off of the grid. (Gillenwater 2013b) As the U.S. Federal Trade Commission has noted, once introduced to the grid, renewable electricity is indistinguishable and inseparable

[3] All interviewees spoke in their personal capacity and their opinions do not reflect the positions of their employers. The interviewees from NRG Energy, Inc. and Energy Web Foundation are involved in the development of a blockchain platforms analyzed in **Chapter 6**. Both interviewees have expertise on RECs and the voluntary market, in addition to their work on blockchain platforms.

from fossil or nuclear energy. (U.S. Federal Trade Commission 2015) The generation of a tradable commodity (*i.e.* the REC) representing the environmental attributes of the RE generation allows consumers to "purchase" renewable electricity. Thus, renewable energy can only be "delivered" to a customer in the form of a REC via a contractual relationship. (Koperski 2017) Notably, the REC is legally distinct from the underlying electricity and must be contracted for separately, either sold bundled with the underlying electricity or purchased entirely separately (unbundled). (Jones, Quarrier, and Kelty 2015)

Figure 3. U.S. Green Power Market (NREL 2017)

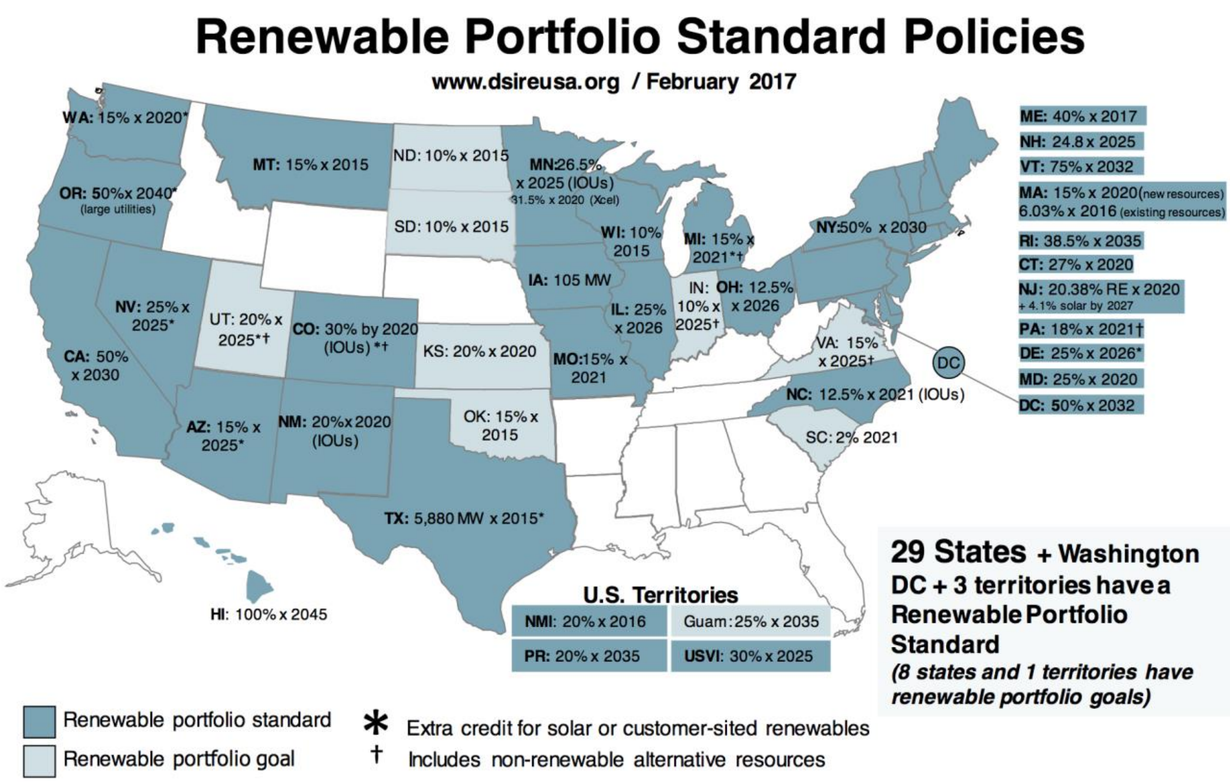


The demand for the right to purchase the REC creates a second income stream for the renewable energy generator (additional to the sale of the electricity) that serves as a market-based subsidy for the renewable energy generation, often referred to as the "green power" market. (Wohlgemuth and Madlener 2000) Similar to a cap and trade system for carbon, REC prices are set by the marketplace and market mechanisms are designed to efficiently allocate the associated green attributes. (U.S. EPA 2018a)

4.2. REC Markets in the United States

In the U.S., there are two distinct but interrelated markets for the purchase and sale of REC – (1) compliance markets and (2) the voluntary market. This thesis will examine the later, but an understanding of the former is also necessary due to the high degree interaction and interconnectivity between the two.

Figure 4. State Renewable Portfolio Standards (U.S. Dept. of Energy 2017)

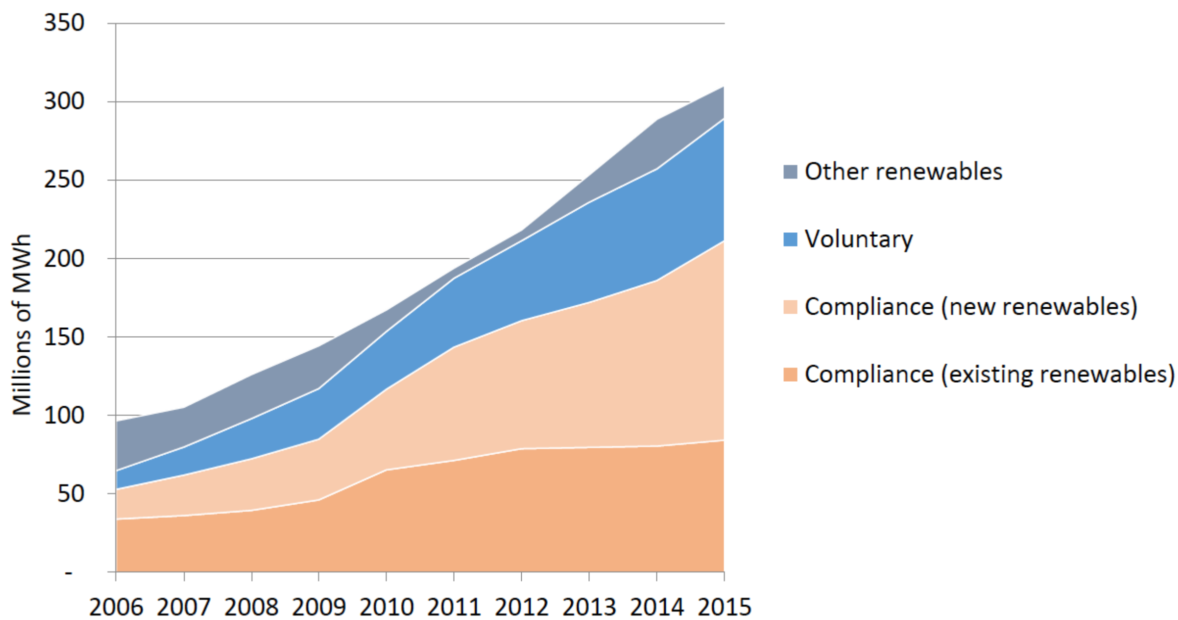


REC ***compliance markets*** are regulated markets created by State renewable portfolio standards (RPS). A RPS is a legal obligation under State law that require utilities to source a certain percentage of their total electricity sales from renewable sources. (Koperski 2017) In addition to building out their renewable generation portfolios, utilities can satisfy a portion of their RPS requirements by purchasing RECs from eligible renewable energy generation. State RPS rules regarding RECs eligibility and the percentage of RPS requirements **that** can be satisfied by REC purchases. RPS requirements create a relatively stable source of demand for RECs and serve to create a REC price floor. Currently 29 U.S. States and the District of Columbia have mandatory

RPS programs from and 8 more have adopted non-binding standards. (Durkay 2017) State RPS requirements range from 10% of a utility's sales to 50% in New York and California by 2030.

In contrast to compliance markets, which are largely regional due to state-based legal requirements for eligible generation, project location and tracking system use, the voluntary market is national. (O'Shaughnessy, Liu, and Heeter 2016) Absent geographic location requirements set by a third-party registry or certifying authority, or purchaser preferences for local generation or a particular renewable technology, there is no limitation on the origin of the voluntary REC.

Figure 5. Voluntary & Compliance Markets (NREL 2017)



4.3. Voluntary Market and Blockchain Platforms

The discretionary nature of voluntary market participation effects the market's structure and incentives in two significant ways that make it unique in the energy sector and potentially attractive as an early commercial use-case for blockchain platforms. (Basden and Cottrell 2017) First, the voluntary market is largely unregulated and operates without direct or meaningful oversight by state or Federal legislatures or regulatory bodies. (Bird and Lokey 2008) Because the majority of customers on the on the voluntary market are under no legal obligation to purchase RECs, there are no laws or regulations governing how many RECs must be purchased or establishing standards for the type or quality of RECs that can be purchased. Despite being tradable commodities, RECs are not subject to regulation as securities and, to date, are considered exempt from oversight from the Commodity Futures Trading Commission. (Kluchenek 2015)

The relative absence of direct regulatory oversight relative to compliance markets or many carbon markets largely obviates the need change or remove regulatory or statutory obstacles. Public policy, and the need to change regulatory and statutory structures to permit blockchain use, together constitute one of the primary obstacles to blockchain adoption in the energy industry and makes the voluntary market a particularly attractive use-case for blockchain commercialization. (Gabison 2016) Two of the interviews opined that the voluntary market represented a particularly useful testing ground for blockchain commercialization due to the lack of regulatory oversight. (Anich 2018; Miller 2018) To succeed in the voluntary market, blockchain systems need to demonstrate value add over existing voluntary market systems and entities, but do not need to change the legal or regulatory structure to be adopted at scale.

Second, neither the composition of the customer base nor demand for RECs on the voluntary market is static. (Dagher, Bird, and Heeter 2017; Andrews 2012) Rather, voluntary market customers choose to participate (with the exception of some government agencies) and there is no obstacle to expanding the customer base or the overall amount of demand. Four interviewees specifically cited blockchain's potential to expand demand as one of the primary means through which the technology could impact the voluntary market. (Miller 2018; Anich 2018; Leschke 2018) However, expert opinion on the plausibility, scope and specific mechanisms for expanding demand ranged considerably and are discussed in detail in **Chapter 5**.

4.4. Voluntary Market Administrative Entities and Structures

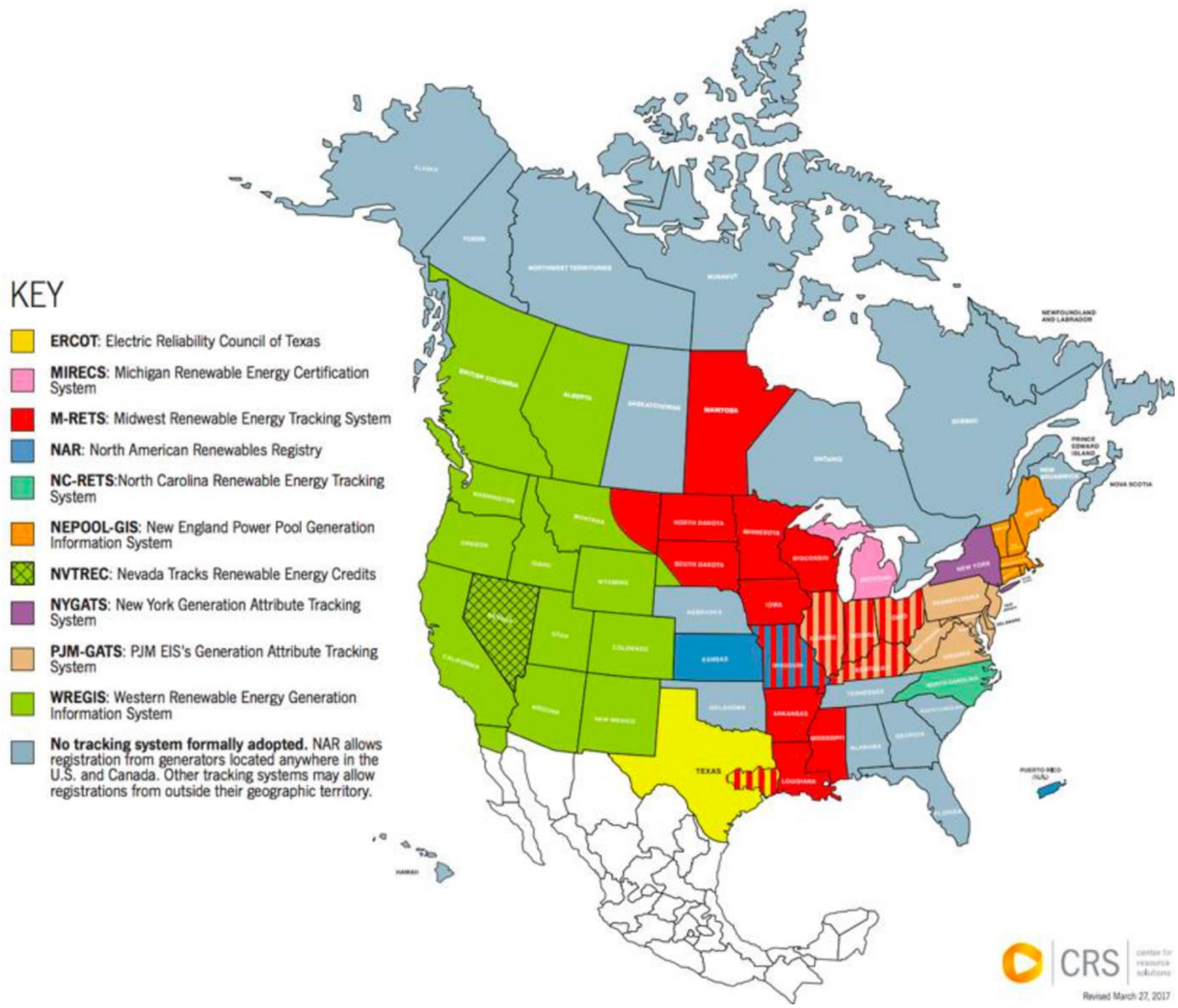
The lack of direct public oversight, relative absence of regulatory or statutory standards, and discretionary participation in the voluntary market does not render it a blank canvas for blockchain platforms. Rather, the voluntary market is administered and governed by established structures and entities. Some of the most integral extant entities are shared with compliance markets and thus subject to public policy and legal considerations. (Andrews 2012) The REC itself is an established mechanism for commoditizing the environmental attributes of RE generation and that generators, purchasers and market administrative and governance systems are set up to work with RECs. (Leschke 2018) Thus, to succeed on a commercial scale, blockchain platforms would need to integrate with, augment or displace existing systems. An understanding of existing market structures and systems is necessary to analyze blockchain technology's potential in voluntary markets and make more granular determinations of the specific pathways and opportunities for blockchain technology application.

4.4.1. Tracking Systems

The 10 REC tracking and issuance entities in North America are the backbone of both compliance and voluntary markets (Jones 2017). All but two are quasi-governmental entities supported to varying degrees by State governments and were established for use on the compliance market. Tracking systems track and reconcile wholesale REC transactions and retirements, ensuring chain of custody and avoiding double-counting. (Bird and Lokey 2008) Tracking systems issue RECs based on verified data received directly from the Regional Transmission Operators (RTO) or Independent System Operators (ISO) that is reported by regulated utilities. (Gerber 2018) RECs are assigned a unique identification number, Information on the location, technology (*i.e.* wind, PV solar, etc.), owner, capacity, time of generation, and year the generating facility commenced operation are included with each REC. (Jones, Quarrier, and Kelty 2015)

Tracking systems issue RECs used on both voluntary and compliance markets and, in general, a REC is the same whether sold on the compliance or voluntary market. (Bird and Lokey 2008) Despite the absence of any legal obligation to use the tracking systems, nearly 70% of RECs transacted on the voluntary market were registered in tracking systems. (Leschke 2018) In particular, voluntary market utilization of tracking systems is due to a significant percentage of renewable generators participating in the tracking system. (Heeter 2013) Many REC generators (*i.e.* eligible RE generation facilities) supply both voluntary and compliance markets. (Bird and Lokey 2008) This overlap and interconnection of the two markets causes demand in one market to influences prices on the other. (Bird and Lokey 2008) State RPS compliance quotas setting, in effective, a REC demand floor for the overall market. In turn, the voluntary market provides demand for compliance RECs in the event the compliance market is oversupplied. Thus, the RPS voluntary market establishes a price floor for the voluntary market by siphoning off excess RECs.

Figure 6. REC Tracking Systems (Jones 2017)



The common use of tracking systems causes a degree of standardization between voluntary and compliance markets but with important caveats that are relevant for blockchain technology application. Compliance markets are fragmented because of state law requirements and, as a result, REC definitions and standards are not uniform among tracking systems. (Koperski 2017) RECs on the voluntary market are further subject to standards and definitions set by third-party voluntary registries and programs, described in **Chapter 4.4.2**. Despite being a national market, the voluntary market's reliance on tracking systems are a significant factor that has precluded a national tracking system. (Leschke 2018; Critchfield 2018)

Further, tracking systems are largely independent of one another and are not required to facilitate the import and export of RECs between tracking systems, even if definitions and standards are sufficiently uniform. (Heeter et al. 2014) Registries are independent entities and only coordinate of their own volition. Some tracking systems have mutual import and export agreements, while others only allow export. Notably for blockchain platforms, the ability to import and export between tracking systems is technically feasible using conventional systems but is prevented by institutional interests and prerogatives. (Gerber 2018) Thus, even in the national voluntary market, blockchain platforms must consider incumbent players, systems and public policy considerations that do not have technical solutions. (Leschke 2018)

Table 5. REC Tracking System Export & Import Agreements (2011)

Export	Import
NARR	**NC-RETS**
NC-RETS	**NARR**
MIRECS	**NARR**
MIRECS	**PJM-GATS**
M-RETS	**NARR**
M-RETS	**NC-RETS**
M-RETS	**MI-RECS**
PJM-GATS	**MI-RECS**
WREGIS	**NARR**
WREGIS	**NC-RETS**
ERCOT	**NC-RETS**

4.4.2. Voluntary Market Registries and Standard Setting Organizations

Adjacent and complimentary to the tracking systems is a network of registries and standard setting organizations. For RECS generated outside the tracking system, registries set eligibility standards for generation facilities selling on the voluntary market, assigns unique REC identifying numbers and generation information, and track the transaction and retirement of voluntary RECs. (Center for Resource Solutions 2017) The largest of these registries is Center for Resource Solution's Green-e Energy Program. REC purchasers participate in the Green-e program voluntarily and abide by its standards in return for the ability to market voluntary REC purchases as Green-e certified. (Jones 2017) Green-e serves as a de facto standard setting authority for the voluntary market.

Green-e's generation standards, tracking and auditing functions ensure that (a) a REC purchased on the voluntary market legitimately represents one MWh of eligible renewable energy and all associated requirements and (b) that the REC is "retired" only once, to avoid double-counting. Further, irrespective of whether voluntary market RECs are in a tracking system, Green-e participants are audited annually by certified public accountants or certified auditors to substantiate REC purchases (*e.g.* auditing a corporation's 100% renewable energy claims based on its purchase of voluntary RECs), sales and retirement claims. (Center for Resource Solutions 2017) Green-e also reviews generating facilities for marketing claims for compliance purposes.

In addition, EPA's Green Power Partnership (GPP) oversees 40% of the voluntary market. Although it has not regulatory authority, EPA GPP provides technical assistance, standards and benchmarks, and market information for participants, largely corporate entities. (U.S. EPA 2016) In exchange for their pledge to purchase green power and abide by GPP standards, GPP participants can publicly market their participation in the program and claim the certified renewable energy purchases associated with the voluntary REC purchases. As will be discussed in detail in **Chapter 5.1**, registries and standard setting programs are critical to ensuring the integrity of the voluntary market and generating demand.

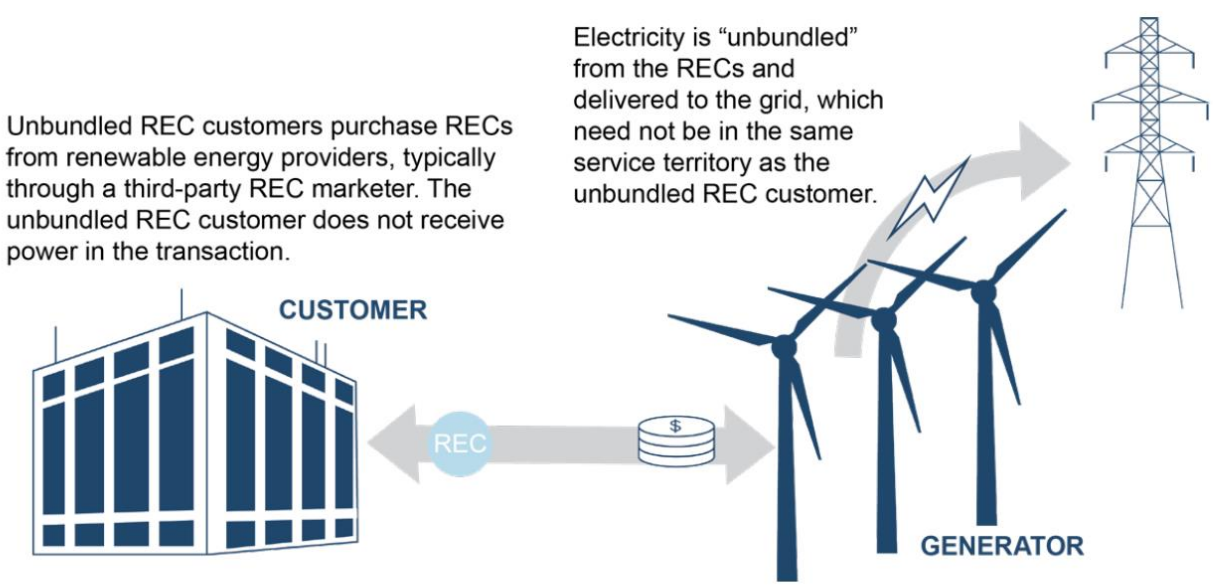
4.5. Voluntary Market Transactions

RECs are transacted on the voluntary market using a variety of different mechanisms. (O'Shaughnessy, Liu, and Heeter 2016) An understanding of voluntary market and REC transactional structures and dynamics is necessary for a more precise and specific analysis of the potential role of blockchain platforms. In particular, an analysis of blockchain's ability to improve the efficiency of voluntary market transactions requires a more granular profile of the extant market and transaction structures in order to understand the structural and systemic context in which these blockchain platforms will operate.

4.5.1. Bundled vs. Unbundled RECs

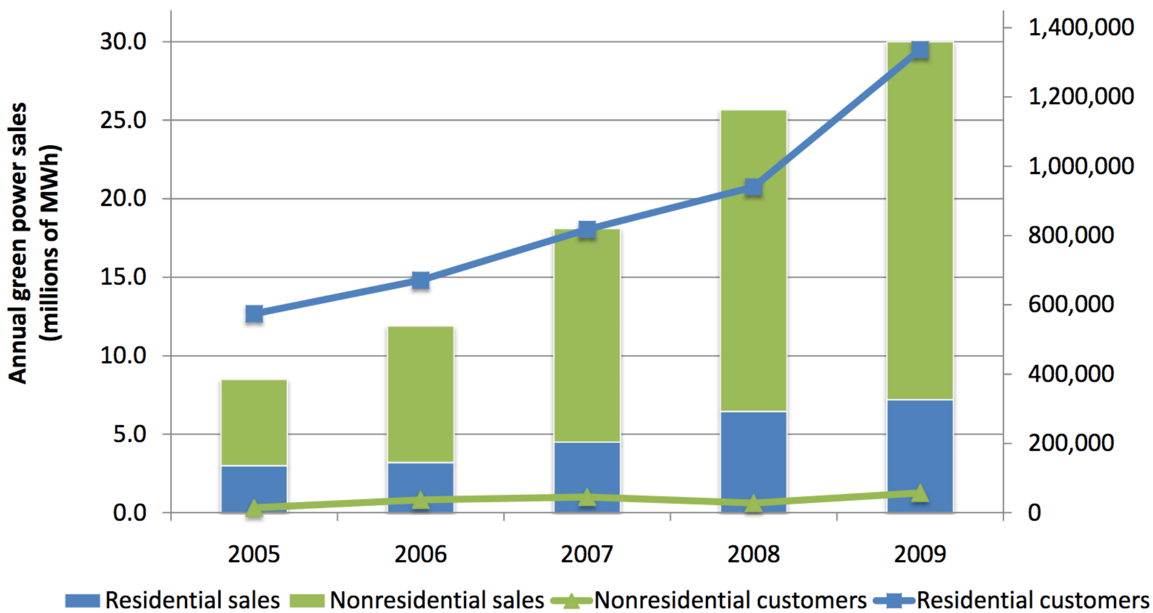
A REC on the voluntary market can be sold "bundled" or "unbundled" from the renewable electricity that generated it. A "bundled" REC is sold packaged with the underlying renewable electricity while an "unbundled" REC is sold separately (Jones, Quarrier, and Kelty 2015) For example, if a corporation entered into a power purchase agreement (PPA) with a wind farm, the corporate purchaser can only claim the environmental attributes of the renewable energy it purchases if it buys the REC bundled with the electricity. (U.S. Federal Trade Commission 2015) If the corporate purchaser does not contract for the purchase of the RECs, the wind farm operator would be able to sell the unbundled REC as a separate commodity on the voluntary market. A REC can be sold multiple times but only one party can claim or "retire" the environmental benefit.

Figure 7. Unbundled REC Transactions (NREL 2017)



Measured in MWhs, unbundled RECs constitute the largest segment of voluntary market REC transactions. (O'Shaughnessy, Liu, and Heeter 2016) However, unbundled REC purchases on the open market are limited to a relatively small number of purchasers. For example, in 2009, residential customers constituted over 99% of overall green power consumers non-residential customers accounted for over 75% of REC purchases by MWh. (Bird 2010) Non-residential customers are primarily commercial or corporate entities and federal government agencies that are under a legislative mandate to develop or procure renewable electricity, either by building generation or purchasing RECs.[4] (Andrews 2012) The strong majority of these unbundled REC transactions are OTC, with buyers and sellers relying on third-party brokers to facilitate transactions. (Holt, Sumner, and Bird 2011; Koperski 2017)

Figure 8. Residential vs. Non-Residential Purchases (NREL 2016)



In addition to the purchase of unbundled RECs on the open market, voluntary market participants can obtain bundled RECs through one of the following mechanisms.

[4] Although under a legislative mandate to buy RECs, non-utility government agencies are considered part of the voluntary market because they are not subject to RPS requirements. For example, the U.S. Department of Defense (DOD) is obligated to purchase at least 7.5% of its annual energy consumption from renewable sources. Although DOD has some renewable generation capacity, it can cover this obligation by purchasing REC in sufficient amounts. (Andrews 2012)

Utility green pricing programs allow residential and non-residential utility customers to purchase green power through an additional charge for the bundled RECs on their electricity bill.

Utility green tariff programs differ from green pricing programs in that they cater to large non-residential customers. Customers are allowed to choose the renewable project from which to source their energy and bundled RECs and involve longer time commitments, both with regard to green energy price and the purchaser's commitment to the project. (O'Shaughnessy, Liu, and Heeter 2016)

Voluntary PPAs allow customers to entered into long-term contracts with off-site renewable energy providers for the purchase of electricity and bundled RECs. (Holt 2015)

Community Choice Aggregation (CCA) involves the aggregation of residential customer load to purchase green power from a renewable energy supplier.

In the contexts in which REC customers receive their RECs though a utility program, the utility will have obtained the RECs either through their own renewable generation or by purchasing RECs on the voluntary or compliance markets. (O'Shaughnessy, Liu, and Heeter 2016) Those RECs would then be bundled with the electricity and sold to the customer.

4.5.2. Voluntary Market Structure

The paucity of spot market or other centralized exchanges and the predominance of third-party facilitated OTC transactions are defining features of the voluntary market. (Gerber 2018; O'Shaughnessy, Liu, and Heeter 2016) In commodity or securities markets, a spot market (also referred to as a cash market) is a centralized exchange where commodities can traded for immediate delivery at the market or spot price (*i.e.* the price for a given commodity at a particular time and place). (Investopedia 2018b) Spot markets for energy commodities include emissions allowance exchanges such as European Climate Exchange or NASDAQ OMX Commodities Europe. The ability to exchange the commodity instantly without reliance on a third party is a critical feature of spot markets for facilitating fast, low-cost transactions at scale. Spot markets for transacting RECs on the voluntary market exist, but to date the volume is low relative to the overall market or market access is limited to electricity serving entities. (Gerber

2018; Leschke 2018) Tracking systems provide an information service (*i.e.* generating and tracking REC transactions and retirements), but do not provide transaction price and volume information or serve a brokerage function, nor do they serve as an exchange or marketplace. (Koperski 2017)

In the absence of robust spot markets, the majority of voluntary market transactions are OTC, with third party REC brokers and retailers facilitating transactions or in the form of PPAs between the REC generator and purchaser. (Holt, Sumner, and Bird 2011; Koperski 2017) The majority of the literature and expert interviews found that reliance on OTC transactions results in market opacity, illiquidity and high fees relative to more liquid commodity or security markets. (Holt, Sumner, and Bird 2011; Anich 2018) REC prices on the voluntary market, particularly long-term, are difficult to ascertain. Even in instances when prices are reported by brokers and retailers, those prices tend to be for short-term purchases. (Holt, Sumner, and Bird 2011) Third-party intermediaries add varying degrees of cost to the REC transactions, ranging from 3-5% of the REC transaction. (Gillenwater 2013c) Further, in the absence of a transparent marketplace, the cost of RECs varies considerably by purchaser. Residential and smaller entities can pay between $15 and $30 per MWh while larger commercial and industrial purchasers pay $1 to $10 per MWh, closer to the wholesale REC price. However, one standard setting expert disagreed that the voluntary market is opaque, noting the existence of tracking systems and contractual relationships that define ownership and chain of custody or provenance tracking. (Critchfield 2018)

4.5.3. Implications for Blockchain Technology

The structure of the voluntary market and transactional dynamics have important implications for blockchain technology's application. As the blockchain literature in reviewed in **Chapter 3** found, blockchain technology has potential value relative to conventional systems in situations with multiple parties to a transaction, using a shared or consistent asset or record, verification or auditing requirements, and the presence of costly intermediaries. (Meunier 2016) In the voluntary market, the REC is the consistent asset and the remainder of the contextual requirements appear satisfied.

NRG Energy's REC purchasing process is an instructive illustration of the transactional dynamics caused by the overall voluntary market structure, particularly the absence of a spot market. For NRG, the purchase of a REC on the voluntary market can involve up to six parties with different roles and separate databases. (Anich 2017) Buyer and seller have separate databases and trade management systems which contain copies of the REC being transacted and must be reconciled. REC transactions have to be reviewed by accountants and auditors and reconciled against the tracking system database. Further, the transactions are facilitated by a broker due to the lack of centralized exchange or spot market, adding an additional party and cost to the transaction.

Blockchain technology's general value proposition is in this area is reducing the amount of time and labor required to copy and reconcile databases used by multiple parties, relative to current systems, and thus improving transaction speed and lowering costs. Currently, transactional dynamics cause RECs to be transacted on a monthly cycles or intervals and the potential labor and time efficiencies offered by blockchain platforms could decrease the transaction interval. (Anich 2017) One standard setting expert believed that one of the reasons blockchain technology is being explored in voluntary markets is the potential to improve transaction speed and unlock the associated value. (Leschke 2018) However, another standard setting expert did find market demand for faster transactions, which could be met by existing market mechanisms if such demand existed. (Critchfield 2018) A platform developer stated that improvements in transactional speed was important to some market entities, particular large commercial entities buyers, but not all buyers. (Miller 2018) For NRG, a blockchain platform has the potential to reduce individual REC transaction times from 1 day to a half an hour and costs from up to 10% of the REC cost to 3%.

In addition, a key feature of the REC transactional dynamic is the auditing and verification process. Four interviewees believed that blockchain platforms could improve REC transactional efficiency by reducing the administrative burden for auditing and verification but differed on the degree to which such improvements were desirable or valuable. The nature of blockchain's data structure would allow for real-time transactional verification, ensuring REC provenance and chain of custody while reducing the administrative burden currently required to perform this function. (Anich 2017)

Finally, the potential ability of blockchain platforms to increase transactional efficiency by disintermediating the current OTC market was noted by four interviewees, excluding the tracking system expert. In particular, all four interviewees described the cost of third-party intermediaries as an inefficiency in the current system and an area of potential discrete and quantifiable value-add for blockchain technology. Currently there is no system for handling the counter-party credit risk, cash-flow and settlement necessary for a direct transaction, which necessitates third-party intermediaries. (Anich 2017) A blockchain system could allow simultaneous purchase and settlement while the transaction is verified by the blockchain system's chain of custody and provenance features.

Notably, two of the experts interviewed emphasized that transparent, liquid markets currently exist in other contexts (*e.g.* stock, carbon credit or commodity futures markets), including environmental commodity markets, and thus not necessarily require blockchain technology. (Gerber 2018; Leschke 2018) The technology also exists to create a national REC tracking system that includes price and volume data. Rather, the obstacle to transparent, liquid markets in the REC voluntary market were identified as being institutional and regulatory.

Chapter 5. Effectiveness of the Voluntary Market

The structural profile of the voluntary market and its transactional dynamics will provide a framework for analyzing the threshold question for the proposed blockchain platforms – does the voluntary market have the contextual features and attributes of a system for which blockchain technology has potential value relative to conventional systems. However, beyond the threshold structural questions, it is necessary to understand the factors that drive and inhibit the efficiency and effectiveness of the voluntary market to analyze the potential of blockchain technology to make quantifiable improvements relative to the *status quo*. **Chapter 5** will survey review the literature on the interrelationship between voluntary market demand drivers, the structural features surveyed in **Chapter 4**, and the significant factors influencing the effectiveness of the voluntary market at developing additional RE generation capacity.

5.1. Voluntary Market Demand

As discussed in **Chapter 4**, participation in the voluntary market and demand for RECs absent government mandates is discretionary. (Bird and Lokey 2008) The discretionary nature of demand removes the traditional regulatory and legal barriers to commercial adoption of blockchain technology in the energy sector and creates an opportunity for blockchain platforms to influence the effectiveness of the voluntary market. (Basden and Cottrell 2017)

5.1.1. Demand for Environmental Attributes

Inherent in the demand for RECs on the voluntary market is some degree of concern about environmental sustainability by the REC purchaser, and a belief that the REC consumer can claim the environmental attributes of renewable generation conveyed with the REC. (Taylor 2017) The most visible and emphasized environmental attribute conveyed by a REC is the perceived reduction in GHG emissions by supporting RE generation. (Moore, Lewis, and Cepela 2010) Particularly for corporate demand, the ability to claim the perceived GHG emission reductions associated with the purchase of green power via RECs is at the heart of corporate demand. (Bird, Holt, and Carroll 2007) A survey of U.S. companies found that 80% of companies actively pursuing RE procurement had GHG emission reduction goals. (Favaloro, Carey, and Gerstel 2016) A stated desire to reduce GHG emissions was the single most cited driver of intent to procure RE generation at 85% of respondents. In practice, the procurement of 100% RE generation can drive corporate decision-making. Facebook's decision on the location for a new data center was driven in part by a desire to source 100% of the electricity from renewable sources. (Tawney, Bonugli, and Melling 2016) New Mexico and Utah developed green tariff programs (the purchase of electricity with bundled RECs) to court Facebook.

However, research further suggests that public-facing, reputational or brand considerations are a significant component of demand for quantifiable reductions in GHG emissions. Research has found that green power purchasers are driven by the "warm-flow" effect - a desire to feel better about themselves, or less guilty about the externalities of their electricity consumption, than by a consideration of the public good or actual environmental benefit. (Dagher, Bird, and Heeter 2017) Corporate voluntary market demand is driven in large part by marketing and brand considerations, in addition to carbon footprint reduction and sustainability goals. (O'Shaughnessy, Liu, and Heeter 2016) The literature does show that environmental concerns, including preferences for RE generation and reductions in GHG emissions are factors, but public perception is a significant motivation. (Moore, Lewis, and Cepela 2010)

It is important to note that the literature suggests a degree of uncertainty on resiliency and elasticity of demand for RECs on the voluntary market. Green power demand was found to be relatively price inelastic, meaning that purchasers would tolerate higher prices. (Dagher, Bird, and Heeter 2017) Further, voluntary REC purchases were not rescinded during the 2008 economic recession. (Heeter, Armstrong, and Bird 2012) However, other research has shown voluntary REC demand is price sensitive and that increases in voluntary REC prices due to compliance market demand has negatively impacted voluntary market demand. (Holt, Sumner, and Bird 2011) Further, as noted in **Section 3.2.2.**, voluntary market price is influence by compliance markets.

5.1.2. Trust and Verification

Given the importance to voluntary market demand of public-facing claims about renewable energy usage, it is not surprising that trust in the veracity and accuracy of the REC is important to driving voluntary market demand. Studies have shown that accreditation and certification of the green power claims boost consumption and demand by up to 30%. (Dagher, Bird, and Heeter 2017) Further, information about the source of the REC has been associated with higher consumer demand and a willingness to pay a premium for green power. (Zarnikau 2003) The relative importance of accreditation and verification to residential consumer demand was found to be more significant than price. Commercial purchasers appear motivated by marketing and brand concerns, seeking to obtain high sustainability scores or accreditations, positive media attention, and obtain and retain employees. (Clark and Master 2012) Among commercial REC purchasers there is competition to appear more "green" for marketing purposes. (Powers and Haddonq 2017) Companies like Google have made public claims that their RECs are more "additional" (*i.e.* have a greater GHG emission reduction impact) than those of their competitors.

The combination of the importance of public-facing or marketing concerns in generating discretionary demand for RECs and the role of trust and verification in supporting that demand reinforce the critical role played by third-party certification and standard setting entities like Green-e and EPA's GPP. Participation in these programs and certification that participants have met their standards helps to ensure market credibility. (Critchfield 2018) Both standard setting experts differentiated blockchain's ability to ensure transactional validity and chain of custody from the technology's ability to replace third-party certification and verification of the RE generation underlying the REC (*e.g.* ensuring additionality standards) and the GHG reduction claims of REC purchasers. Both described this as critical to generating demand on the voluntary market. (Leschke 2018; Critchfield 2018)

Notably, there is little evidence to suggest systemic or large-scale fraud or double-counting occurs on the voluntary market. Existing tracking systems settle transactions upon retirement, preventing double-counting, and there is no evidence of market demand for improved security in this area. (Gerber 2018) For voluntary transactions outside the tracking system, registries like Green-e audits purchasers to verify RECs are not double-counted. (Leschke 2018) However, there is some evidence that it does occur, despite the presence of tracking systems and voluntary registries like Green-e. (Environmental Tracking Network of North America 2009)

While two of the experts interviewed did note blockchain's superior fraud and double-counting prevention capabilities, none of the experts interviewed cited evidence of market demand for improved security in this area. (Critchfield 2018; Leschke 2018) Further, these experts noted that nothing inherent to blockchain technology guards against fraudulently inputted RE generation data.

5.1.3. Market Access

All experts interviewed agreed that one or more aspects of the voluntary market's structural and transactional dynamics inhibited the ability of smaller and less sophisticated generators and purchasers to buy and sell unbundled RECs on the open market, thus influencing demand.

The proponents of blockchain's ability to increase demand uniformly noted the ability of blockchain platforms to serve demand from distributed generators and small-scale purchasers that are underserved by the existing system. (Anich 2018; Miller 2018) As described in **Chapter 4.5**, the substantial majority of unbundled REC purchases on the voluntary market are done by large, sophisticated commercial purchasers. Smaller, residential purchasers rely on third-party programs like utility sponsored green pricing programs. The absence of spot markets and the transactional complexity demonstrated in the NRG REC purchase example demonstrate how transactional complexity would impact less sophisticated or smaller scale buyers and sellers (*e.g.* distributed renewable sources like rooftop solar) who require a third-party to assist with the transaction. (Leschke 2018) In turn, the reliance on third-parties increases the cost of transactions, impacting residential and non-residential purchasers. (Gerber 2018; Anich 2018)

Participation in the tracking system adds additional costs that can be prohibitive for smaller entities, including account creation, transaction and retirement fees. (Leschke 2018) However, one expert noted the existence of aggregation services that serve distributed sources and interface with the tracking system and utility-sponsored green power purchasing programs for residential purchasers. (Leschke 2018)

In addition, experts identified the 1 MWh REC standard as disincentivizing smaller buyers and sellers because they may only generate or consume approximately 10 megawatt hours per year. (Miller 2018; Anich 2018) A more granular units of REC measurement (*e.g.* 1 KWh rather than the current 1 MWh standard) combined with easier access to the voluntary market were cited as potential increasing demand by directly engaging the customer to the RE generation. These respondents analogized a more granular voluntary market to airline rewards programs or other customer engagement programs.

5.2. Effectiveness of the Voluntary Market

The literature analyzed in **Chapter 5.1** suggests that ability to claim the environmental attributes associated with the REC, and particularly the GHG emission reductions, is integral to voluntary market demand. However, the environmental attributes conveyed with a REC, even when limited to GHG emissions, are conceptually complicated, difficult to quantify and not uniformly defined. (Gillenwater 2014) As such, there is not a consensus in the literature as to whether REC purchases on the voluntary market convey any quantifiable environmental benefit or emission reduction at all. (Holt, Sumner, and Bird 2011; Gillenwater, Lu, and Fischlein 2014) Further, two experts interviewed for this thesis did not fully agree with the literature finding that the voluntary market was ineffective. (Critchfield 2018; Leschke 2018)

A determination on the merits of this question is outside the scope of the thesis and unnecessary for an analysis of the potential efficacy of blockchain technology in the voluntary market. Instead, this section will develop a set of criteria or factors for analyzing the potential of blockchain technology to improve the voluntary market's effectiveness from an emissions reduction perspective relative to the *status quo* by first analyzing the standards for "additionality" as it pertains to the development of additional RE generation and the factors that the literature finds have inhibited the effectiveness of the voluntary market.

5.2.1. Additionality of the Voluntary Market

The concepts of additionality and displacement are central to determination of the effectiveness of the voluntary market (*i.e.* whether it has a quantifiable impact on net GHG emissions) and a determination of the significant factors impacting its effectiveness. (Gillenwater 2013c) In short, a REC is "additional" if the purchase of the REC will cause the development of additional renewable energy generation capacity relative to a "business as usual" or *status quo* scenario in which no RECs were purchased. (Bird and Sumner 2011) The question of additionality is not merely academic. Per U.S. EPA, additionality is what gives voluntary markets their "environmental integrity and marketability" and is integral to demand on the voluntary market. (U.S. EPA 2006; Critchfield 2018) Discretionary voluntary market demand is underpinned by an assumption that REC purchases will cause the development of additional renewable energy generation. (Holt and Wiser 2007)

For emissions accounting purposes, the GHG emission reduction attributes conveyed by REC are a reduction in indirect or Scope 2 GHG emissions, not direct emissions reductions as are conveyed by a carbon credit. (Sotos 2015) The purchased and retired REC legally displaces the emissions associated with the corresponding 1 MWh of electricity purchased from the grid. A reduction in indirect emissions is the delta between the emissions associated with a purchase of 1 MWh of electricity off of the grid and the 1 MWh of RE generation conveyed by the REC. (U.S. EPA 2018b) Thus, under both EPA GPP and Green-e standards, a company that covered 100% of its annual electricity consumption in MWh via voluntary market REC purchases would be permitted to claim that 100% of its electricity came from renewable sources and that it had no indirect GHG emissions. (Center for Resource Solutions 2016)

However, the claimed indirect emission reduction from the REC purchase and retirement does not *ipso facto* reveal the extent to which an overall net GHG emissions were quantifiably reduced by the REC retirement. (Powers and Haddonq 2017) Or, alternatively, were indirect emissions merely shifted from one party or location to another? To be additional, the REC purchase must, to some degree, be a "but for" cause leading to the financing and development of additional RE generation and the environmental benefits associated with it. (Powers and Haddonq 2017) Displacement means that the additional RE generation displaced some quantity of fossil generation (either existing or that would otherwise be developed to meet future demand). The overall GHG emission impact of a REC represent the delta between the *status quo* and REC purchase scenarios.

5.2.2. Additionality Standards

Additionality as it is applied to REC-driven GHG emission reductions can be grouped into two general categories: (1) quantifiable project-specific additionality and (2) general market additionality. Project-specific additionality indicates that a RE generation project was financed and developed due, at least in part, to the ability to sell RECs. (Powers and Haddonq 2017) The literature suggests that, at least in some circumstances, additional projects were developed (that would not have otherwise been developed) due to REC income streams. (Bird and Lokey 2008; Powers and Haddonq 2017) Analysis of publicly available data and interviews with experts and project developers found that REC value can cause project-specific additionality in certain situations. (Holt, Sumner, and Bird 2011) However, financial modeling has shown that the voluntary market has "negligible influence on the economic feasibility of [wind energy] facilities," undermining the possibility of an impact on project development (Gillenwater, Lu, and Fischlein 2014)

RECs certified under EPA GPP and Green-e standards must satisfy additionality protocols but proof of neither requires proof of project-specific additionality, nor displacement of fossil generation. (Center for Resource Solutions 2016) As a preliminary matter, a REC must be retired to "claim" the environmental attributes and cannot be claimed by more than one entity (or double-counted). (Jones 2017) There is no environmental integrity if the environmental attribute of the corresponding 1 MWh of renewable electricity can be claimed by more than one party. In addition, RECs must satisfy additionality protocols are comprised of three significant categories of requirements. (Center for Resource Solutions 2016; Gillenwater 2014; Powers and Haddonq 2017)

- ***Regulatory Surplus***. RECs cannot be double-counted (*i.e.* sold on both the compliance and voluntary markets or retired by multiple voluntary purchasers), nor generated by a RE project built in response to government mandate or be subject to a cap and trade system. (Moore, Lewis, and Cepela 2010) Without regulatory surplus there would be no demand signal for the market and thus no additional renewable energy development in aggregate. (Bird and Lokey 2008)
- ***Technology***. A REC must be generated by an eligible renewable technology (*e.g.* PV solar or wind). (Center for Resource Solutions 2016)
- ***Vintage***. The RE project generating the REC must be "new" as defined by the relevant protocol. Under Green-e's protocol, the project must have been developed within the 15 years. Allowing pre-existing RE generation projects to generate RECs would not send a market signal for new and additional projects.

In lieu of proving project-specific additionality, Green-e and EPA GPP's additionality tests serve to preclude RECs that cannot be additional from a GHG emissions perspective: projects that definitely would have been built otherwise, emit or cause to emit GHGs and projects that are sufficiently old as to be baked into the status quo. Under these standards, the market impact of the REC purchase is the demand-side purchasing signal in the market for renewable energy, leading to more renewable energy development in the aggregate, even if there is no demonstrable project-specific additionality. (Sotos 2015) In this regard, the REC is similar to an economic subsidy that is intended to influence behavior but does not demand a rigorous additionality analysis. (Powers and Haddonq 2017)

There is evidence in the literature to suggest that project-specific additionality is more desirable to some voluntary market purchasers relative to the more general market demand additionality offered by Green-e and EPA GPP. (Powers and Haddonq 2017) Prioritizing project-specific additionality is most important to commercial, industrial and institutional investors (C&I) REC purchasers due to the competitive advantage of being more "green" than competitors. For this segment of voluntary market demand, RECs representing verifiable project-specific additionality are more valuable and desirable than RECs that meet the more general Green-e standards. (Powers and Haddonq 2017)

5.2.3. Factors Limiting Voluntary Market Additionality

In addition to the baseline additionality standards for project vintage, technology and regulatory surplus, a review of the literature found three further factors that significantly influence the effectiveness of voluntary markets in causing additional project financing and development: (1) low REC prices on the voluntary market due to low demand, and (2) price instability due to market illiquidity and transparency.

5.2.3.1. REC Supply Outstrips Voluntary Market Demand

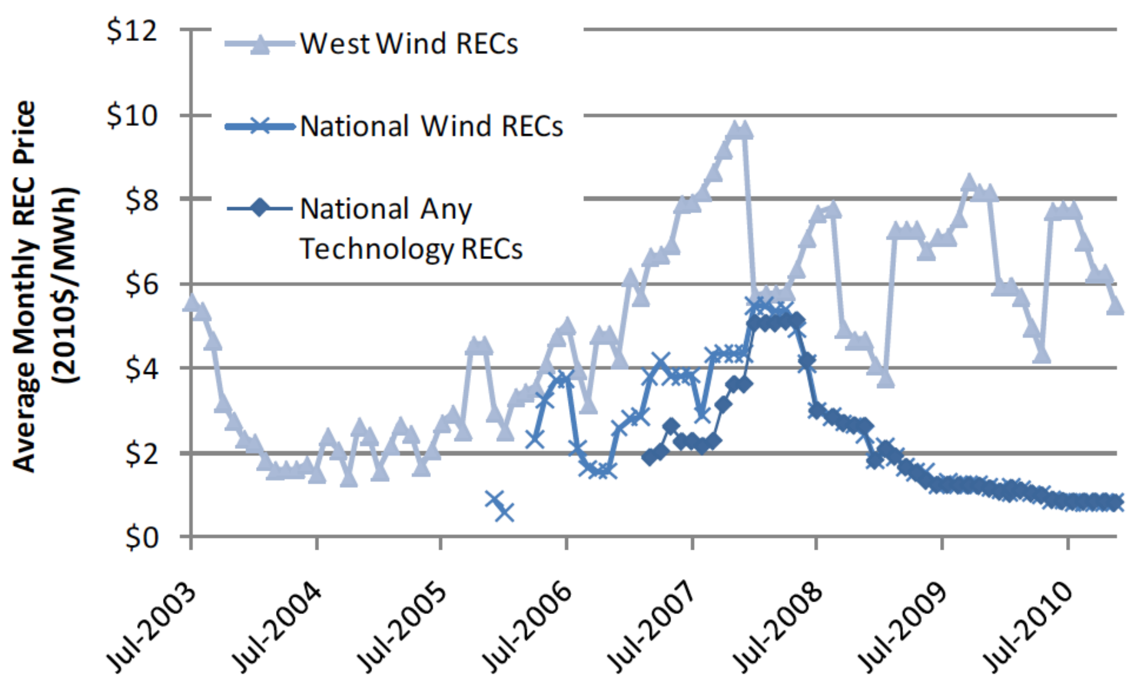
The literature review found that one of the strongest determinants of the voluntary markets ability to cause additional RE generation develop is the price of RECs. (Gillenwater, Lu, and Fischlein 2014; Holt, Sumner, and Bird 2011) Low REC prices have been a feature of the voluntary market for nearly a decade due primarily to a "massive oversupply" of RECs relative to demand in almost all areas of the U.S. (Powers and Haddonq 2017; Roberts 2015) Despite overall growth in the voluntary market in the past decade, REC prices continued to remain "historically low throughout 2015" on the voluntary market, falling from $1.13/MWh in January 2014 to $0.89/MWh in January 2015 and $0.34/MWh in January 2016." (O'Shaughnessy, Liu, and Heeter 2016; Di Capua 2010)

REC sales serve as a supplement to whole electricity sales and other income sources (*e.g.* tax credits) and must represent an economically significant source of project revenue per MWh to impact financing and development decisions. (Gillenwater 2013c) However, REC sales represent only 1 to 10% of total project income on average, compared to roughly 60% from wholesale electricity sales and 40% from the Production Tax Credit and accelerated depreciation policies combined. (Holt, Sumner, and Bird 2011) Academic literature has found that low REC prices impede project development because the prospective income from RECs "does not offer developers a significant risk-adjusted revenue stream." (Gillenwater 2013a) Even voluntary REC advocates agree that low prices have made RECs "all but irrelevant to the financing and investment decisions of the power industry." (Powers and Haddonq 2017; Roberts 2015)

5.2.3.2. REC Price Unpredictability

The second factor significantly impacting the effectiveness of the voluntary market in causing the financing and development of additional RE generation is REC price unpredictability. Price unpredictability is a product of a variety of factors, but long-term demand unpredictability, market illiquidity and the absence of long-term contracting have been found to be significant. (Holt, Sumner, and Bird 2011; Gillenwater 2013a) In restricted or less liquid markets, REC prices can be sensitive to individual generation projects or large amounts of demand from a small number of REC purchasers. (Mack et al. 2011) More liquid markets are less variable and more predictable in the longer term. A lack of liquidity in REC markets reinforces and is exacerbated by the lack of transparency and price information in the market. As discussed in **Chapter 4.5.2**, the predominance of OTC transactions and reliance on third-party intermediaries means that voluntary market prices are difficult to determine in the present or predict in the long-term. (Holt, Sumner, and Bird 2011)

Figure 9. REC Price Variability (NREL 2011)



The economics of RE project development typically require a steady and predictable stream of capital. (Holt, Sumner, and Bird 2011) Some research has found that the effectiveness of RECs on RE development is determined as much by supply and demand characteristics of the REC market as by the market price. (Wohlgemuth and Madlener 2000) One study concluded that a voluntary REC price of $50 would be insufficient to drive renewable energy development without long-term contracting to secure a predictable income stream from REC sales. (Van der Linden et al. 2005) Another found that voluntary RECs prices would need to increase thirteen-fold and be sold under a firm long-term contract (between 10 and 25 years) in order to have an effect on wind power project developers' decisions. (Gillenwater 2013a)

Longer term REC supply contracts can help alleviate price fluctuations. Indeed, long-term supply contracts are important to REC effectiveness even without price variability. (Holt, Sumner, and Bird 2011) However, long-term contracts are not a common feature in the voluntary market. Commercial practices appear to play a role in the absence of long-term contracting, but an exacerbating factor is that voluntary RECs are only usable for a limited period of time, ranging from several months to three years. (Van der Linden et al. 2005) One expert noted that the presence of long-term supply contracts is a market trend and not caused by structural factors. (Leschke 2018)

Chapter 6. Results

This chapter describes the findings from the results of the primary research on blockchain platforms designed for application in the voluntary market. Five blockchain platforms were analyzed in detail through interviews with persons involved in the development of the respective platforms and an analysis of available documentation online, primarily in the form of project white papers. In addition, white papers prepared for five additional platforms, WePower, Volt Markets, Electricy.Asia, New Era Energy LTD's NERA Blockchain and Grid+ were reviewed.

As shown in **Chapter 3.1**, blockchain technology can have a variety of designs or implementations and can be configured for use in a multitude of contexts. The purpose of an analysis of specific blockchain platforms is not to judge the potential or respective merits of an individual project or projects. Rather, research into proposed platforms will be used to develop a more specific and contextual profile of blockchain technology as it is being designed for application in U.S. voluntary markets or analogous contexts. A profile of blockchain technology based on actual projects designed for application in the context of the voluntary market will allow for a less speculative and theoretical discussion than an analysis of blockchain technology's general potential. Specifically, the research focused on (1) the system architecture, (2) purpose, (3) perceived market efficiency improvements (*i.e.* transactional efficiency, market liquidity and fraud avoidance) and (4) market effectiveness improvements (*i.e.* demand and additionality).

6.1. Blockchain Projects & Platforms

Blockchain platforms designed primarily in part for application in voluntary markets or to serve an analogous function can be grouped into two categories for analytical purposes: (1) green token projects and (2) market integration projects. The categorization describes legitimate differences in purpose, design and relationship to existing voluntary market structures and systems. It also creates a useful heuristic for analyzing the potential impact of blockchain technology on voluntary markets, as will be discussed in **Chapter 7**.

Green token platforms are designed to establish a new commoditization system in which the environmental attributes of renewable energy are commoditized in the form of a tradeable token in lieu of a REC or REC-like commodity (*e.g.* Guarantee of Origin) that is native to the platform's blockchain-based market or trading system. Green token projects are designed to create a new system outside or adjacent to existing REC markets rather than integrate into existing market structures and systems. The green token functionality can be primary or secondary. Swytch's platform is designed to create a REC-like token for RE generators for the primary purpose of incentivizing the financing and development of additional RE generation. (Swytch 2018) For Greeneum and Power Ledger, the green token functionality is layered on top of their platforms' core P2P energy trading and grid management functionality. (Greeneum 2018) When discussing the Power Ledger or Greeneum green tokens, I will be referring to the green commoditization functionality and not the platform as a whole unless otherwise noted.

The ***market integration*** platforms are designed for incorporation into the existing voluntary market structures and systems and would retain the REC as the unit of exchange and utilize existing standards and protocols. (Anich 2018; Miller and Griesing 2018) One market integration platform is NRG Energy's private and permissioned inhouse blockchain platform for REC transactions. (Anich 2017) The second is Energy Web Foundation's Energy Web Origin (EW

Origin), a public blockchain with permissioned validation intended for use by existing voluntary market entities, including transacting parties, tracking systems and registries. (Miller 2018)

Table 6. Green Token Platforms

	Greeneum	Power Ledger	Swytch
Blockchain[5]	Consortium	Consortium	Consortium
Consensus Mechanism	Delegated Proof of Stake	Not specified	Not specified
Smart Contracts	Yes	Yes	Yes
Platform's Primary Function	P2P energy trading & grid management	P2P energy trading & grid management	Commoditizing environmental attributes and incentivizing RE generation financing
Native "Green" Token	Yes	Yes	Yes
Generation Unit	Not specified	1 KWh	Flexible based on emissions impact of generation
Eligible Generation	Not specifically enumerated but could include wind, solar, wave, geothermal, hydro and biomass	Not specified	"[W]ide range of renewable and sustainable assets and infrastructure" including solar, wind, and storage
Vintage or Regulatory Requirement	Not Specified	Not Specified	Not specified
Project & Generation Verification	Smart meter and algorithm	Not specified	Smart meter and Protocols
Third Party Verification or Standards	Not specified	Not specified	Not specified
Demand Driver	Carbon reduction claim, token exchange, and marketplace	Green tokens exchangeable POWR tokens (tradeable cryptocurrency)	Tokens exchangeable for sustainability goods and services; cryptocurrencies

[5] All three blockchains are all built on top of the Ethereum blockchain, which is a public and permissionless blockchain. The type of blockchain indicated in this row is second layer blockchain platform designed by the individual companies and used for the environmental attribute commoditization function.

Exchangeable (Fiat or other Cryptocurrencies)	Yes	Yes	Yes
Green Token Retirement	Yes	Not specified	Not specified

6.2. Platform Architecture

The green token projects utilize consortium or hybrid public-private blockchains. Access to the platforms is public (*i.e.* anyone who holds a token can use the platform) but token generation, transaction validation and block formation rights are limited to certain nodes that are selected based on pre-set criteria. For example, access to the Greeneum platform for users is open to anyone holding its native tokens. (Greeneum 2018) However, RE generators are verified before they can generate green tokens and the platform allows for semi-private local chains that can be customized to manage local or microgrids. Transaction validation rights are not pre-determined (*i.e.* allocated to certain entities) but are instead voted on by token holders using a using Delegated Proof-of-Stake, a decentralized consensus protocol. Similarly, EW Origins utilizes a public blockchain but transaction validation is permissioned to verified "authorities" that meet specified criteria. (Miller 2018)

Tokens serve as the native medium of exchange on the platforms and the green tokens perform the function of a REC as the system's tradeable green commodity. Like RECs, the green tokens serve as reward or incentive for the RE generation upon generation of a qualifying amount of eligible renewable electricity. For example, Swytch issues tokens to RE producers as a reward for their renewable energy generation (or storage). (Swytch 2018)

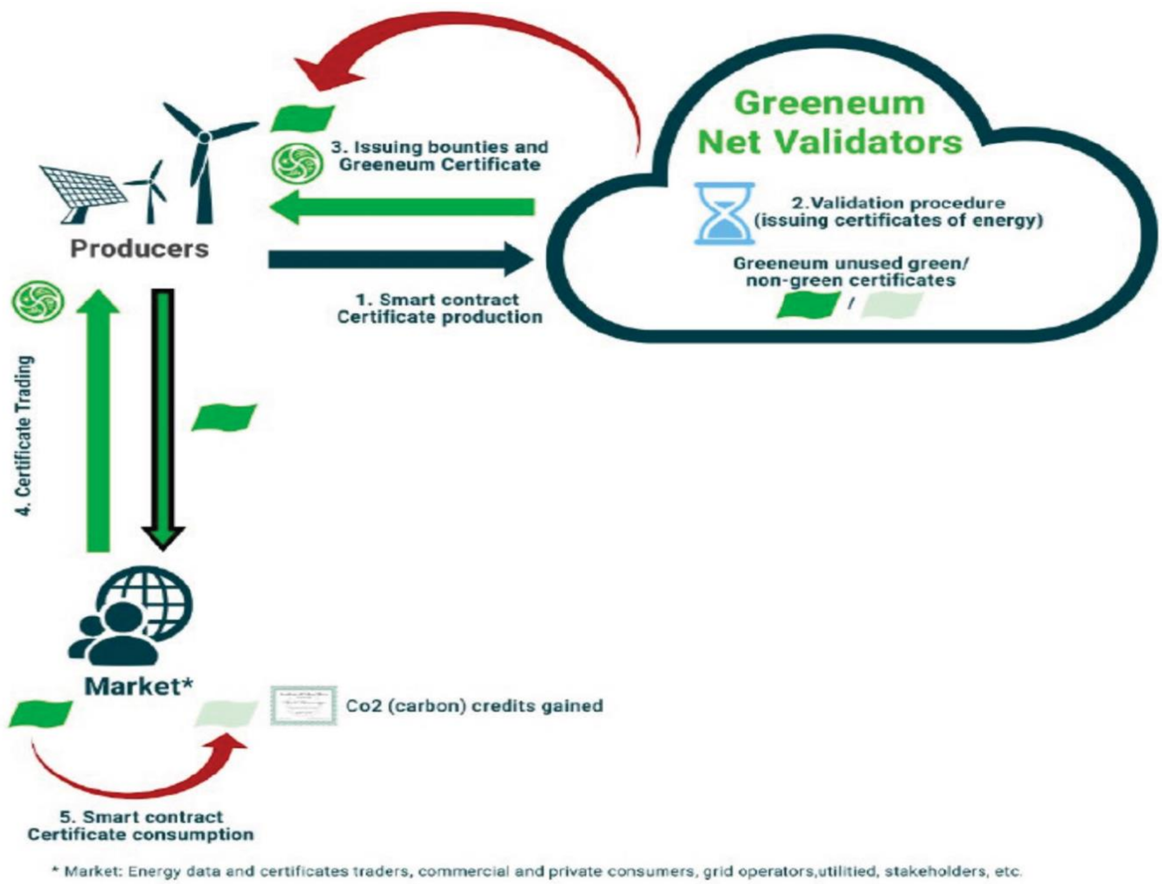
NRG Energy's platform utilizes a private blockchain.[6] (Anich 2017) Blockchain access and use is permissioned to transaction participants and transaction validation rights are limited to the pre-selected parties to the transactions (*e.g.* NRG, REC seller, auditor and the tracking system).

[6] NRG Energy refers to the American electricity utility and their proof of concept phase blockchain REC trading blockchain platform. Confusingly, there is an academic green token project at the Vrije Universiteit in Brussels called NRGcoin. All references to NRG in this thesis are to the former and not the later.

6.3. Platform Purpose

Incentivizing the financing and development of RE generation is explicitly the primary or secondary goal of two of the green token platforms. Swytch's token is designed to provide an "incentive for clean energy producers" and states that token purchasers will support renewable deployment and generation additional renewable power globally. (Swytch 2018) Greeneum's token system is designed to "incentivize the transition to renewable energy" and the green tokens are intended to serve as a "financial reward" to encourage renewable energy production by tokenizing and monetizing the environmental attributes. (Assaf 2018)

Figure 10. Greeneum's Green Certificate Flow Chart (Greeneum 2017)



The EW Origin platform is intended to utilize blockchain technology (and additional user-friendly functionality and applications) to "unlock clean energy investments" that have not be accessed by existing green commodity market and transactional structures. (Miller and Griesing 2018) NRG's platform is more narrowly focused on improving the transaction efficiency of

NRG's REC purchasing process. (Anich 2018) The platform's primary purpose, at least in the initial phase, is transaction cost reduction. Integration with tracking systems and Green-e and improved market liquidity are secondary and longer-term goals.

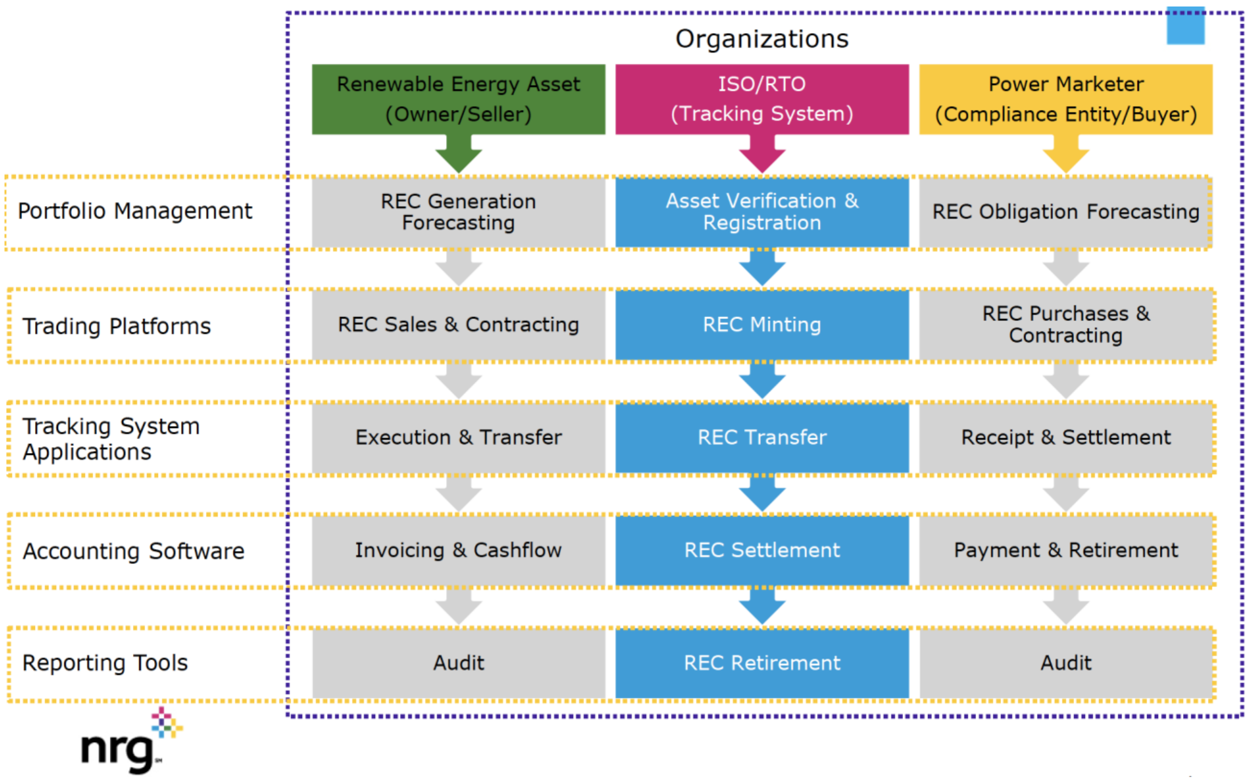
With the possible exception of Power Ledger, for which information was not available, all platforms are designed and intended for integration into voluntary markets. Greeneum and Swytch have compliance and voluntary market integration as long-term goals. (Assaf 2018; Swytch 2018) EW Origin is open-source and intended for adoption by a variety of entities in the voluntary market, including transacting parties, tracking systems and registries. (Miller 2018) NRG's platform is designed specifically for voluntary market transactions and potential integration with tracking systems and registries. (Anich 2018)

6.4. Transactional Efficiency

All platforms surveyed contemplate the ability of a blockchain system to improve transactional efficiency relative to existing market systems.

The primary purpose of NRG's platform is to improve the efficiency of REC transactions, measured in speed, labor and cost. (Anich 2018) As described in **Chapter 4.5.3**, the purchase of a REC on the voluntary market can involve up to six parties with different roles and separate databases. Verification and real-time reconciliation is inherent to the technology and the platform would consolidate all databases onto one distributed ledger, shared between parties with different permissions for transacting parties and auditing parties. Individual REC transaction times could be reduced from 1 day to a half an hour and costs from up to 10% of the REC cost to 3%. The green token platforms and EW Origin would utilize the same blockchain attributes to improve transactional efficiency. (Greeneum 2018) That is, multiple parties would transaction on an immutable, distributed database that provides transactional verification and real-time reconciliation. (Power Ledger 2017; Miller 2018)

Figure 11. REC Lifecycle and Transactional Steps (Anich 2017)



All platforms surveyed are designed to disintermediate voluntary market transactions and allow for direct and instant P2P transfers of RECs or green tokens by utilizing blockchain's inherent prevention of double-counting, immutability and real-time transaction reconciliation. NRG's private blockchain platform is designed to facilitate P2P transactions between known parties. (Anich 2018) The green token platforms would all use this feature to create a decentralized P2P market for all generators and purchasers using their platform. (Assaf 2018; Swytch 2018) EW Origin similarly contemplates P2P transactions on a large scale if its platform is adopted and contains functionality to allow trading between RECs and carbon credits. (Miller 2018)

Power Ledger and NRG both highlight the ability of their blockchain platforms to facilitate direct and instant financial settlement and avoid counter-party credit risk without need for a third-party. (Anich 2018; Power Ledger 2017) Smart contract capability can automate transactions while providing counter-party credit risk and verifying and enforcing transactions. (Power Ledger 2017) On Power Ledger's platform, a purchaser would deposit money into an escrow on the blockchain for receipt of a token (or, if configured for REC trading, a REC). The token is then automatically transferred once conditions of the smart contract are met (*e.g.* the transfer of the REC by the seller).

6.5. Liquidity

Swytch, Greeneum and EW Origin all cite increased market liquidity as a primary value-add relative to current systems. NRG cites it a secondary and longer-term goal. The Greeneum and Swytch platforms are both designed to create blockchain-based global, liquid markets. Greeneum states that the ability to exchange its green tokens with Ethereum and the existence of a seamless global market based on its platform will create “liquidity, stability and reduced volatility” in its network. (Greeneum 2018; Assaf 2018) Further, both tokens and Power Ledgers are exchangeable with other cryptocurrencies and thus fiat currency on public exchanges. (Swytch 2018; Power Ledger 2017)

Swytch and EW Origin focus on improving liquidity by increasing interoperability, ease of exchange and standardization. Swytch specifically targets the illiquidity of U.S. REC markets and the “difficulty” of transferring RECs generated “in one part of the grid to be transferred or sold as on offset in another grid.” (Swytch 2018) The Swytch White Paper highlights the lack of standardization and coordination on an international level as well as the fragmentation within U.S. REC markets as well. The illiquidity and lack of efficiency is directly tied to the inability of the market to “maximize financial gains” for RE producers. Increased liquidity and interoperability would be achieved through adoption of Swytch’s token that would be standardized and could be used globally without the need for third-party intermediaries. EW Origin is designed to connect disconnected markets, including REC and carbon offset markets, and bring standardization to REC markets. (Miller 2018) Intra-REC market liquidity would be increased by obviating third-party intermediaries and increasing transactional efficiency and transparency.

6.6. Fraud & Double-Counting

Only Swytch highlights its platforms ability to prevent fraud and the associated costs as a value add relative to current systems. (Swytch 2018) EW Origin does not tout fraud and double-counting prevention as an advantage relative to current REC market systems but does note that it could be more valuable in developing markets without robust systems in place. (Miller 2018)

The green token projects and EW Origin are designed to improve REC or green token transaction reliability relative to conventional systems. Greeneum and Swytch both feature an algorithmic verification features that would replace the need for human third-party audits of the underlying generation project as well as the green token transactions. Greeneum would use a three-step automated validation protocol that would verify generation project ownership electronically, validate energy generation device algorithmically, and use machine learning to validate generation information in real-time and award green tokens. (Assaf 2018) Swytch aims to obviate need for third-party verification of production and ownership using blockchain architecture. (Swytch 2018) Energy production data would be fed into platform by smart meters connected to the RE generation and analyzed by Swytch's "oracle" algorithm to identify "outliers" that attempt to upload fraudulent production data.

6.7. Market & Demand Expansion

Corporate entities with sustainability goals are primary early market for Swytch, EW Origin and Greeneum. (Swytch 2018; Miller 2018; Assaf 2018) Reducing the cost, time and labor associated with REC purchases (as described in the NRG example) would be a value add for commercial entities and expand the market to include new purchasers.

These platforms intend to expand market participation removing many of the obstacles that prevent or disincentive access, particularly for small-scale generators and purchasers. EW Origin's platform includes more granular data (KWh level), real-time carbon accounting, lower transaction costs, disintermediation, and the inclusion of aggregation and demand-matching capabilities as features that would reduce barriers to entry and expand the market. (Miller and Griesing 2018) Swytch states that adopting its token-based system would provide currently excluded individuals with access to green incentive markets. (Swytch 2018) Greeneum is designed to expand the market by targeting underserved decentralized generation, particularly solar. (Assaf 2018)

The green tokens platforms intend to create additional demand through a variety of incentive structures designed to increase the value of the green tokens. Power Ledger rewards producers and consumers of renewable energy with its POWR tokens, with incentives weighted toward producers. (Power Ledger 2017) All three green token platforms would allow for the monetization of their green tokens through the ability to exchange them for other cryptocurrencies and fiat currency on public cryptocurrency exchanges. For example, Power Ledger's native token POWR is listed on a number of cryptocurrency exchanges and has ranged in price from an all-time high of $1.88 to $0.30 as of July 2018.[7]

In addition, Swytch and Greeneum intend to establish marketplaces for token-holders to trade tokens for "green" services and goods. Greeneum's token holders will also have access to a proprietary marketplace that will allow the purchase of "goods and services related to sustainability, ecology and renewable energy," including consulting services, renewable energy equipment and other sustainable products sold by "[l]ocal, organic and agro-ecological producers." Swytch's tokens are intended to be tradeable for energy efficiency upgrades, solar panels, smart meters and other similar products. (Swytch 2018)

6.8. Additionality Standards

NRG and EW Origin's platforms are designed to integrate into current market structures and would retain RECs as the unit of commoditization and the associated definitions, standards, protocols and retirement functions. (Miller 2018; Anich 2018)

The green token platforms have not specified precise definitions for their green tokens nor additionality protocols or standards. Only Greeneum specifies a retirement function, allowing its green tokens can be claimed for carbon credit on the Greeneum system (*i.e.* claiming the emissions reduction associated with the green token). (Assaf 2018) Swytch's platform attempts to create a scarcity by issuing its tokens in proportion to the environmental impact of the RE generation. (Swytch 2018) That is, a greater number of tokens are issued per MWh to projects located in areas with high carbon emissions or low penetration of power generation.

Finally, none of the green token platforms indicate how their platform would function in areas where REC or similar environmental attribute commoditization markets exist. Specifically, there is no indication of whether green tokens would be issued (or not issued) on the blockchain platform in addition to REC generation.

[7] Coinmarketcap.com. 2018. Power Ledger (POWR) - Cryptocurrency Market Capitalizations. Available at, https://coinmarketcap.com/currencies/power-ledger/.

Chapter 7. Discussion

The literature on blockchain technology and contextual advantages and the analysis of the voluntary market's structural and transactional dynamics, discretionary demand drivers, and effectiveness provided a framework and criteria through which to analyze the surveyed blockchain platforms. This chapter will discuss and attempt to present findings to the research sub-questions set out in **Chapter 1.1** based on the blockchain literature review, voluntary market profile, and substantive research into blockchain platforms.

7.1. The Voluntary Market is Contextually Suited to Blockchain Technology Application

The first research question is effectively a threshold question – do voluntary markets and REC transactions have the systemic and contextual features necessary for blockchain systems to present a plausible value add relative to conventional or existing systems and technologies? The research strongly indicates that the voluntary market possesses the contextual and structural attributes of a system, as identified in the blockchain literature, in which blockchain technology presents a plausible value-add relative conventional, centralized or decentralized systems.

The literature found that blockchain can offer value relative to conventional systems in contexts where the following factors are present: (1) multiple parties, (2) consistent and shared asset or record, (3) costly third-party intermediaries, and (4) verification requirements. (Meunier 2016; Jaikaran 2018) These factors are all present in voluntary market. A voluntary market transaction involves multiple parties sharing a piece of information (*i.e.* the REC) housed across multiple databases, all of which need to be updated and reconciled to reflect information about the REC (*e.g.* ownership, provenance of chain of custody, verification and retirement) is updated by multiple parties over the course of the REC's lifetime. (Anich 2018) A REC is a consistent asset. the medium of commoditization and exchange, and it the REC's information (*i.e.* identification number, project information, vintage, geographical location, etc.) must remain static. (U.S. EPA 2018a) The voluntary market is highly dependent on third-party intermediaries, primarily in the form of third-party transaction brokers. (Holt, Sumner, and Bird 2011; Koperski 2017) Verification and certification are critical to voluntary market demand. (Dagher, Bird, and Heeter 2017)

Further, four of the experts familiar with the voluntary market and blockchain technology agreed that blockchain technology had the potential to improve upon existing voluntary market systems, even if the scope and strength of that belief varied considerably. The platform developer experts were optimistic about blockchain technology's potential applications in voluntary markets, emphasizing a number of problems and inefficiencies that could be addressed through blockchain technology. (Anich 2018; Miller 2018) Both standard setting experts expressed an openness to working with blockchain technology and platforms. (Leschke 2018; Critchfield 2018)

7.1.1. Importance of Blockchain Platform Architecture and Design

The literature on blockchain architecture in **Chapter 3.3** and survey of the blockchain platforms in **Chapter 6** indicate the importance of designing the blockchain system for the context in which it will be applied. A public, permissionless blockchain would be inappropriate for any conceivable application within the voluntary market. The degree of consensus protocol security and data immutability would be out proportion to the needs of a market with little systemic fraud and existing mechanisms for the prevention of double-counting. (Gerber 2018) A system that relies on verifying the information contained in the token or transactional asset (*i.e.* the REC) requires enforcement of standards and protocols (*i.e.* additionality requirements for generation assets), which a public and permissionless blockchain is not designed to allow. (Buterin 2015) As a result, none of the platforms reviewed use this structure.

The surveyed platforms tailored their blockchain architecture to the intended purpose. NRG's platform utilizes a private and permissioned platform to handle REC transactions between known parties, a situation with a relatively high degree of trust and the need for efficiency. (Anich 2018; Jaikaran 2018) Parties to the transaction could write information to the chain while accountants and third-party verifiers simply require the ability to view the information on the blockchain. The green token platforms all use variations on a consortium blockchain, a middle ground between public and private blockchains. (Buterin 2015) This format retains some degree of control over parties that can write (*e.g.* generators creating tokens) and verify transactions while allowing transactional access to anyone holding a token, purchasable on public exchanges.

7.1.2. Structural Obstacles to Commercial Adoption

In addition to satisfying the threshold contextual features for successful blockchain application, the voluntary market presents an attractive use-case for blockchain application relative to other energy and environmental commodity markets due the discretionary nature of participation and dearth of direct regulatory oversight or administration. (Anich 2018; Miller 2018) Blockchain deployment in other regulated markets has required a regulatory sandbox and application at small scale to avoid illegality, and widespread application would require changes to the regulatory or statutory framework. (Gabison 2016; Basden and Cottrell 2017)

However, the voluntary market has established structures and systems that present structural obstacles to large-scale blockchain adoption. As shown in **Chapter 4**, the voluntary market is interconnected with the regulated compliance market through use of tracking systems and market and price dynamics. (Bird and Lokey 2008) Voluntary market use of tracking systems presents an obstacle for the green token platforms in particular. Tracking systems are public institutions subject to regulatory oversight and created to serve regulatory compliance markets. (Jones 2017) Despite no obligation to do so, a significant portion of voluntary market RECs utilize the tracking systems and many RE projects generate RECs for both compliance and voluntary markets. As such, while the voluntary market may be largely unregulated and discretionary, it relies on public institutions that are set up to use RECs. Wide-spread green token use would require integration with the tracking systems or a sufficient value add to move the voluntary market away from tracking systems.

Voluntary market reliance on tracking systems further illustrates that many of the structural problems with the voluntary market that cause market inefficiency or inhibit demand are, to a significant degree, human or institutional and not technical problems. (Gerber 2018) For example, the technology exists to create spot markets and national tracking systems or allow interconnection between all tracking systems. (Environmental Tracking Network of North America 2009) Blockchain technology may be revolutionary but to improve the functioning of the market, technical solutions are not sufficient in many areas.

The REC itself presents an incumbent system and thus an obstacle for green token systems. Despite a lack of standardization across the market of REC definitions and standards, RECs are established legal instruments that are recognized as property rights under U.S. State and Federal, legally enforceable and have a body of standardized contractual agreements (*e.g.* PPAs). (Jones, Quarrier, and Kelty 2015) All established voluntary market structures and entities are set up to use RECs as the mechanism for environmental attribute commoditization and instrument of transaction. (Leschke 2018) Voluntary market use of the REC does not present an obstacle for blockchain platforms generally, as the NRG and EW Origin platforms are designed to retain the REC as the instrument or unit of exchange. (Anich 2017; Miller and Griesing 2018) However, the REC does present an obstacle for the tokenization of the voluntary market. Again, wide-spread commercial use of the token would require a change to established systems to accommodate the token.

Notably, four of the voluntary market experts expressed the opinion that markets without existing systems for the commoditization of the environmental attributes of RE generation were more promising than developed markets, like the U.S. voluntary market, for early commercial-scale application of blockchain technology due to lack of established systems and incumbent entities in this space.

7.2. Blockchain Technology's Impact on Market Efficiency

The second research question was to examine whether blockchain systems, as they are being designed for application in the voluntary market, have the potential to improve voluntary market efficiency. To test this broader question, efficiency was narrowed to three constituent elements based on a review of the body of literature on the voluntary market and expert interviews – transactional efficiency, market liquidity, and the prevention of fraud and double-counting.

7.2.1. Transactional Efficiency

The research robustly supports the conclusion that the blockchain platforms could improve voluntary market transactional efficiency. The literature on blockchain technology found that it was well-suited to improving transactional efficiency in contexts involving multiple parties, third-party intermediaries and compliance and asset tracking requirements. (U.K. Government Office for Science 2016; PricewaterhouseCoopers 2017; Merz 2016) The literature on voluntary markets and expert interviews identified all three contexts as applying to the voluntary market. Further, all blockchain platforms surveyed target transactional efficiency as a primary value add relative to conventional systems. The NRG platform is designed primarily for this particular function by a sophisticated commercial entity with robust voluntary market transactional experience. (Anich 2017)

The NRG example described in **Chapter 4.5.3** is illustrative of the transactional efficiencies gained by the use of a distributed and immutable blockchain-based database that allows multiple parties to a REC transaction to work on a shared system that is automatically updated and reconciled. (Anich 2017, 2018) Administrative costs (*i.e.* manually copying and reconciling databases) as measured in labor and time are reduced. Further, the blockchain databases' transparency for permissioned users (if properly configured and permissioned) combined with its inherent transactional validation and double-spending prevention reduces verification and auditing expenses and time and facilitates accountants and auditors working on the same database as the parties to the transaction. The efficiency gains are quantifiable, with transaction cycles expected to be shorted from the current monthly cycle to a daily transactional cycle and transactional costs reduced from as high as 10% of the REC purchase to 3%. (Anich 2018)

The application of blockchain platforms can be expected to improve voluntary market transactional efficiency by disintermediating REC transactions. The reliance on third-party intermediaries and OTC transactions is a defining feature of the voluntary market. (Holt, Sumner, and Bird 2011; Koperski 2017) Bitcoin, the first blockchain application, was designed primarily to facilitate P2P transactions in an electronic setting, obviating the need for a third-party intermediary. (Nakamoto 2008) Blockchain's ability to disintermediation capabilities can be expected to offer efficiency gains in transactional settings reliant on costly intermediaries. (Meunier 2016) More specifically, the voluntary market reliance on third-party brokers is significantly due to the absence of institutions that facilitate direct, instant transactions and reduce counter-party credit risk (*e.g.* spot markets or exchanges). (Anich 2018) Blockchain's architecture is designed for this purpose generally and the surveyed blockchain platforms are tailed to provide counter-party credit risk and disintermediate transactions in the context of environmental commodity trading. For example, Power Ledger's escrow feature and use of smart contracts to automate, verify and enforce the terms of the contract is an excellent illustration of blockchain's capabilities in this regard. (Power Ledger 2017)

7.2.2. Market Liquidity

The overall causal relationship between blockchain's attributes and a reduction in voluntary market illiquidity and opacity is less robust than it is for transactional efficiency improvements.

The ability of blockchain platforms to improve transaction efficiency by reducing transactional costs (*i.e.* speed, labor and capital costs of a transaction) through database consolidation, efficient transactional verification, and transactional disintermediation can be expected to result in marginal market liquidity improvements. (Yermack 2017) Voluntary market liquidity is a combination of (1) relative ease with which the REC can be transacted and (2) the level of costs associated with a sale, either in the form of transaction costs or in the need to accept a lower price than desired in order to sell the REC quickly. (Elliott 2015) A substantial cost associated with REC transactions is the reliance on third-party intermediaries and OTC transactions. (Holt, Sumner, and Bird 2011; Koperski 2017) As has been shown, blockchain technology and the platforms surveyed have the potential to disintermediate the voluntary market, at least to a certain degree. Improved transactional efficiency due to reduced labor and time costs would further reduce the cost associated with REC sales and should lead to some degree of improved market liquidity.

Reliance on third-party intermediaries increases opacity by obscuring REC price information. (Gerber 2018) The literature finds that a lack of price transparency can decrease market liquidity because it is difficult to know the price needed to sell an asset quickly. (Elliott 2015) While blockchain platforms may disintermediate transactions, transparency will only increase if a blockchain platform is designed to increase overall market transparency. Not all blockchains are designed for full transparency. Consortium chains can be configured in a variety of ways, including different levels of viewing permissions. (Buterin 2015) A private chain like NRG's is permissioned and thus only transparent to authorized users. EWF's platform has functionality to allow for encrypted smart contracts to hide the terms of a transaction. (Miller 2018)

If scaled, the green token platforms like Swytch and Greeneum have the potential to create a transparent market. The green tokens would be tradable on their respective platforms, both for goods and services, cryptocurrencies or fiat currencies. (Swytch 2018; Greeneum 2017) Thus, the green token value would be set by several interlocking market mechanisms and the price would be relatively transparent both on the proprietary platforms and on public cryptocurrency exchanges. The structural obstacles to scaling a green token platform were discussed in **Chapter 7.1.2**. impact transparency because the green token platforms require scale to establish the blockchain-based, transparent market. Further, it is important to note that the absence of a national REC spot market or exchange is not a technical problem. (Gerber 2018) Spot markets and exchanges exist in other settings, including carbon offset markets. Further, APX, the company that develops the software used by most tracking systems, could establish national tracking system with price and transactional volume data at "no extra cost." (Environmental Tracking Network of North America 2009)

7.2.3. Fraud and Double-Counting

Blockchain's inherent transactional verification, double-counting prevention and record authenticity features do offer increased transactional security and fraud prevention relative to conventional systems. (Meunier 2016; Singh and Michels 2017) The automation of these functions can improve transactional efficiency, as described in **Section 7.2.1**. However, beyond improvements in transactional speed and efficiency, there are two significant factors mitigating any improvement in voluntary market efficiency due to any increase in fraud and double-counting prevention.

First, there is simply little evidence that fraud or double-counting is a problem and, as a result, there is little room to add value. The literature and expert interviews were unanimous that the existing market structure utilizing registries, tracking systems and EPA GPP and similar program requirements precludes fraud or double-counting. (Bird and Lokey 2008; Critchfield 2018) The tracking system stated that there was little to no market demand for increased security, whether blockchain-based or otherwise, and noted the increased costs of a transitioning to a blockchain system. (Gerber 2018)

Second, blockchain architecture, when used for records or off-chain asset tracking, does not guarantee the reliability of the record. (Lemieux 2016) Nothing in blockchain's architecture guards again fraud or inaccuracy in the process of creating or digitizing the record. (Pisa 2018) The distinction between record authenticity and reliability is important the voluntary market. The accuracy and reliability of the information contained in a REC or green token (*i.e.* generation technology, project vintage, location and time of generation) is critical to the functioning of the market and sustaining discretionary demand. (Critchfield 2018; Leschke 2018)

The existing system has established and proven systems for ensuring REC reliability that rely on human verification and third-party auditing of generation assets. (Critchfield 2018; Leschke 2018) Two of the green token projects surveyed, Swytch and Greeneum, would use algorithmic verification processes to replace human verification while ensuring REC reliability. (Swytch 2018; Assaf 2018) As described in **Section 4.1.5**, these verification systems would validate the RE generation information uploaded to the blockchain platform via a smart meter. The technical feasibility of this type of solution is outside the scope of the thesis. It is sufficient to note that algorithmic verification technology is not dependent on connection to a blockchain platform and could be used by more convention systems.

7.3. Market Effectiveness

Voluntary market effectiveness has been defined as a causal connection, however attenuated, between the discretionary purchase of RECs and the financing and develop of additional RE generation capacity sufficient to lower GHG emissions relative the *status quo*. Additionality standards were identified by the literature as a baseline preventing RECs that could not possibly be "additional." The literature and expert interviews further identified several factors that significantly impact the effectiveness of the voluntary market in causing additional RE generation capacity.

In light of the foregoing discussion in this chapter, the final research sub-question is, in light of blockchain technology being contextually suited for application in the voluntary market and the realistic potential for transactional efficiency and liquidity improvements, do the surveyed blockchain platforms have the potential to cause an improvement in the efficacy of the voluntary market in terms of causing the financing and development of additional RE generation sufficient to cause a reduction in GHG emissions.

7.3.1. Additionality Standards

Additionality standards or protocols for project vintage, generation technology, regulatory surplus and double-counting serve to exclude projects from generating RECs that could not possibly be "additional" from the perspective of causing the financing and development of additional RE generation. (Center for Resource Solutions 2016) Without additionality standards, RECs could be generated by projects that emit GHGs or would have been built due to regulatory requirements (*e.g.* a cap and trade program or State RPS). Additionality standards both ensure the environmental integrity of the voluntary market and discretionary market demand. In the absence of these standards, there is no mechanism to connect REC purchases with the development of additional RE generation capacity and thus reduce net GHG emissions relative to the status quo. (Gillenwater 2013c)

Currently, voluntary market additionality standards are set and enforced by the tracking systems and Greene-e. (U.S. EPA 2006; Critchfield 2018) The market integration platforms are designed to function within the broader structure of the voluntary market and retain the REC as the unit of transaction. (Miller 2018; Anich 2018) Thus, these platforms and their users will essentially adopt existing additionality standards and thresholds.

The green token projects surveyed have not set out additionality standards regarding regulatory surplus, project vintage or eligible technology, and have not indicated whether third-party standards will be adopted. The white papers reviewed do name technologies that would be considered "clean" or "renewable" for the purpose of green token generation and clearly contemplate that the platforms would be limited to renewable or clean generation technologies. (Swytch 2018; Assaf 2018) Further, both Swytch and Greeneum explicitly contemplate eventual integration with the compliance market, suggesting that these platforms would adopt existing additionality protocols and standards. However, to date, there is no information on the nature of the standards and protocols that would be adopted, particularly with regard to project vintage and regulatory surplus.

Absent regulatory, vintage and technology standards, additionality requires that the REC be retired and the environmental attribute claimed by one party only and not be double-counted. (Gillenwater 2013c; Jones 2017) Token-based systems must have a mechanism for retirement of the token or there is no claim to the environmental attribute. (Anich 2018) Based on the available information, only Greeneum appears to allow for retirement of a green token to claim its environmental attribute. (Greeneum 2018) However, Greeneum and the other green token platforms would allow for the exchange of their green tokens for services, goods or other cryptocurrencies. For the emission reduction to be "claimed," the green token or REC must be retired. The purchaser of a green token cannot claim the environmental attribute if the token is spent or converted to another currency. (Anich 2018) Finally, it is not clear whether under the current system in the U.S. the generation of a green token would preclude the simultaneous generation of a REC for the same 1 MWh. (Jones, Quarrier, and Kelty 2015) RECs are legally recognized instruments whereas green tokens are not as yet.

Ultimately, without additionality standards, retirement capabilities and integration with the existing system to prevent token generation that is duplicative of REC generation, blockchain-based systems cannot ensure an additionality threshold is met. Without the additionality threshold, there is no way to ensure that the purchase of green tokens will cause the development of additional RE generation and reduce net GHG emissions.

7.3.2. REC Price & Demand

Assuming baseline additionality standards are satisfied, low REC prices were identified by the literature as one of two factors significantly inhibiting voluntary market effectiveness, particularly from the perspective of project-specific additionality. (Gillenwater, Lu, and Fischlein 2014; Holt, Sumner, and Bird 2011) The primary cause of the low REC price was identified as low discretionary demand relative to the supply of RECs. (Powers and Haddonq 2017; Roberts 2015) Although the imbalance of supply and demand is, on its face, economic and not technical, there is evidence to suggest that blockchain technology could expand voluntary market demand.

As a preliminary matter, all three green token platforms and EW Origin note the ability of blockchain platforms to drive to demand. Two voluntary market experts noted expanding demand as a possible impact of blockchain platforms but cautioned that any demand expansion capacity was speculative at this juncture. (Critchfield 2018; Leschke 2018) Underlying the claim that blockchain platforms can increase demand is the belief that there is untapped consumer demand that is not met by the current system. The surveyed blockchain platforms would unlock this demand through a variety of mechanisms.

Common to the green token and EW Origin is the use of blockchain technology and integrated platform features to remove obstacles that disincentivize participation in the voluntary market, particularly by small-scale REC generators and purchasers. EW Origin explicitly targets a number of disincentives it identifies as limiting market participation, including high tracking system fees, the absence of a central marketplace or exchange, reliance on brokers, and the 1 MWh REC standard. (Miller 2018; Miller and Griesing 2018) Many features of the EW Origin platform are designed to specifically to remove these barriers and expand demand, including granular data (KWh level), lower transaction costs, disintermediation, and the inclusion of aggregation and demand-matching capabilities. Greeneum's initial target market is distributed solar due to its lack of participation in the current voluntary market. (Assaf 2018) Voluntary market experts echoed many of these same barriers but also noted the presence of aggregation services and programs like net metering that compensate distributed sources. (Gerber 2018; Leschke 2018)

In addition to easing participation, the green token platforms all have various mechanisms to increase the value of the green tokens, including marketplaces and the ability to exchange green tokens for other cryptocurrencies or fiat currency. (Swytch 2018; Assaf 2018; Power Ledger 2017) These mechanisms are intended to drive demand for the green tokens, increasing their market value and thus demand. However, using a REC-like token in this fashion would undermine its additionality. A token would need to be retired to claim the environmental attribute. See discussion of additionality in **Chapter 5.2.2**. Further, as noted in **Chapter 6.1.6**, the value of tokens has fluctuated considerably since listing. Additional value would be mitigated by price uncertainty.

Underlying the blockchain platform's effort to ease market participation is the premise that there is substantial unmet demand on the voluntary market. However, there is some evidence to suggest that there is not. Residential and less sophisticated commercial customers may be precluded from purchases on the voluntary market but they have access to bundled RECs through the programs described in **Chapter 3.2.3**, including utility green pricing and green tariff programs. (O'Shaughnessy, Liu, and Heeter 2016) These programs cover roughly 50% of U.S.

electricity customers. However, participation in these programs is low. The largest and most successful program in the U.S., Portland General Electric's Green Source program, has a participation rate of 19.44% of its customers, accounting for less than 14.40% of sales by MWh. (NREL 2015) While far from a perfect proxy, the participation rates in green power programs caution against the belief that there is significant unmet residential demand.

Similarly, there is some evidence to caution against the premise that there is substantial unserved distributed generation. For distributed RE generators, existing programs like Net Metering purchase the electricity directly at a fixed price and, in some instances, the associated REC. (National Conference of State Legislators 2018) These programs exist in 38 States and the District of Columbia. Blockchain platforms would need to offer value relative to such programs or identify unserved distributed resources. Further, in the context of improving REC (or green token price), adding additional generation would increase supply. REC prices are low because of an oversupply of RECs and increasing the amount of generation capacity, whether through additional RECs and green tokens, would serve to exacerbate supply-demand imbalance. Unless increased demand outstripped the increase in generation participation, any demand increase would be mitigated.

Finally, the literature on the elasticity of discretionary demand for RECs is inconclusive on the effects of higher prices. (Dagher, Bird, and Heeter 2017; Holt, Sumner, and Bird 2011) In regions with compliance and voluntary markets, the increased demand and competition between purchasers for RECs has driven up REC prices but research has shown that voluntary purchasers are more sensitive to price than compliance markets, driving demand down. (Holt, Sumner, and Bird 2011) Any increased demand from currently untapped purchasers that is fostered by blockchain platforms could be offset by the price elasticity of demand on the voluntary market.

The blockchain platforms are designed to remove recognized voluntary market barriers and thereby increase overall voluntary market demand. Many of the platform design features are targeted toward structural issues that experts agree serve as a disincentive for participation, particularly by residential and loss-sophisticated or sustainability brand conscious consumers. Were these design features to prove successful in practice, there it is not unreasonable to conclude that voluntary market participation and demand could increase, increasing REC price and overall market effectiveness relative to the *status quo* baseline. However, the mitigating factors identified regarding the scope of unmet excess demand, tension between increasing the participating share of generation, and the uncertainty regarding the interaction REC price and voluntary market demand caution against even preliminary conclusions in this area.

7.3.3. Price Predictability

Of all the questions posed, the lack of commercial data most significantly inhibits the ability to draw conclusions about the impact of blockchain platforms on price predictability. Conceptually, it is possible to draw the connection between the blockchain platforms' features that are designed to increase voluntary market liquidity and a theoretical reduction in price unpredictability. The literature on voluntary market effectiveness suggests that price unpredictability is as significant a hindrance to voluntary market effectiveness as low REC prices. (Gillenwater 2013b) In turn, voluntary market price unpredictability is, to a significant degree, a product long-term demand unpredictability, market illiquidity and the absence of long-term contracting. (Holt, Sumner, and Bird 2011; Elliott 2015)

However, as discussed in **Chapter 7.3.2**, there is insufficient evidence to warrant preliminary conclusions on the blockchain technology's potential impact on voluntary market demand. Two of the platforms surveyed are designed to improve market liquidity by increasing interoperability, ease of exchange and standardization. (Swytch 2018; Miller 2018) The green token platforms are designed to increase the liquidity of their green tokens by making it exchangeable with other cryptocurrencies. (Swytch 2018; Greeneum 2018)

However, an analysis of the potential for success of these features is simply too attenuated, particular in light of the inability to draw firm conclusions about the impact of the blockchain platforms on demand.

Finally, the literature suggests that the absence of long-term contracting for REC supply negatively impacts price predictability. (Holt, Sumner, and Bird 2011) However, there was not consensus on whether this was a reflection of structural factors or market trends. (Van der Linden et al. 2005; Leschke 2018) Nothing inherent to blockchain technology renders it more or less capable of causing long-term contracting than conventional systems. In particular, smart contracts would be able to execute over longer time horizons. (Buterin 2014) However, none of the green token platforms discuss or seem to contemplate long-term contracting functionality.

Chapter 8. Conclusion

The purpose of the analytical framework developed and applied in this thesis was to analyze the potential impact of blockchain technology application on the efficiency and effectiveness of environmental commodity markets by using the U.S. voluntary market for RECs as a case study. Ultimately, the research and analysis were able to draw robust conclusions about the suitability of blockchain technology for voluntary markets and the ability of blockchain platforms to improve transactional efficiency. Conclusive findings with regard to the remaining sub-questions were not possible given the nascent stage of blockchain technology deployment in environmental commodity markets and the attenuated linkage between the proposed platforms and the issues identified in the literature as impacting market effectiveness. Nevertheless, the analysis provided useful findings and provided the basis of the research and policy recommendations in **Chapter 8.1**.

The threshold analysis indicates that, from a contextual and structural perspective, the voluntary market has the attributes of a system for which blockchain technology could offer value relative to conventional systems. It is reliant on costly third-party intermediaries to build trust and places a premium on verification and validation. In a transactional setting, multiple parties are involved and currently operate on multiple databases that must be reconciled. The REC itself is a consistent record and a unit of transaction. The research suggests blockchain particularly well suited to improve systems with these features. Further, the blockchain platforms surveyed for this research are designed architecturally to fill different niches within the broader structure of the voluntary market.

The voluntary market may be largely unregulated but established systems and institutions are present and commercial scale application of any blockchain platform will require a degree of integration with some established systems. The structural obstacles identified do not impact the blockchain platforms uniformly. Projects narrowly focused on transactions and that retain the REC as the unit of exchange are not as directly impacted by the market use of tracking systems and other established systems. Nevertheless, even these narrowly tailored platforms would require ultimate reconciliation against the tracking system in most transactions and thus, to fully scale, would require some degree of integration. For the green token platforms, established structures and systems present a greater obstacle because of the fundamental and systemic change that a blockchain-based tokenized system would represent relative to the *status quo*.

Beyond the threshold question, the ability to improve transactional efficiency is the discrete area in which blockchain technology has the most immediate promise to improve market efficiency. Disintermediating transactions and consolidating databases have quantifiable efficiency gains in terms of transactional costs and transaction speed. The blockchain platforms designed to address and improve these transactional dynamics can be expected to add efficiency to the overall market by improving transactional efficiency, though overall market benefits are more qualitative and less quantifiable at this juncture.

Robust conclusions about the impact of improved transactional efficiency on overall market liquidity are not possible at this point. However, blockchain technology's ability to improve transactional efficiency and disintermediate the voluntary market without the need for a centralized spot market or exchange have the promise to improve voluntary market liquidity. However, the extent to which blockchain platforms will introduce transparency to the market is an open question and one dependent on the design and permission structures of the successful blockchain platforms.

Finally, it is not possible to draw preliminary conclusions regarding blockchain technology's ability to improve the effectiveness of the voluntary market at financing and developing additional RE generation capacity. The absence of market data and the nascent stage of blockchain platform deployment hinders the research on this sub-question. It is clear that the surveyed blockchain platforms contemplate the structural dynamics that inhibit voluntary market effectiveness – high fees, third-party intermediary reliance, insufficient demand, low REC prices, market illiquidity and REC price unpredictability – and are designing the platforms with these issues in mind. Nevertheless, any conclusions drawn regarding voluntary market effectiveness based on platform design and expected marginal improvements in voluntary market efficiency and liquidity would be speculative at best. The research and analysis did make clear that in order to avoid an overall reduction in voluntary market additionality, blockchain platforms need to contemplate and develop additionality standards and protocols to limit green token generation to legitimately "additional" projects.

8.1. Recommendations

The research and analysis revealed a two significant categories of recommendations for further research and policy recommendations.

- The ability to unlock additional voluntary market demand is one of the most promising areas of impact for blockchain platforms. However, the available research on obstacles to voluntary market participation, particularly by residential customers, is incomplete.
    - The surveyed platforms all emphasized variations of the idea of connecting REC (or green token consumers) more directly with the underlying generation (*i.e.* the RE project that generated the REC or green token). Analogies to rewards programs or frequent flier programs were particularly instructive. Further, the academic research on consumer "warm glow" indicates that the social aspect of REC purchasing may be critical to demand, suggesting that a more quantifiable, social and direct connection between the REC purchaser and generator could unlock additional demand but additional research is necessary.
    - Participation rates in utility green power programs, particularly among residential customers, is relatively low. This suggests that there is not a large reserve of unmet residential demand for blockchain platforms. However, there is little research on why participation rates are low. A more robust understanding of why participation rates are low and whether blockchain platforms would represent a sufficiently different alternative to address these reasons would further understanding of the amount of unmet demand.
- The interconnectivity between the voluntary and compliance markets presents obstacles and opportunities for the blockchain platforms surveyed, particularly the green token platforms.
    - Green token platforms should work more closely to integrate their technology with the REC tracking systems and registries. At minimum, work to avoid a situation in which 1 MWh of eligible RE generation generates both a REC and

green token, which would cause double-counting and undermine the integrity of the voluntary market.

- The interconnectivity of demand and price between the compliance and voluntary markets suggests that blockchain proponents could increase demand for their platforms through policy and legislative lobbying to establish more stringent State RPS standards and a Federal RPS standard.

Abbreviations

EPA – U.S. Environmental Protection Agency

GHG - Greenhouse Gas

GPP – Green Power Partnership

RE - Renewable Energy

REC - Renewable Energy Certificate

RPS - Renewable Portfolio Standard

OTC – Over the Counter

P2P – Peer-to-Peer

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